Mikroniek

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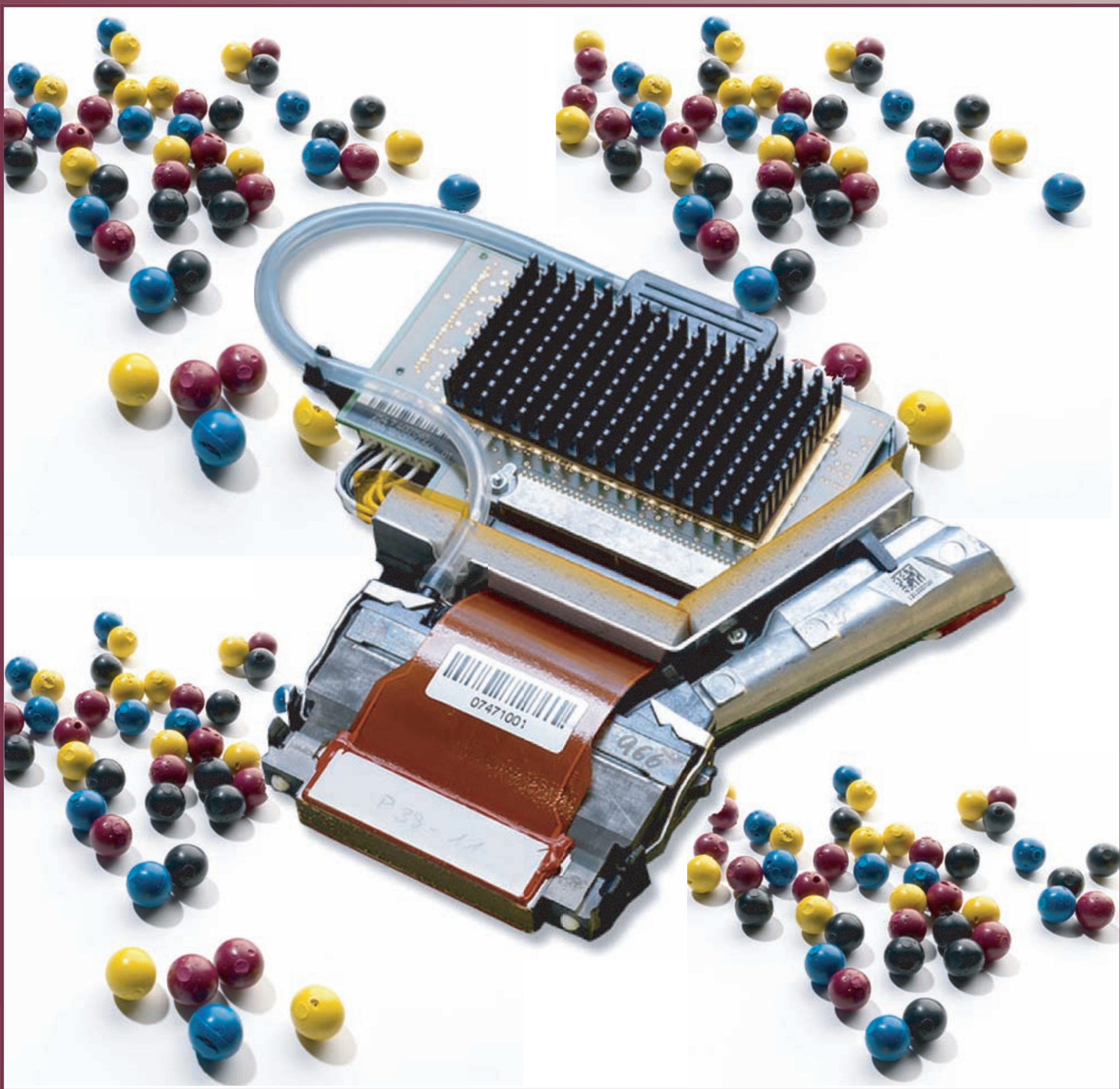

Special Issue Printing

Océ's Inkjet Application Centre, printing beyond paper • Microstereolithography
Affordable micrometers for inkjet printing and rapid manufacturing
FIB-SEM, printing with electrons and ions • Plasma printing, towards plastic electronics
PrintValley • Report on the 2010 Precision Fair • Precision engineering awards

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- Materialen, zoals nano- of biomaterialen

In this issue

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Professional journal on precision engineering and the official organ of DSPE, the Dutch Society for Precision Engineering. Mikroniek provides current information about scientific, technical and business developments in the fields of precision engineering, mechatronics and optics. The journal is read by researchers and professionals in charge of the development and realisation of advanced precision machinery.

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The cover photos (CrystalPoint printhead and TonerPearls) are courtesy Océ.

editorial

The fine art of industrial printing

Christophe Plantin would be amazed if he could see how printing has evolved since the days he was printing his first books in Antwerp and Leiden in the 16th century. Many technological steps have been taken to turn printing from a fine art into an industry. These changes have made printing better, faster and, most of all, cheaper. The introduction of personal computers and small-sized inkjet systems has seen a dramatic expansion of printing systems; today almost everyone has a personal printing system, as a result of which the printing industry has had to refocus.
Inkjet has had a similar story. For many years, it was stuck in the office/home market, but over the last decade there has been a change with several companies suddenly turning towards industrial printheads and new potential short-run applications. Besides increasing chemical endurance, they put many hundreds of jetting nozzles into a single printing device.

Unfortunately, the downside to this boom was increased weight. These new printheads were initially installed in traditional printing machines, but most of them failed because this new non-impact technology was not that compatible. A mechatronic solution was required to mature industrial inkjet systems. Motion systems need to carry a substantial mass and have to fly the printheads and the substrates at a distance of only a millimetre, as well as at incredible speeds and with incredible accuracy. Multiple printheads also require multiple adjustments, controls and much, much more. It is here that mechanics are being replaced by automation and mechatronics, thereby significantly reducing service times compared to pure mechanic systems.

Printing today has become much more than just graphic arts, with new applications such as printed electronics, printed biochemicals, printed solar and 3D rapid prototyping, to name but a few. These new applications try to combine the very tough requirements with a printing technology that was basically not designed for them. Although printhead manufacturers are focusing their skills on these new applications, the first achievements have a different origin. The extreme production reliability demands fast intelligent responses from the printing system as a whole, which requires some embedded mechatronic intelligence.

Looking around, mechatronics is everywhere. I have also realised that reliable and affordable mechatronic systems are mainly found in the Netherlands. Is it some professional Philips residual mentality or is it just because it is so much fun being ‘smart’ in the high-end?

Werner Van de Wynckel
R&D consultant for the industrial inkjet industry
Wolvertem (Belgium)

Printing beyond paper

Printing and copying is Océ's main business. It all started more than 130 years ago, with butter colouring, blueprint material evolving into diazo coatings, and many other techniques. Innovation has been the key to Océ's success ever since. This has resulted in many printing technologies, e.g. Organic Photo Conductors, Direct Imaging Press and – the latest in inkjet technology – CrystalPoint. All these techniques are used to print on paper, but since 2006 Océ has been investigating new industrial ("non-paper") applications at its Inkjet Application Centre.

• *Eric van Genuchten* •

Author

Eric van Genuchten is a physicist working in new business development for Océ Technologies' Research & Development department. Océ's headquarters are in Venlo, the Netherlands. Its Inkjet Application Centre is located on the High Tech Campus in Eindhoven, the Netherlands.

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Open innovation

Océ's Inkjet Application Centre (IAC) is located outside the main R&D facility in Venlo for two main reasons. Firstly, Océ wants to develop new industrial applications together with external companies in an open innovation environment. This open innovation strategy is employed at the IAC, because Océ has developed technology for the graphical industry, but it has no market knowledge of industrial applications like solar cells or printed circuit board manufacturing. Therefore, collaborations between Océ and application owners are essential to successfully develop new printing applications. The second reason is because the High Tech Campus is the place to be for open innovation technology development in the Netherlands.

Figure 1. Océ ColorWave 600 is the world's first colour-toner large-format printer using Océ CrystalPoint technology.

The main Océ technology used for industrial applications at the IAC is CrystalPoint. This inkjet technology is used in commercially available systems such as the ColorWave 600, as shown in Figure 1. The ColorWave 600 is used in the large-format printing market for technical documents and posters. The printhead used in this printer is shown in Figure 2.

CrystalPoint is an inkjet technology that has printheads operating at increased temperatures, so polymer-based inks can be jetted. The printhead's operating temperature reaches up to 150 ºC, so that a whole range of inks, from polymer-based to UV, can be jetted with the CrystalPoint printhead. CrystalPoint's simplified working principle is illustrated in Figure 3; this is similar to how your desktop inkjet printer works, for instance.

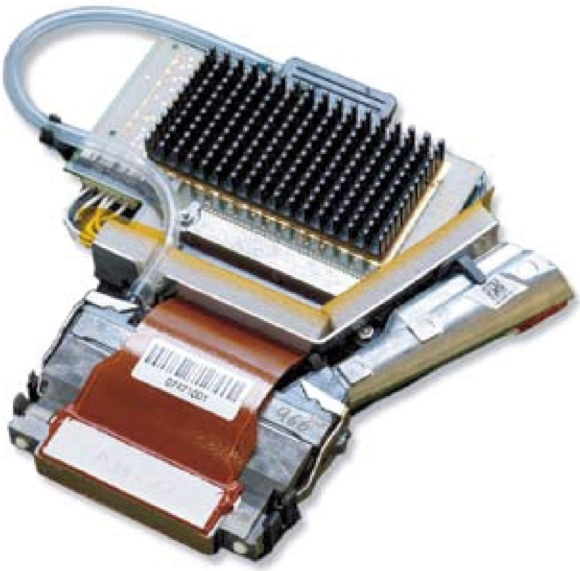


Figure 2: The CrystalPoint printhead with TonerPearls.

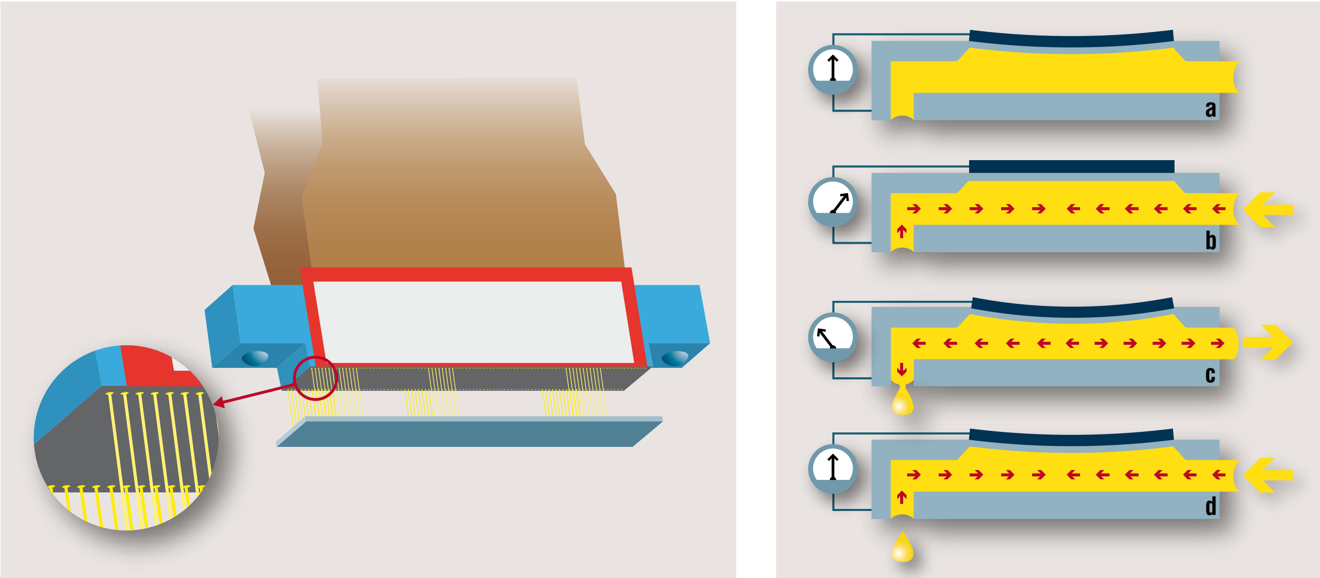


Figure 3: Schematic of CrystalPoint printhead and working principle. The printhead contains piezoelectrically driven ink channels. Applying a voltage results in peak pressure and suppression in these channels. (Infographics: Albert Groenendaal)

An ink channel is filled with a liquid ('a' in the schematic on the right of Figure 3); in the case of CrystalPoint, the temperature of the polymer-based ink in the channel is above 100 ºC. The moment a droplet needs to be jetted, the actuator receives a pulse and creates a shockwave in the liquid (b). This shockwave results in peak pressure in the channel. In general, there are two actuation types: thermal and piezo. CrystalPoint technology uses a piezo element to actuate the chamber or channel. After the actuation, a droplet starts to form at the nozzle of the ink chamber (c). If the actuation power is sufficient, a droplet of the liquid is jetted in the chamber (d). At the moment of droplet ejection, the channel is in a suppressed state and new liquid enters the channel.

Extending CrystalPoint technology

At the IAC, Océ is trying to extend CrystalPoint technology to industrial printing. Narrow lines are required for industrial applications; therefore both high accuracy and precision are crucial. Furthermore, every droplet counts, i.e. every droplet must be printed on the surface. Since the droplets have a diameter of 60 µm, any deviation, no matter how small, has a major impact. Such deviations are often caused by a small amount of air trapped in the printhead ink channel. Against this background, Océ has developed a system that continuously monitors the flow of the polymer-based ink into the channels.

A piezo element, which in industrial inkjet systems is placed at the back of the printhead channels, is crucial for the monitoring system. The material for this element, i.e. crystals based on barium, lead or magnesium compounds, deforms when a voltage is applied. This deformation effect causes a shockwave in the ink channel, which results in ink being jetted from this channel, as previously explained in Figure 3.

The same piezo element on the other hand can also be used as a sensor; when the material deforms it produces a voltage. Therefore, in the Océ printhead the piezo actuator first softly 'hits' the ink channel, resulting in minor shockwaves in the polymer ink. These shockwaves are too small to actually jet the liquid out of the ink channel, but they do result in dynamic behaviour inside the ink channel. If there is an air bubble trapped in the channel, the dynamic behaviour is different than usual. The piezo element then produces a deviating signal. At that point, the printhead holds off on jetting from that specific ink channel and another printhead quickly takes over the task of jetting a droplet in that place. Meanwhile, the air bubble dissolves into harmless smaller bubbles in the polymer-based ink. As soon as the piezo element senses normal dynamic behaviour, the 'paused' printhead reactivates. This 'listening' with the piezo means that Océ is sure that every droplet is jetted, which is crucial for industrial applications where 'every drop counts'.

The CrystalPoint inkjet system can print with an accuracy of 5 µm and is able to jet five million droplets per printhead per second. These speeds and accuracies are only possible if the ink dries quickly and does not flow much. The polymer-based TonerPeals for the Océ ColorWave printer have these exact properties. Solid polymers are melted in the printhead at temperatures above 100 ºC, which liquefies them. The liquid contains a kind of gelling substance that gives the droplets high surface tension. Furthermore, there is a controlled crystallisation of droplets on the substrate thanks to a crystallisation medium in the ink.

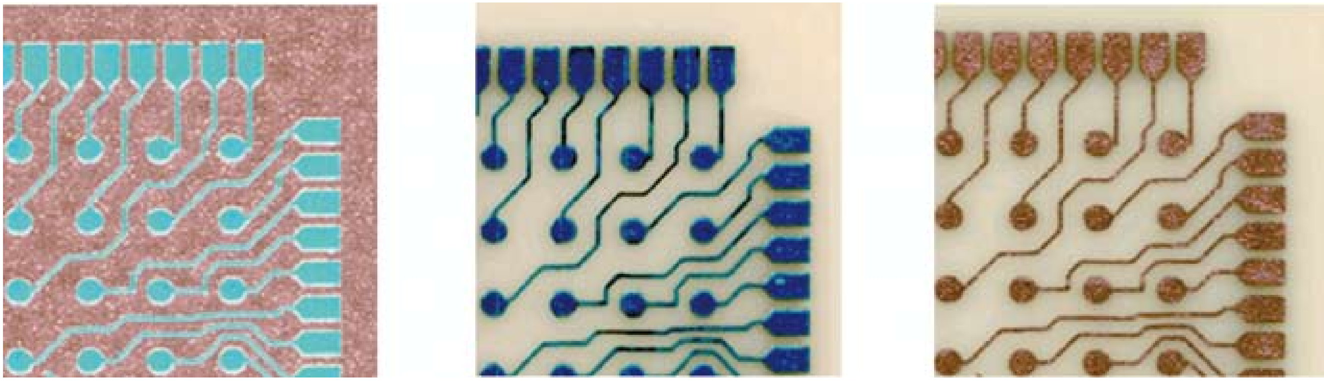


Figure 5. Three pictures showing the PCB printing solution using inkjet: printing a mask, etching the copper and eventually removing the ink, resulting in a PCB without using any lithographic processes.

Inkjet Application Centre

The applications Océ is working on at its IAC range from distributing medicine to printing solar cells. This is done in an open innovation setting with partners. Their market knowledge is combined with Océ's printing knowledge to develop industrial printing applications in joint projects. Industrial applications give rise to a great deal of new technical challenges, with which graphical printing applications are unfamiliar. Some of these challenges are: reliability, productivity, precision, and – in the case of medical applications – (material) variety and traceability. These challenges are application-specific and defined/researched according to the 'inkjet triangle' as shown in Figure 4. Every industrial application has different demands with regard to ink/fluid, substrate and printhead.

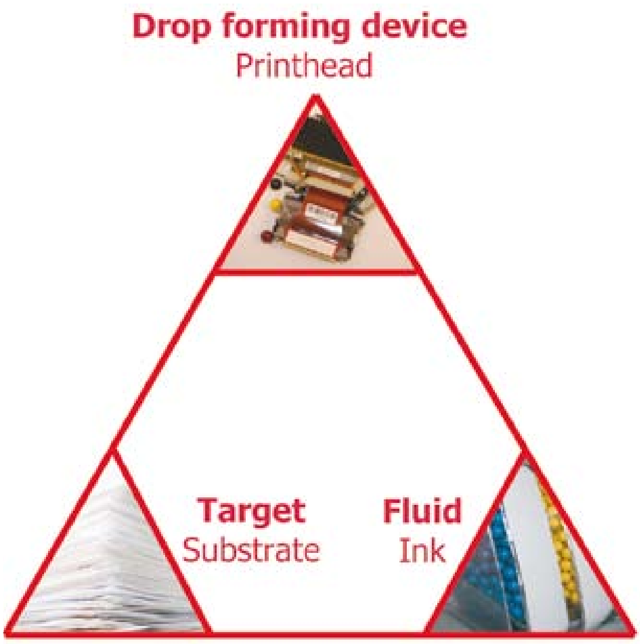


Figure 4. The 'inkjet triangle', which IAC research employs for every application, e.g. droplet-substrate or printhead-ink interactions, which differ for every ink.

Printed circuit boards

IAC's first industrial printing idea was to develop a printed circuit board (PCB) inner layer printer with inkjet and etch-resist ink. The goal was to replace the expensive lithographical production steps in conventional PCB production with inkjet. The solution is shown in Figure 5, where the three pictures show how inkjet can potentially revolutionise PCB production.

On the left in Figure 5 is a standard copper clad with the desired PCB pattern printed on it with resist ink. This has been mask-applied with inkjet. The PCB is then processed with the standard acidic etch to remove the uncovered copper. The resist ink is subsequently stripped, resulting in the desired PCB. This is done using a direct digital process that does not use lithography, thereby eliminating 11 of the 15 process steps prior to inner layer optical inspection (AOI). Etch-resist imaging is, of course, much more than just droplets on copper. The interaction between droplets and substrate, and the droplet-droplet interaction and flow behaviour must be understood and controlled.
Inkjet is by nature an intrinsically unreliable process. This is also the case for the CrystalPoint technology printhead. Thanks to a unique patented technology Océ has been able to master this and can now measure the condition of the nozzles during printing. By using redundant nozzles, the application can guarantee that every drop is printed. This is a classic example of using years of experience in this field to deliver a solution in which these elementary inkjet characteristics have been mastered.

Contemporary methods of inner layer production have not changed significantly over the last forty years. Plotters have become faster and more accurate, and imaging can be replaced by a Laser Direct Imaging process. Whatever the imaging technique, the basic process has remained the same. Many different vendors supply interdependent equipment and chemicals to completely cover a panel with photoresist and then develop the non-exposed image. This is a time-consuming, wasteful and costly process. Figure 6

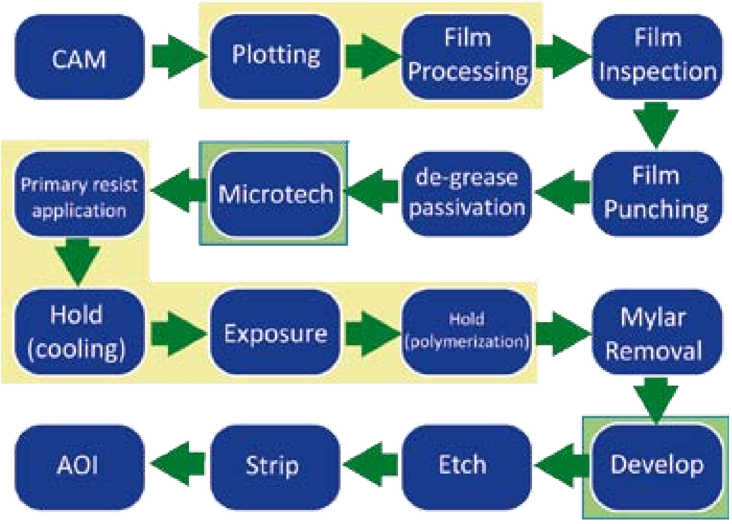


Figure 6. Contemporary inner layer production flow – conventional lithography.

shows the contemporary inner layer production flow using conventional lithography.

This conventional lithography has a number of disadvantages: it is costly and complex, registration (of different inner layers with respect to each other) is difficult to control, resulting in a low yield, with costly infrastructure required, and it is not very environmentally friendly. It takes days to get from data to printing the PCB. When applying an etch-resist mask, the number of production steps is significantly reduced, as shown in Figure 7. This is called the Lunaris production flow, which has the following advantages compared to conventional production: significant cost savings, reduced complexity, from data to print in minutes, and the elimination of registration, environmental and infrastructural constraints as well as film work.

The prediction and subsequent elimination of imaging errors is fundamental to the success of this application. The biggest problem is air entrapment, something that occurs in every inkjet head. This can cause two problems: nozzle spraying, with spurious copper in the PCB application, and nozzle blockage, with missing copper in the PCB application. Empirical data suggests a failure rate of one in one billion droplets. Putting this into context, however, we will fire between 25 and 50 million resist droplets per second, depending upon the CAM data, which means a potential problem every 20-40 seconds.

With the use of CrystalPoint inkjet printing technology air entrapment can be detected and predicted. By using the piezos as a microphone, future problems in the print chamber are predicted, and nozzles are switched before an error appears on the printed image.

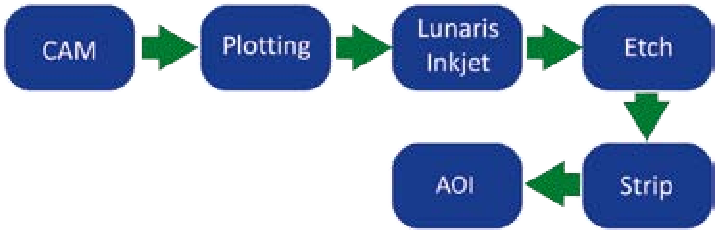


Figure 7. Lunaris inner layer production flow.

Having stable conditions for resist ink jetting in the form of drop size, known angle, known frequency and known timing only meets part of the requirements. The second crucial part is controlling the flow and how the droplets interact on the substrate. This is called the print strategy, which operates within the resist gelling window to ensure that the final etch resist image is a perfect facsimile of the CAM data. Without a print strategy, the resist flow would be uncontrolled and with disastrous results, as can be seen in Figure 8.

The combination of three unique features, i.e. jetting a gelling etch-resist, predicting nozzle failure and using redundant nozzles, and developing a print strategy, makes it possible to replace lithography in the PCB manufacturing industry processes and ensure enormous production cost savings.

This industrial printing project was continued by the first Océ spin-out MuTracx, which was established in January 2009. The project is a classic example of how the IAC operates and searches for applications outside the

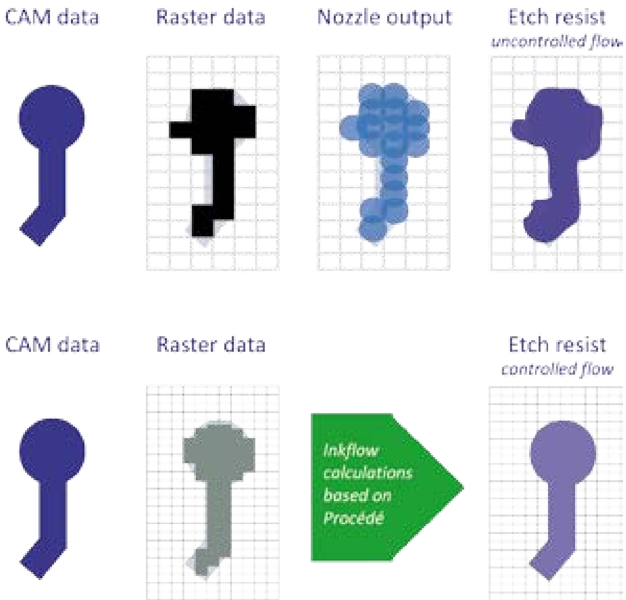
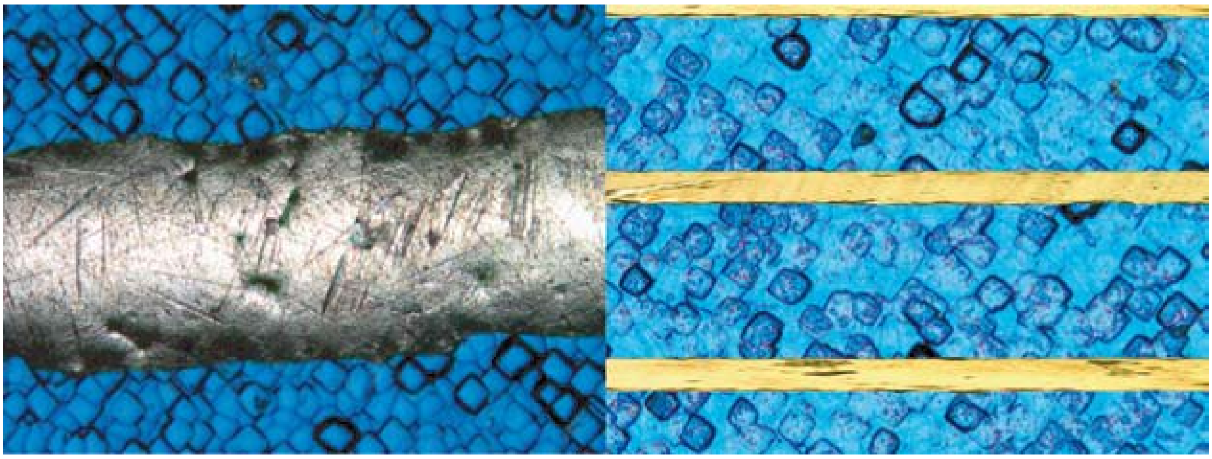


Figure 8. Printing resist ink on copper.
Above: without print strategy.
Below: with print strategy.



a b

Figure 9. Comparison of frontside metallisation line application.
(a) Standard screen printing.
(b) CrystalPoint technology.

traditional Océ field of use to utilise CrystalPoint technology; or in other words, Océ working – according to the 'triangle' – together with an application partner to develop a new industrial application according to the demands of that industry.

The CrystalPoint printhead is unique in jetting a polymer-based etch resist, because the printhead works in temperatures of up to 150 ºC in combination with the prediction of ink channel failure, which is crucial for this application.

Solar

The PCB inner layer market is not the only industrial market on which Océ is focusing at the IAC. Other current projects include using CrystalPoint for the solar market, the goal being to achieve smaller and better defined frontside metallisation in terms of line width and height. These metallisation lines convert the electrons created by sunlight into useful energy. These lines are normally created by screen printing, where the problem is that the minimum line width is ~120 µm. To increase a cell's efficiency it is crucial that the amount of uncovered silicium surface is increased or, in other words, the line width decreases.

Using CrystalPoint, these frontside metallisation lines can be made narrower and better defined. With this increase in open silicium surface, the efficiency of a single crystalline solar cell improves, in theory, by 5%. Feasibility experiments have been conducted to link this to reality. In Figure 9 a screen-printed frontside metallisation line is compared to the lines applied using the CrystalPoint process.

Inkjet is used instead of a screen to print a mask on the cell with a resist ink, resulting in better defined and narrower lines. Using a metallisation process, silver lines are applied to the spaces of the mask; the silver attaches to the substrate in those spaces. After metallisation, the mask is removed in an environmentally friendly process. The resulting lines are well defined and one order narrower, as can be seen in Figure 9.

The increased efficiency of the solar cell produced using CrystalPoint technology in combination with metallisation is not the only advantage over screen printing; material costs are reduced as well. This can be attributed to two factors: the expensive silver paste can be replaced and thinner wafers can be used. Pressure during the screen process requires a certain wafer thickness, because otherwise the wafers will break. There is no contact in inkjet printing, which opens up the possibilities of using much thinner wafers and even foils.

Conclusion

PCBs and solar cells are two examples of industrial printing applications that Océ is working on at the IAC. There has been a shift from classic analogue printing to digital solutions such as inkjet. Océ is focusing on addressing these applications using inkjet in general, but not restricted to CrystalPoint, and with its open innovation strategy at the IAC. With inkjet it is possible to replace analogue techniques, like screen printing or lithography, with digital techniques that offer all kinds of advantages: single-piece production, no contact and cheaper. The popular slogan "Everything can and will be printed" will be a reality much faster than we think.

What has to be what can

Inkjet printing and rapid manufacturing are relatively new areas in the field of what are known as additive technologies. Many different technologies and layouts are used and higher accuracies/resolutions, especially in functional printing and rapid manufacturing, are developing fast. Meanwhile, in the field of graphics printing the focus is on productivity and robustness, aiming for a breakthrough in the conventional high-volume printing business. This article presents work by the NTS-Group and focuses on the considerations that led to motion system layout/detail design choices specifically for inkjet printers and rapid manufacturing machines. Where series products are concerned, the price/performance ratio is always a decisive factor for making the final choice.

• *Mike Curvers, Bert de Swart and Jos Gunsing* •

Inkjet printing and rapid manufacturing are businesses which, on the one hand, are competing with conventional processes, e.g. screen printing, offset printing and (pressure) casting technologies. On the other hand, however, they also offer tremendous new possibilities:
- printing or manufacturing flexibility/freedom without the restrictions of conventional processes;
- response speed in delivering digitally ordered products;
- less auxiliary material waste, so potentially 'green(er)' processes.

The rapid developments in inkjet and rapid manufacturing technologies are very closely related to developments in digital (image) data transformation/transport technologies. Over the last 20 years, handling huge amounts of data has become progressively cheaper, thus creating opportunities for affordable, highly productive inkjet printer and rapid

Authors' note

The authors are employed by the NTS-Group in Eindhoven, the Netherlands. Mike Curvers is a system architect, Bert de Swart a senior mechatronics engineer and Jos Gunsing a business development technology manager. Jos Gunsing is also a lector in Mechatronics at Avans University of Applied Sciences in Breda, the Netherlands.
The NTS-Group is active in the field of developing/engineering and manufacturing mechatronic systems for medical, semicon, solar, material analysis and digital printing/rapid manufacturing applications; motion and optics are the dominant technologies in these systems.

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accurate;
be inaccurate?

manufacturing equipment. At the heart of inkjet technology is the so-called ‘golden triangle’; see Figure 1.

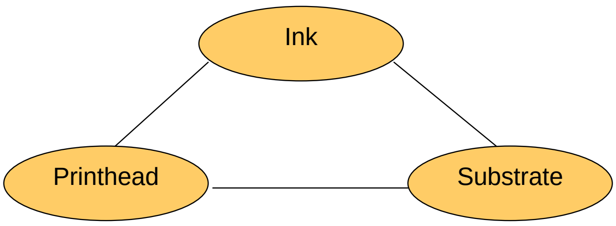


Figure 1. The ‘golden triangle’ of printing: balancing the choice of the ink/substrate/printhead combination.

It is of the utmost importance that great care be taken when choosing the ink/substrate/printhead combination. Inkjet printers like the OTB Pixdro LP50 are designed to do the necessary test and optimization work especially within this ‘golden triangle’; see Figure 2.

Figure 2. OTB Pixdro LP50 laboratory printer for testing in relation to the ‘golden triangle’ choice.

In rapid manufacturing, the process (base material/additive material and/or light/heat for curing) is also paramount. There are a great deal of different processes available in rapid manufacturing. The motion aspects will be discussed in detail for a system where multiple UV beams are used to form particles in a liquid bath by way of a curing process, thus building up a 3-dimensional structure.

Having chosen the core process and its crucial components, a great deal more functionality still has to be added to finalise an industrial system for making high-quality products in inkjet printing or rapid manufacturing.

General trends for the future of inkjet printing and rapid manufacturing include:

Inkjet printing

- Graphical:
  - In general, the productivity increase in single-sheet printing more or less follows Moore’s law (see Figure 3), doubling the m^2/h every two years from 2 m^2/h in 1994 up to 700 m^2/h in 2009 (roll-to-roll or roll-to-sheet single-pass printers can already have considerably higher productivity).
  - Flexibility in terms of substrate material and size including automated substrate handling.
  - Human perception limits the useful resolutions and the corresponding positioning errors for the inkjet droplets; for small format photo/offset qualities a few microns in motion accuracy is acceptable.
- Manufacture based on inkjet technology:
  Meanwhile, inkjet is also being used for depositing functional layers, examples of which are:
  - Replacing lithography for printed circuit boards.
  - Manufacturing flat-panel display.

  Increase in productivity (m^2/h) is a constant issue with these examples. This also applies to improving resolutions/accuracies, for example, in the case of manufacturing printed circuit boards (‘Moore’s law’). In that case, the requirements (will) go beyond the demands of graphical inkjet printing.

Rapid manufacturing

- 3D structures/Rapid prototyping/Rapid manufacturing:
  Given that rapid prototyping productivity has increased very quickly over the past decade, rapid manufacturing that uses similar processes will become more common. This increase in productivity will of course continue in the future. The volume of products coming out of a rapid manufacturing system will grow and in the quest for finer details regarding controlled surface roughness/structure, resolution/accuracy demands will increase as

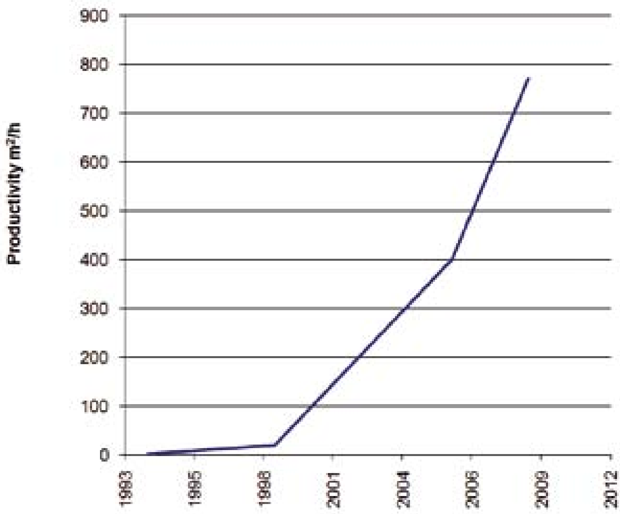


Figure 3. Productivity increase in photo/near offset quality sheet inkjet printing since the early 90s.

well. Apart from that, there is a clear trend of working with more than one material for one and the same product.

Motion system layouts

Basically, there are two important questions that have to be discussed with the inkjet or rapid manufacturing process owner regarding the overall requirements for the motion system:

- What has to be accurate?
- What can be inaccurate?

The second question may result in more discussion with the inkjet or rapid manufacturing process owner than the first one, but it will provide a degree of freedom when choosing low-cost solutions and/or functional integration options from all the disciplines involved. It will also provide insight into specific items in the inkjet or rapid manufacturing process that may affect the qualities of the product that is being produced by the inkjet or rapid manufacturing system. By and large, the following process items will be part of the discussion on inkjet that will lead to a proper set of requirements for the motion system and to a sound concept as well:

- Image quality (resolution, colour aspects, multi/single-pass printing, print strategies, etc.)
- Printhead (drop speed/angle, drop size, missing drops, rotation/perpendicularity to printing direction).
- Ink (bi-directional printing, drop shape, gloss, colour overlay, coalescence, curing, etc.)
- Substrate (flatness, thermal stability, dry-wet stability, flexible vs. rigid, automated or manual substrate change, etc.)
- Printhead maintenance concept and automated/manual calibration.

A multidisciplinary approach is more than essential in these cases and is very important for establishing useful requirements to make the proper and affordable concept choices. Different concepts for the motion layout (e.g. moving or stationary printheads versus substrate) can be checked in relation to the performance/sensitivity/risks related to the abovementioned items.

Motion systems in inkjet for single-sheet printing on paper and rapid manufacturing systems are very similar in approach; in both cases multiple passes are necessary to reach the required resolution. Of course, in a rapid manufacturing machine, height (‘*z*’) is the additional coordinate to take into account. For a 2-D graphical inkjet, height is merely an adjustment parameter that takes different substrate thicknesses into account.

Examples of inkjet printer systems will be presented below.

DuPont Cromalin

Stork Digital Imaging has been active mainly in the field of producing inks and equipment for colour proofing purposes. Colour proofing can be regarded as rapid prototyping for offset (paper) and screen printing (textile and paper). In this way, corrections to the offset print plates (‘master plates’ for each colour) can be made at an early stage in order to obtain the right offset print performance.

The DuPont Cromalin printer motion system was originally developed around 1995 and redesigned in 2000/2001. After several thousands of units were produced, production came to an end in 2008. The inkjet printer motion system consists of a rotating drum (with a speed of up to 300 rpm) and a moving printhead table; see Figure 4. The substrate is automatically attached to the circumference of the drum. The printhead table starts to move on the left-hand side of the print and several minutes later, when finishing the printed image, the printhead ends up on the right-hand side (productivity of up to 2 m^2/hour). The printhead table is driven by a capstan/friction wheel drive. This friction wheel is attached to a rotary encoder; thus providing a high relative accuracy for each 42 μm step of the printhead table with respect to the previous step. The absolute accuracy of the total print length is less interesting; this may vary up to 0.5 mm over a length of 700 mm, but for this colour proofing application it was not perceived as a problem.

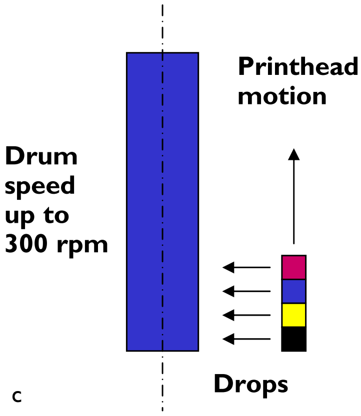


Figure 4. The DuPont Cromalin printer was designed/delivered by Stork Digital Imaging, the motion system by the NTS-Group.
(a) The printer motion system.
(b) The drive module.
(c) Schematic of the motion system.

Stork Amethyst

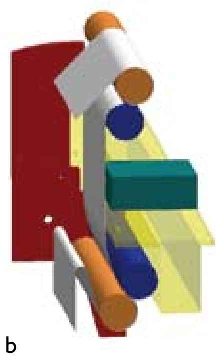
In the late 90s, NTS developed and built the printhead motion system for Stork as well as the substrate transport of the Amethyst textile inkjet printer for roll-to-roll textile printing; see Figure 5. The main challenge was the accuracy of substrate transport of 30-40 µm over the full width of 1,600 mm. Fortunately, the textile is pre-treated to give it a more or less paper-like stretching quality. The rollers are moved by direct-drive motors. Backlash and quirks in geared drives result in uncertainties that are too high. The substrate hangs freely in the printing area, due to the fact that part of the inkjet droplets will fly straight through thin silk-like textiles. A carrier plate/roller or belt behind the textile in this area would cause problems with the ink being brought to the wrong place before it is dry, thus spoiling the image. The printhead carriage (mass 20 kg) is placed on a linear motor platform with a stroke of over 2 m. Productivity totals 15-20 m^2/hour.

Océ/NTS feasibility model for etch-resist printing

Etch-resist printing will be part of printed circuit board production. Several processes can be replaced by a single step, thus resulting in a higher yield and less waste material (and cost) in the overall process.
Océ initiated a number of projects together with parties like NTS to develop other applications for inkjet technology. An etch-resist printing process and machine was developed as a result of one of these initiatives. In March 2006, a team started feasibility studies into the process, the market and possible equipment layouts. In June of that year, NTS started developing a feasibility model which was tested and ready for inkjet process integration by the end of 2006; see Figure 6.

The required (motion) accuracies for printed circuit boards are higher than those for graphical imaging. Therefore, 100 µm tracks ± 7.5%/100 µm spaces ± 7.5% and etch compensation with 5 µm steps had to be taken into account. The layer-to-layer registration (bottom-top side) requires an accuracy of 25 µm. In order for there to be sufficient productivity, standard formats of 24” x 24” printed circuit board material had to be printed within 30 seconds per side with a first-pass yield of at least 95%.

To develop this platform in a very short period of time, as much knowledge as possible was reused from earlier projects. The motion concept was scaled down to this



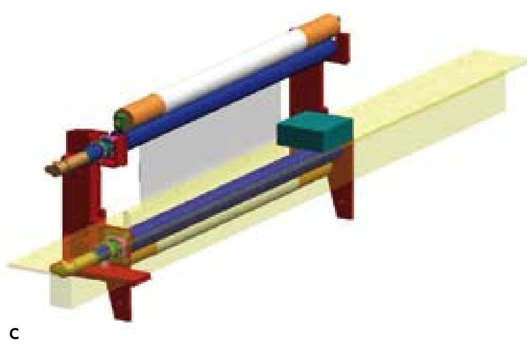


Figure 5. Stork Amethyst inkjet printer for roll-to-roll textile printing.
(a) Total system.
(b) Schematic of motion system, side view.
(c) Ditto, front view.

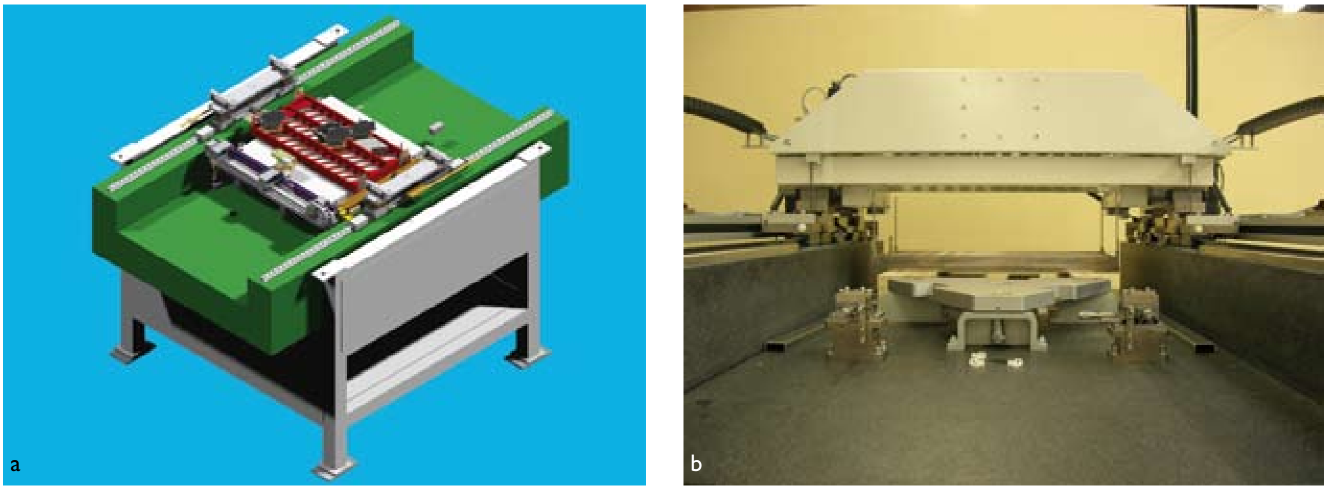


Figure 6. Océ/NTS feasibility model for etch-resist printing [1].
(a) Design.
(b) Realisation.

particular size, while accuracy increased considerably to under a few micrometers. This project preceded the product development that was continued by Océ spin-out company MuTracx.

Agfa Graphics' :M-Press Tiger

Product description
Agfa's :M-Press Tiger (see Figure 7) is a large-area (1.6 x 2.6 m^2) digital printer fully integrated into a screen-print line by Thieme (see Figure 8). Its objective is to add flexibility to a production process traditionally

Figure 7. The Agfa :M-Press Tiger.

characterised by long set-up times and very high productivity. In such a line, a feeder (1) supplies media directly from a pallet into the digital printer (2). Up to four screen-print stations (3) can be included in the line. These screen-printing units are typically meant to print white, transparent, metallic, fluorescent or brand-specific colours (e.g. 'Heineken green'). The ink is treated in between printing stations in a UV dryer. Finally, the media is piled up by a stacker. The media is transported through the line by a chain-driven gripper system. The productivity is set at 686 m^2/h, which roughly translates to 12,000 sheets of A4 an hour. The digital printer adds to the screen-printing resolution, up to 1,260 dpi, with the colour gamut reaching near-offset quality.
Media can be anything that can be fed into the line in sheets like paper, backlit material, self-adhesive vinyl, fluted display board, metal plates, corrugated board, PVC and much more.

For this application, the NTS-Group developed the digital printer motion platform including the application layer software of the digital printer using Agfa Graphics' technology. This resulted in a module that is easily integrated into the screen-print line; see Figure 9.

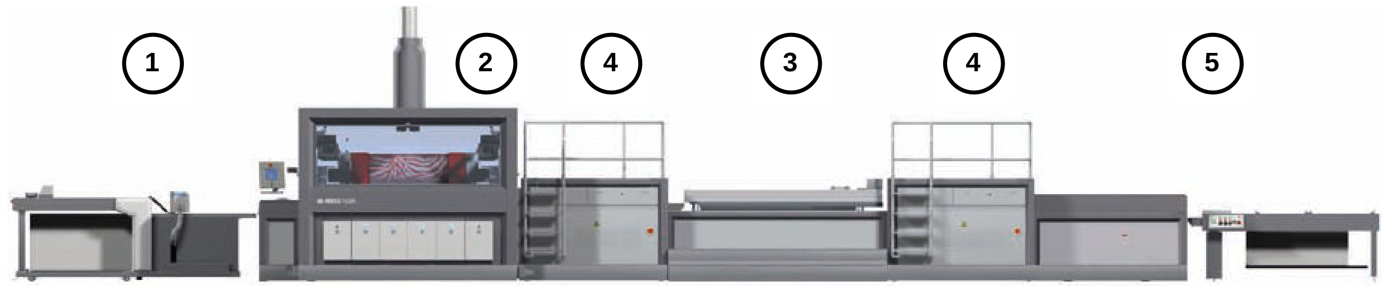


Figure 8. Thieme screen-print line with integrated digital printer.

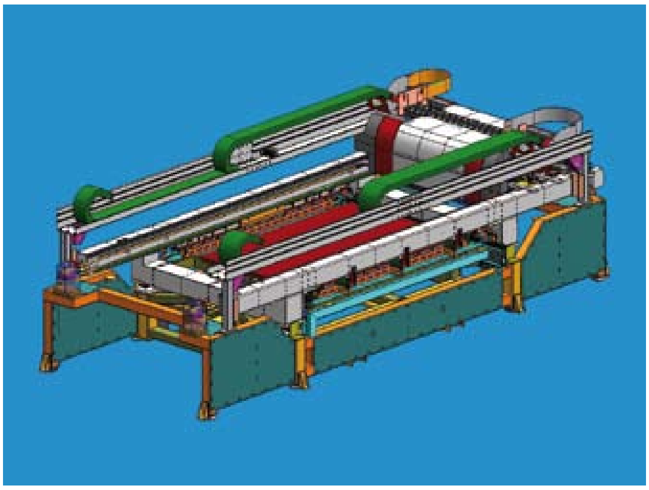


Figure 9. The :MPress Tiger digital printer motion platform.

Layout

UV-hardening ink is deposited by a range of 4x16 greyscale printheads. The heads are positioned in a shuttle that comprises a stepping motion and a scanning motion. The print-scanning speed can be up to 1 m/s. The media is positioned on the media table which, during a print, is held firm to the frame by a clamping mechanism. When the media is being transported, the table is unclamped and lowered to make way for the gripper.

In addition to ink droplet placement, the printer includes functionalities such as ink curing, automatic head-to-head distance calibration, purging and head cleaning.
Some auxiliary units are included for these functionalities:

- two 10 kW UV lamps with real-time operated shutters;
- a camera unit;
- a head adjustment unit;
- a maintenance unit.

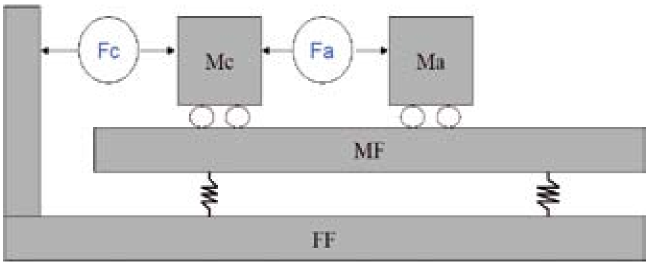
Naturally, collisions between the medium and the shuttle must be avoided and collision-avoidance sensors capable of detecting objects that are a tenth of a mm in size are included on both sides of the shuttle.

Concept choices

Basically, there are two motion concepts:

- moving media,
- moving printheads.

The advantage of the first concept is that cabling and tubing is simpler. The advantage of moving printheads is that integrating into screen-print media handling is easier and the required floor space in the production site is smaller, but still 6 m in length. Once these characteristics were weighed up, the second concept was chosen for this application.



Mc: Coarse motion mass
Ma: Accurate motion mass
MF: Metroframe mass
Fc: Coarse actuator force
Fa: Accurate actuator force
FF: Forceframe mass

Figure 10. Hybrid motion control with forceframe and metroframe.

The accuracy required for this application was set at < 10 μm for each colour and < 50 μm for colour to colour. Tubing for ink, cooling water, vacuum and electrical power have to be provided to the moving part of the printing process. To eliminate disruptions from the cable slabs, a hybrid drive was implemented. This drive carries out a coarse motion by means of a timing-belt drive, while a short-stroke linear motor drive on top provides the accuracy for the printheads. This system ensures that costs are kept down because a system with long linear drives would be far more expensive. One major advantage is that the cable slabs for the accurate stage are significantly lighter than the ones for the inaccurate stage.

Given that acceleration forces of up to 6,000 N can be expected, the frame is split into two parts (see Figure 10):

- a base that leads forces to the floor (forceframe);
- a metroframe that handles the accurate printing.

To set the right product cost, the choice of construction options played a central role in product development. As a result, many sheet metal constructions are used throughout the machine. The print shuttle is an example of such a construction: a light, stiff and cost-effective module. Even the 1,700 kg metroframe is a sheet-welded construction. The use of calibration tables, which compensate for mechanical deviations such as straightness and flatness, dramatically reduced the need for accurate parts. Also, all the auxiliary units were built using the same timing-belt drive concept with slight variations. This not only saves on product costs, but also reduces the complexity for the service engineer.
Finally, during the concept phase, the cost of commercially available controllers versus proprietary motion control was evaluated. Based on the number of controllers and I/O needed, it turned out that a proprietary motion platform would be the most cost-effective solution. The motion control framework has grown over time into a printing application framework with reusable concepts also in higher software layers.

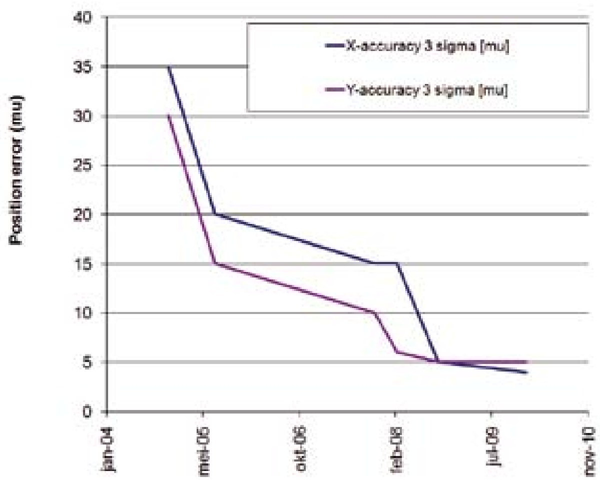


Figure 11. Shuttle accuracy improvement over time.

Product progress

During the development phase it was clear that the market was still looking for the perfect balance between the key elements in the abovementioned 'golden triangle'. The product has evolved from one with an initial near-photographic quality with resolutions of 360 dpi into one with a commercially available near-offset quality with resolutions of up to 1,260 dpi (depending on the selected quality mode). As a result, some of the positioning requirements became a factor 5 to 10 more strict compared to the original specification. Improvements were made especially during the prototype phase and with the introduction of the page-wide head arrangement; see Figure 11.

For such improvements to be made, it was important to determine what type of position errors were closely related to image quality and which were not. In addition to disturbance forces, the errors in control setpoint tracking (by means of calibration tables) had a huge influence on performance. The proprietary motion control was particularly convenient since it allowed for customisation of the required feed-forwards.

Improved accuracy was not the only progress made. Several major hardware changes, such as head arrangement and UV-lamp control, contributed to the improvements.

Given the ongoing success of this product, more changes are expected in the future. A software design that elegantly supports hardware variations has played a vital role in facilitating product development.

The choice of a sound motion concept, together with a flexible and extendable printer application platform, has proven to be a crucial element for supporting Agfa Graphics' need for constant improvement at all levels.

Araldite®Digitalis®

The Huntsman Araldite®Digitalis® is a 3D printer that uses a UV-curable liquid resin as a base material; see Figure 12. The resin is cured layer by layer with UV light, thus enabling a 3D product to be built. Standard resin-

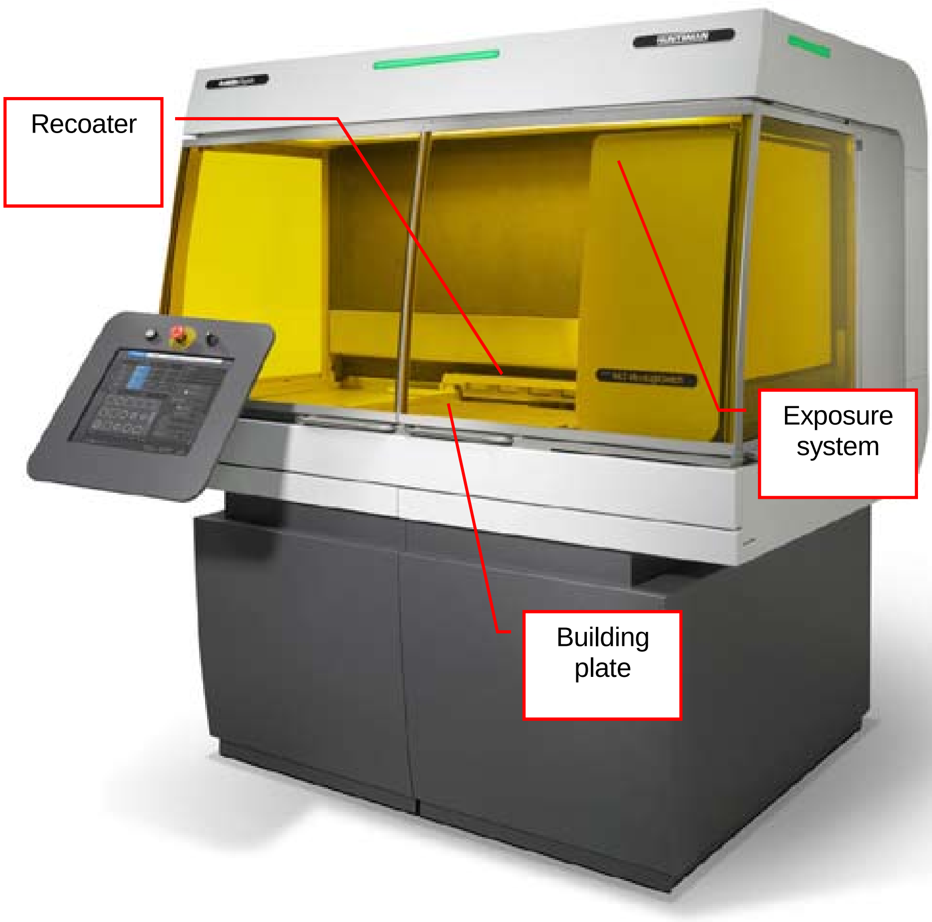


Figure 12. The Araldite®Digitalis® 3D printer.

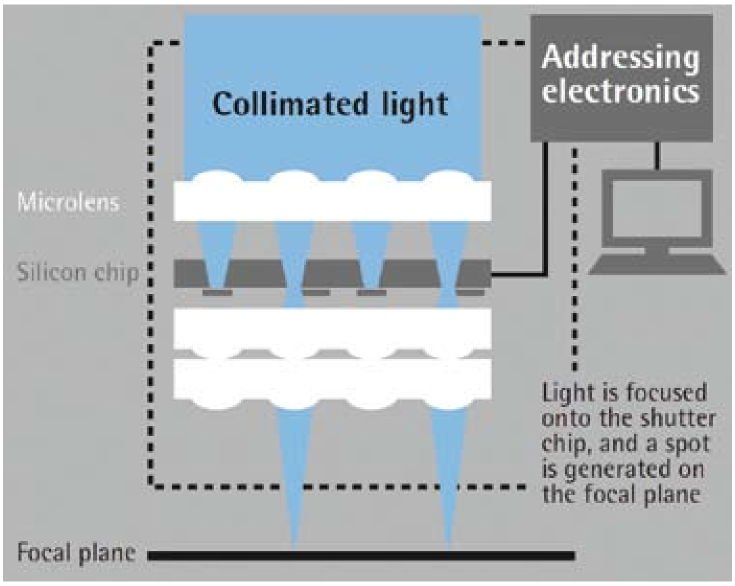


Figure 13. Working principle of the Araldite®Digitalis® exposure system.

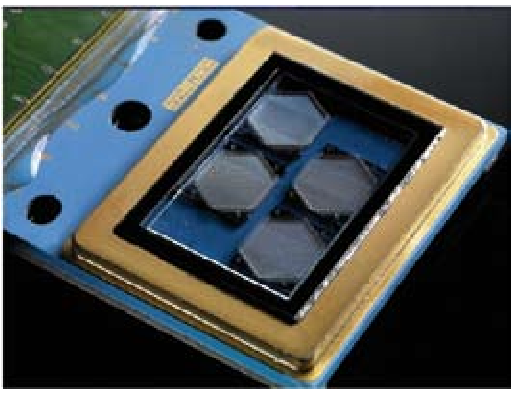


Figure 14. MLS MicroLightSwitch® module.

based 3D printers cure resin by using a UV laser beam that 'sketches' each layer in the resin. Another method, which is only feasible with small-scale 3D printers, uses TI DLP technology (Texas Instruments' Digital Light Processing), which is also used in projectors. Araldite®Digitalis® uses a different technology that is comparable to inkjet printing.

Product description

Araldite®Digitalis® is a new rapid manufacturing machine capable of producing large numbers of parts simultaneously at high speed and with high accuracy. It is based on entirely new MEMS (micro-electromechanical systems) technology. Fundamentally different to other technologies, Araldite®Digitalis® is neither based on laser nor on light-reflecting MEMS, as used in 3D printers.
At the heart of Araldite®Digitalis® is an MLS MicroLightSwitch®, a radical new exposure system operating via a computer-controlled micro-mechanical shutter system that selectively exposes a larger surface area of radiation-curable resin in a single step; see Figure 13.

Figure 15. MLS MicroLightSwitch® module (microscopic picture) shutter.

A collimated UV light source is supplied to each MLS module; see Figure 14. This MLS module contains 2,352 shutters divided over four hexagon-shaped silicon chips; see Figure 15.

The resin level is located in the focal plane of the UV light. Therefore, very sharp UV 'dots' can be placed onto the resin. The penetration depth of the UV light into the resin is dependent on wavelength, UV power, resin type and exposure time/speed. This relationship is the same for all types of resin. As a result, an accurate layer thickness can be obtained. After a layer is exposed, the building plate to which the first layers are connected is moved down (typically 100 μm). A recoat function in the machine makes sure the resin level is flat again before the next layer is exposed.

NTS became involved in the project after Huntsman tested MLS modules for curing resin on a proof-of-principle set-up. Van Berlo created the industrial design ('look & feel') and graphical user interface design. NTS developed the complete machine, including the frame design, the motion and the software for motion control and process control. Huntsman initially carried out the design of all process-related hardware such as exposure optics and MLS control.

Layout

The Araldite®Digitalis® machine has been divided into a number of subsystems. The exposure system contains all the optical elements as well as the motion system for moving the exposure system accurately over the resin to cure it. After a layer of resin has been exposed, the building plate onto which the parts are attached moves down one layer of thickness. Straightness and perpendicularity to X and Y are paramount for this axis to ensure that the parts being built are within the tolerances. After the building plate has moved down, the resin level is adjusted to an accurate zero level. The recoater system is then moved over the resin to create a flat surface. This is necessary because certain parts with a particular geometry have trapped areas, even if the viscosity of the resin has been carefully designed.

Concept choices

Three basic concept choices have been made:

1. Include as much functionality as possible in (mechanical) parts that need to be accurate or are inherently complex. This will reduce overall cost, because there will be fewer complex parts.
2. Use the NTS proprietary printer application platform as the controller for all motion and I/O functionality. Using the platform made it possible to develop a dedicated control system for the Araldite®Digitalis®, which kept development time and system costs at an acceptable level.
3. The exposure bar, to which the MLS modules and lens systems are mounted, is a good example of a complex part with a lot of integrated functionality. It has accurate mounting planes for mounting the MLS modules; the holes for the lens system also need a high accuracy. Once these requirements were considered, the decision was made to also create a highly accurate mounting plane for the motion system, thus obviating the need for adjustment.

The use of the NTS printer application platform has proved a good choice for controlling Araldite®Digitalis®. It has allowed the use of a number of features developed on the platform, such as generating a reference signal for the exposure unit. The reference signal is a position signal, which can be derived from the setpoint position, the linear scale position or the exposure system position after compensating for scale calibration and temperature effects. One of the printing platform's other helpful features is the availability of a parameter control system. This system stores all the machine data. It also separates data applicable to all machines in the same series, and data belonging to a single machine.
Without the printing platform software, setting up such an infrastructure would have taken a great deal more time.

Conclusions

It is clear that the development and construction of correctly operating printer systems involves a number of success factors:

- Very close cooperation with the process owners (such as Stork, Océ, OTB, Agfa and Huntsman) to understand the inkjet or rapid manufacturing process, so that the correct requirements/concepts/specifications can be established.
- Close cooperation with equipment end-users is a must, especially in new markets (e.g. in etch-resist printing).
- Close cooperation is essential with experts in design/development in several areas. In the abovementioned examples, NTS cooperated with companies such as NBG Industrial Automation, CCM, MI-Partners, Van Berlo, Tegema, ACE, Info Support and TCPM.
- Reusing application know-how, concepts and especially proprietary hardware and software (NTS printing platform software) has proven to be a key factor for reducing development risk, development lead time and product cost.
- Do not only think about what has to be accurate, but also what can be inaccurate.

References

[1] H. Veenstra, Inkjet Application Centre/ Océ Technologies, *Inkjet Printed Electronics, The Future of Inkjet*, 2006.

Note on trademarks

Araldite® and MLS MicroLightSwitch® are registered trademarks of the Huntsman Corporation or an affiliate in one or more, but not all, countries.
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Information

www.agfa.com
www.agfa.com/en/gs/products_services/all_products/mpress_tiger.jsp
www.youtube.com (search "M-Press Tiger" or "huntsman araldite digitalis")
www.huntsman.com/advanced_material (tab "rapid manufacturing")

Young - and older - show

Again the precision industry demonstrated its power, on 1 and 2 December at the 2010 Precision Fair. Of course, Dutch precision specialists were in majority, but also German and Belgian colleagues took the opportunity to show their expertise. However, the precision industry is doomed to die if young people are not prepared to follow the tracks of senior precision engineers. Fortunately, the Technology Hotspot gave students from various educational institutes the opportunity to demonstrate challenging examples from their graduation or Ph.D. work in precision mechanics. They made evident that young people still are willing to pursue a study in science or engineering, in spite of the – incorrect – negative image of technical education. With the disappointing observation that girls hardly ever dare to step into such a study.

• *Frans Zuurveen* •

a

b

Figure 1. Precision products from the LIS, the Leiden school for instrument makers.
(a) Hot-formed and cold-ground glass products.
(b) Machined metal products.

innovators their skills

Prominent was the stand of 3TU, the federation of the three universities of technology (TUs), Delft, Eindhoven and Twente, in alphabetical and chronological order. Colleagues or competitors? Both, in a healthy cooperative and competitive atmosphere. Some universities of applied sciences (HBO, in Dutch) were also present, and not to forget the LIS, the famous Leiden school for instrument makers, see Figure 1, founded by Nobel Prize winner Heike Kamerlingh Onnes, who was the first to produce liquid helium.

Young innovators

Oscar van de Ven and Johan Vogel of TU Delft demonstrated a master & slave tele-operated haptic micro-assembly system. It measures tactile forces exercised by a human hand when making a slave mechanism to grasp parts that have to be mounted in a micro-assembly; see Figure 2.

Jasper Wesselingh of TU Delft showed the contactless positioning of a silicon wafer with an active air film. Air films in 6 x 6 squares support the wafer and angle-controlled laminar flow makes it possible to move it; see

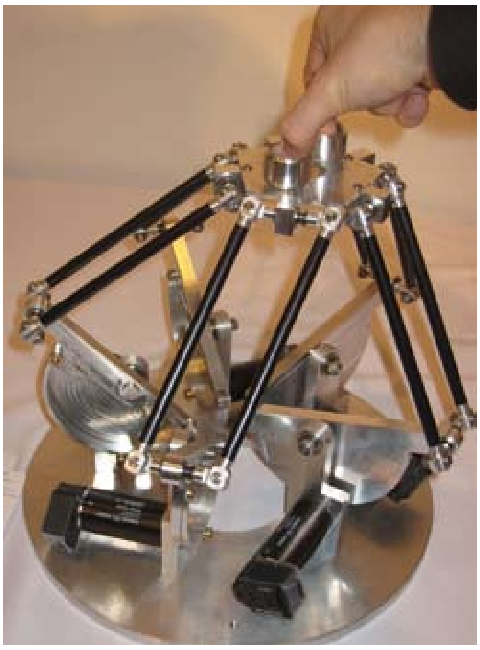
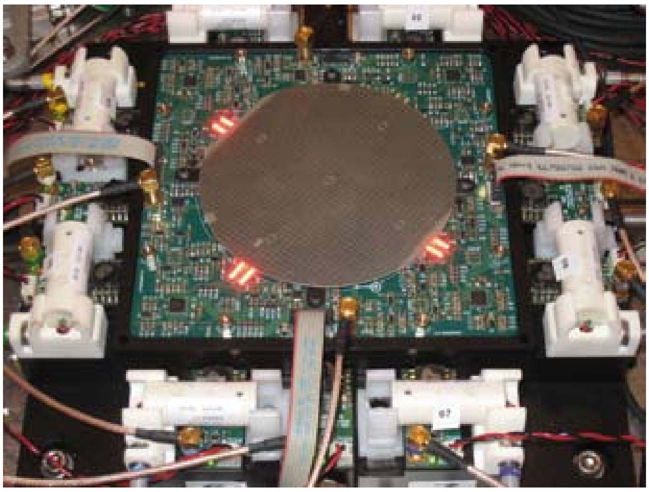


Figure 2. A master mechanism from TU Delft to be tele-coupled to a slave mechanism for mounting micro-assemblies. It is going to form a haptic system for measuring grasping forces.



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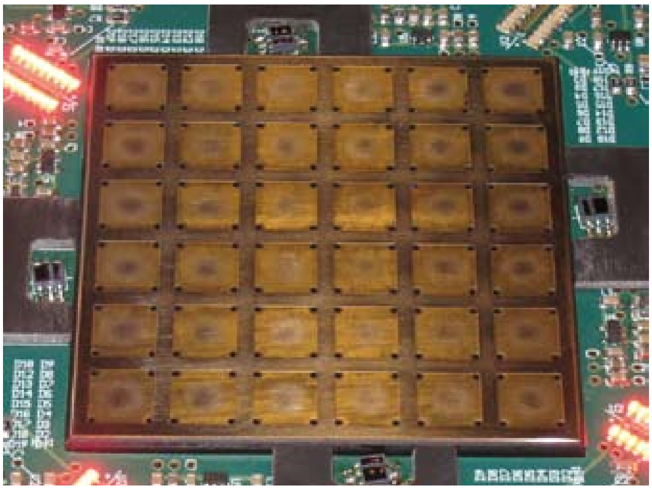

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Figure 3. Positioning a silicon wafer with an active air film, demonstrated by TU Delft.
(a) The 4" wafer with electronic valve control and measuring system.
(b) With removed wafer, 6 x 6 squares become visible with each four diagonally-positioned air pockets for controlling laminar flow.

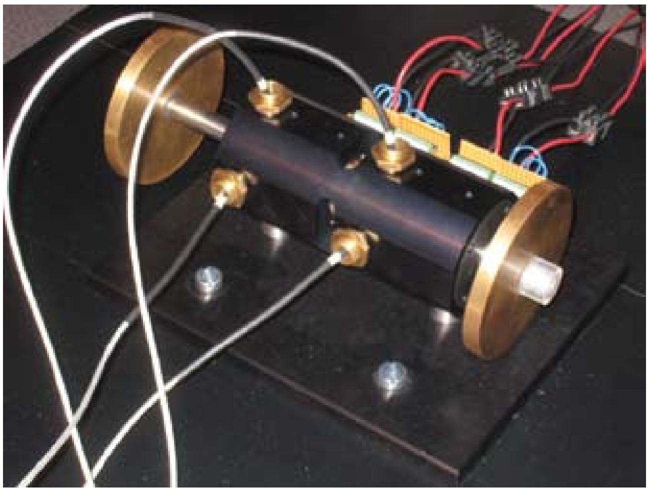

Figure 4. Two homopolar magnetic bearings for supporting a shaft that rotates, and translates as well, shown by TU Eindhoven.

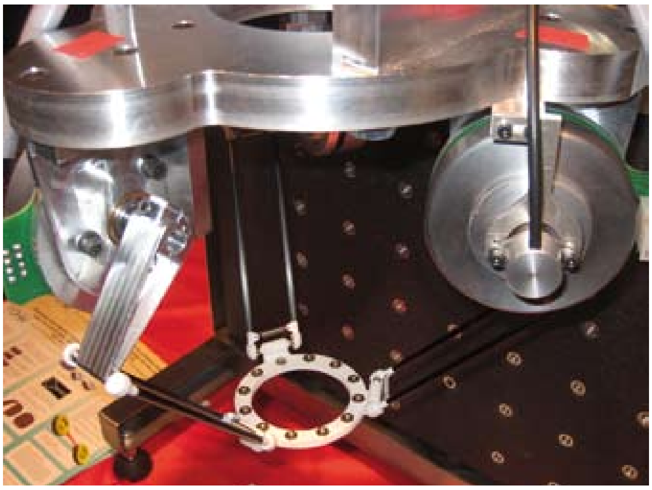

Figure 5. A positioning system with stepping motors and integrated angle encoders, designed by Hogeschool Utrecht. Below, see the object table to be manipulated.

Figure 3a. Therefore, each square is provided with four diagonally-positioned orifices connected to electronically controlled air valves; see Figure 3b. Absence of a carrier stage means an extremely low moving mass. Four reflectance-based optical sensors measure the wafer position by edge detection. In future, Renishaw scales will be used.

Reyhan Zanis of TU Eindhoven designed a magnetic bearing as part of a future electromagnetic system with a linear actuator for positioning in vacuum. The prototype shown consists of two homopolar magnetic bearings to support a shaft that translates and rotates freely; see Figure 4. A dynamic stiffness of 10^5 N/m in a frequency range of 5 to 20 Hz is achieved. Two mass rings emulate the mass of the actuator to be added later.

Edwin Diepeveen of Hogeschool Utrecht, university of applied sciences, demonstrated an experimental low-cost precision manipulator and positioning system; see Figure 5. It is provided with stepping motors in which angle encoders are integrated. Components still have to be redesigned for cheaper manufacturing.

Measuring instruments

As usual, measuring instruments attracted much attention. Of course well-known suppliers of precision measuring equipment were prominently present. Renishaw – among other interesting items – showed its comprehensive range of styli, see Figure 6, highly useful in conventional measuring instruments.

But new measuring instruments show up, in which lasers replace styli. Such a laser successively measures distances to an imaged spot on the object to be measured. The result is a cloud of measuring points, which a computer transforms into an accurate 3D image of the object.

Some firms add such a laser measuring system to – rather well-known – measuring arms, as shown by Metris (now part of Nikon Metrology) in its MCA II manual CMM arm, see Figure 7. The laser throws a light line on the object, which consists of 1,000 measuring points. Manual scanning of the line across the object provides the cloud of measuring points. Similar systems were demonstrated by FARO Europe: FARO Gage and FAROArm.

For larger objects, like car bodies, etc., mobile laser scanning systems are able to measure with relatively high accuracies, up to 50 μm at 10 m measuring distance. FARO showed its Laser Tracker ION, see Figure 8, which measures distances up to a maximum of 55 m by using a ball-shaped reflector, to be attached at the object to be measured. The system is based on 'time-of-flight'

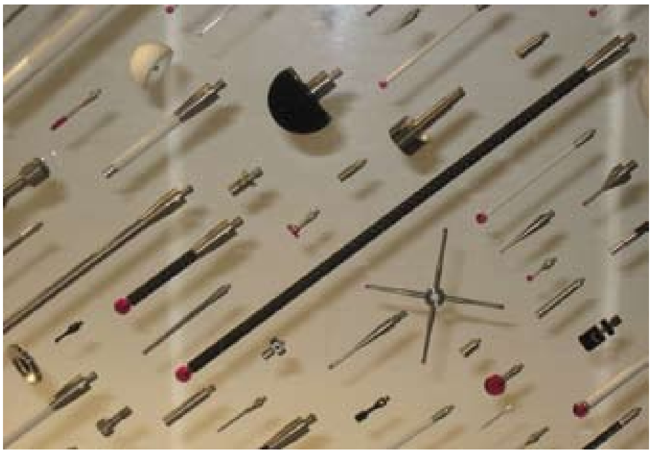

Figure 6. A selection of styli from the Renishaw delivery programme.

Figure 7. Wouter Beeterens demonstrated a Metris MCA II manual CMM arm with laser light line, scanning a Volvo automotive part (photo: Mikrocentrum). The inset gives a detailed view of laser and light line; a ball stylus probe is also available (upper right).

Figure 8. A FARO Laser Tracker ION in use for the measurements of a large object. (Photo: FARO)

measurement, determining the time for a laser pulse to travel to and fro the object. Another laser system, the FARO LaserScanner Focus3D, measures distances by detecting phase differences between four laser beams with different wavelengths after reflection by the object.

Wenzel also demonstrated a mobile laser scanning system, the ScanTec MobileScan3D. This system applies a triangulation measurement principle with one laser, a mirror and a camera detecting the reflected laser spot, see

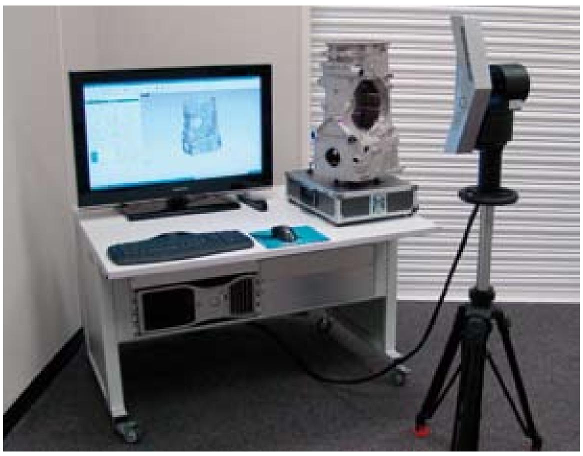

Figure 9. The Wenzel ScanTec MobileScan3D is a triangulation laser scanning system for volume measurements. (Photo: Wenzel)

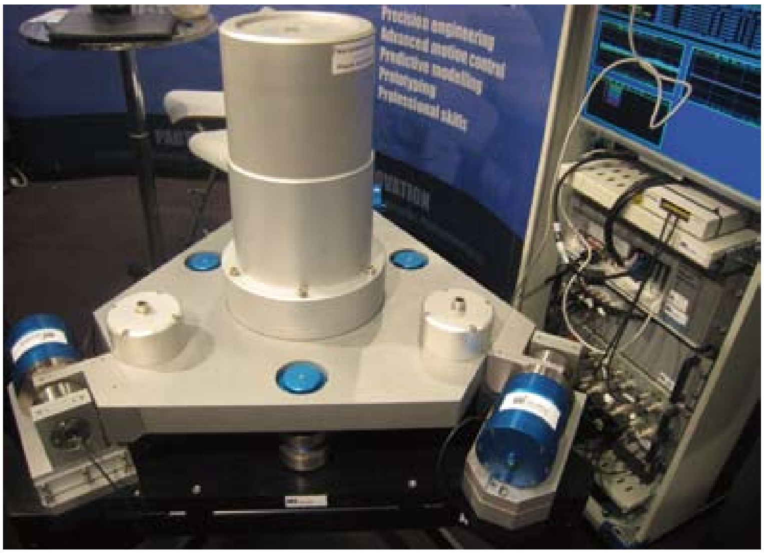

Figure 10. A vibration isolating platform designed and made by MI-Partners, with sensors of Magnetic Innovations.

Figure 9. The largest system encloses a measuring space with over 3 m diameter. The Wenzel CORE-DS, with a working range of 300 x 200 x 450 mm^3, is a stationary measurement machine in which the same laser system has been integrated.

A quite different measuring system was shown by by Helmut Fischer Meettechniek, for non-destructively measuring coating thicknesses: X-ray fluorescence spectrometry. This kind of material analysis makes use of the emission of a characteristic X-ray spectrum by an element when hit by an incoming X-ray beam. For analyzing a coating with several layers, the entering beam first penetrates all the layers and a part of the substrate. The resulting emitted beam shows a spectrum that is the sum of the spectra of all elements in the layers and the substrate. The wavelengths of the peaks in the spectrum of the outgoing beam correspond with the type of element, whereas the height of the peaks corresponds with the respective layer thickness.

Precision manufacturing

Once again many firms showed their ability in machining metal products with narrow tolerances. Those firms not only dispose of advanced CNC machines, they also have experienced craftsmen to operate them. On the contrary, many stands obviously represented one-man firms with the message to help their clients in solving mechatronic engineering problems, especially regarding accurate positioning. It seems that the (past?) times of economical crisis forced precision engineers to start their own one-person precision engineering office.

History proves that such one-man offices may grow out to sizeable engineering firms. An example is CCM Centre for

Figure 11. A complicated product from Al_2O_3 firstly milled by Ceratec Technical Ceramics from ‘green’ (unsintered) material and sintered later on. Expensive finishing is unnecessary.

Concepts in Mechatronics, once started by inventor Alexandre Horowitz (1904-1982) to work out his brilliant but often immature ideas. CCM together with Frencken Development and Engineering showed a Pathology Scanner, which they developed and manufactured for Philips Healthcare. Normally, pathologists have to examine tissue samples one by one to diagnose and characterise diseases. But by digitising the images the routine examination can be done by a computer, leaving the final inspection and diagnosis to the human pathologist. The instrument handles tissue samples on slides that are being transported by an ingenious interchange mechanism. The scan resolution is 0.25 µm.

Another fine example of cooperation between designers and manufacturers is the vibration isolating platform shown by MI-Partners; see Figure 10. It is a six-degrees-of-freedom system with actuators and appropriate sensors. The sensors are a development of Magnetic Innovations. Originally, these sensors, tuned to a very low natural frequency, are geophones for measuring earth vibrations. The isolating platform might be applied for the set-up of a transmission electron microscope of FEI, because of the 40 dB vibration reduction at 3 Hz. In such an instrument the sample should have a positional stability of about 25 pm.

'Green'

Ceratec Technical Ceramics shows a complicated product from aluminium oxide that could be made with relative ease from 'green' material, see Figure 11. In fact, such unsintered material is white and can be machined on conventional milling machines and lathes. After sintering the hard endproduct, it does not need an expensive grinding operation, as the volume shrinkage due to the sintering process has been accurately taken into account.

To conclude

Visiting the 2010 Precision Fair was more than worthwhile, were it not for the technological aspects then quite sure for the achievements of young ambitious people. They promise hope for the future of Dutch precision technology. And, of course, the fair gave many chances to fulfil the theme of this year: Business in Precision Technology.

Author's note

Frans Zuurveen is a freelance text writer who lives in Vlissingen, the Netherlands. Photos are also by Frans Zuurveen, unless otherwise indicated

Successful Precision Fair despite winter weather

The 2010 Precision Fair was organised by Mikrocentrum, supported by DSPE and Agentschap NL. On the (rather cold) 1st and 2nd of December, the fair attracted some 220 exhibitors (12% from abroad: 5% Belgium, 5% Germany) and 2,200 visitors (11% from abroad: 8% Belgium, 2% Germany). Only 28% of the visitors in the Koningshof in Veldhoven, near Eindhoven, the Netherlands, had also visited the 2009 Precision Fair, so the majority were 'freshmen'. Some 900 people attended one or more lectures in the programme that comprised four plenary and fourty commercial lectures.
The next edition of the Precision Fair will take place on 30 November and 1 December 2011.

www.precisiebeurs.nl/business-in-precision-technology

Impression of the 2010 Precision Fair. (Photo: Mikrocentrum)

Printing with electrons

In his famous "There is plenty of room at the bottom" talk Richard Feynman predicted the use of electron microscopes and ion beams for nanostructure creation [1]. That was in 1959… Today these tools are indeed used for this purpose, but because of the low throughput (compared to parallel techniques like lithography) they are not used for mass production. Instead, they are mostly used for diagnostics: to reveal, visualise and analyse failures in semiconductor devices. Below, we describe how they can also be used for prototyping, where small dimensions and iteration cycle time are more important than throughput. But we will first introduce the existing imaging and patterning techniques.

• *Pybe Faber, Hans Mulders and Loek Kwakman* •

Imaging

The reason electron microscopes can show smaller details than optical microscopes is the much shorter wavelength of electrons compared to photons. Atomic scale imaging is nowadays standard in Transmission Electron Microscopes (TEM), and in fact people are saying that "for TEM the resolution race is over": even if the resolution were improved further, there would be nothing more to see.
The resolution of Scanning Electron Microscopes (SEM) is roughly an order of magnitude worse (0.5 nm), and of Focused Ion Beams (FIB) another order of magnitude (5 nm). Where TEM works like a slide projector, requiring very thin samples that are exposed with a broad beam, SEM and FIB use a finely focused beam that is scanned pixel by pixel over the surface. This allows almost any sample to be imaged, and also to expose only certain areas (patterning).

Patterning

Any geometric shape can be patterned by scanning the area of that shape with the electron or ion beam. Where optical lithography is moving to extreme UV to allow smaller details, Electron Beam Lithography (EBL) is already able to write the smallest details in resist layers (for example to create the masks for optical lithography). Today a typical EBL resolution is around 10 nm. In Electron Beam Induced Deposition (EBID) the electrons decompose a precursor gas adsorbed to the specimen surface, allowing site-specific material deposition.

About the authors

The authors work for FEI Company, a leading manufacturer of electron microscopes and focused ion beam tools, delivering solutions to the nano-research, nano-electronics, life science and natural resource markets. Pybe Faber and Hans Mulders are application development scientists in the nano-research market. Pybe Faber is working on proof of concepts for new ways of nano-device creation, characterisation and analysis. Hans Mulders is focusing on beam chemistry related processes for direct deposition and etching. Loek Kwakman is responsible for the marketing and development of new microscopy technologies for the nano-electronics industry.

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and ions

While the electron beam can only make chemical changes by breaking bonds, the Focused Ion Beam (FIB) can actually remove atoms from the specimen (milling). This can be used to reveal subsurface structures (cross-sectioning), to modify existing structures, or to create structures from scratch; see Figure 1. Similarly to EBID, the addition of a precursor gas can allow material deposition (Ion Beam Induced Deposition, IBID), or increase the milling rate (etching). Although single-beam SEM and FIB tools exist, DualBeam FIB-SEM tools (Figure 2) offer the greatest versatility (for example, imaging of subsurface structures with the SEM after exposing them by milling with the ion beam).

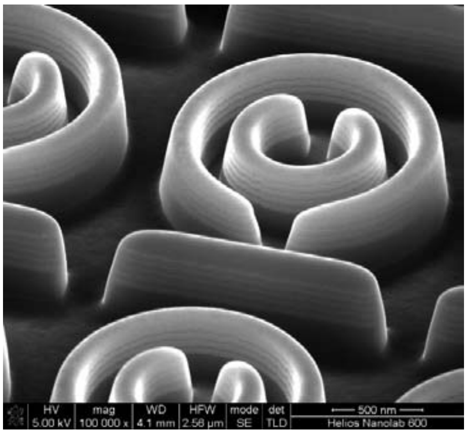

Figure 1. Split-ring resonators for nano-photonics created by milling with the FIB.

Figure 2. FEI Helios 600 DualBeam microscope.

Compared to other techniques the advantage of EBID, IBID and FIB-milling is that these are direct-write (maskless) techniques, allowing immediate design modifications. They also allow creation of 3D structures, including overhangs and structures with different heights/depths in one operation, which are difficult to create with other techniques. The weak points are the inherently slow speed (due to the sequential exposure), the relatively poor purity of deposits and the ion implantation damage by the FIB. The new techniques presented below solve some of these problems.

Site-specific ALD with EBID

Atomic Layer Deposition (ALD) is an existing technique to grow layers of material with very high purity, perfect thickness control and excellent step coverage. It grows a single atomic layer in a 4-step process; by repeating the cycle any desired thickness can be reached. The first step exposes the surface to a first vapour (the precursor), which partially reacts with the surface, leaving a single adsorbed monolayer when the excess gas is pumped away in the second step. The third step introduces a second vapour (the activator), which completes the reaction, growing a single monolayer of the desired material. The fourth step pumps away the second gas, so the cycle can repeat. As all reactions are self-limiting, the gas pulses are not critical.

The disadvantage of ALD is that it is not site-specific; the layer grows on the entire surface. However, as adsorption in the first step of the reaction only occurs on a suitable material, the ALD process in principle can also be selective. It is possible to deposit a very thin layer of a suitable material using EBID, and then grow this only ~1 nm thick seed layer to the desired thickness using ALD, inside the SEM [2]. This combines the site-specificity of EBID with the high purity and speed of ALD. However, the ALD layer grows in all directions, so the lateral dimensions (width and height) of the seed structure grow with the thickness. In addition, surface defects or impurities may also act as a seed, growing to noticeable size after many cycles. As the process depends on the surface material, the seed layer material and the choice of both precursors, there are at least four parameters to influence the chemistry, giving a massive number of combinations to optimise the process.

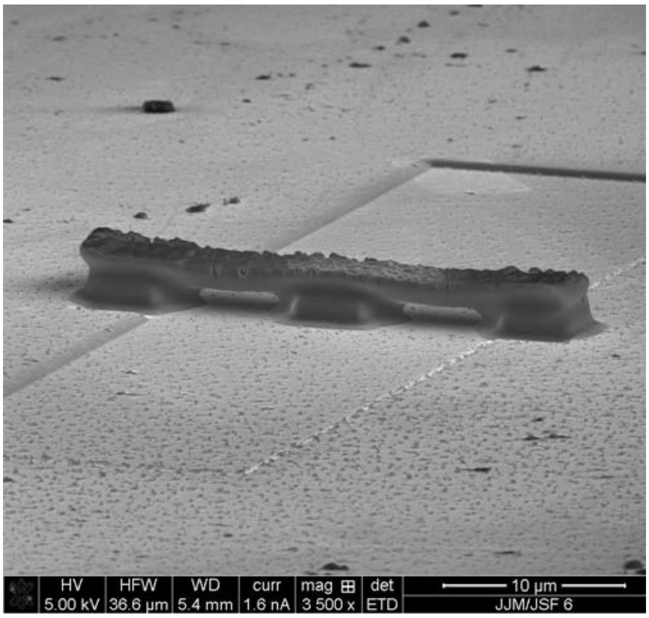

Figure 3. Free-standing bridge created with MaxEBID.

MaxEBID

The MaxEBID technique is inspired by 3D macro printing, but works on a much smaller scale. The specimen is first cooled to a temperature where the precursor vapour freezes to the surface. Next a thin layer of precursor is frozen to the surface, the thickness of which is controlled by the gas flux and flow time. The electron beam then exposes selected areas in the frozen layer to decompose the precursor into the targeted deposition material and volatile byproducts, a new layer is frozen on top of the previous one, and the cycle repeats. At the end, the specimen is warmed up and all unexposed precursor evaporates, leaving only the deposition material behind in the exposed volumes. This technique can create real 3D structures, such as ‘bridges’, that are very difficult to create in other ways; see Figure 3.

It requires matching of the layer thickness and beam energy, such that the thickness matches the interaction volume (the volume in which the electrons scatter inside the material until they have lost their energy, see Figures 4 and 5). The entire thickness must be exposed by the beam, with a small overlap into the previous layer to ensure adhesion.

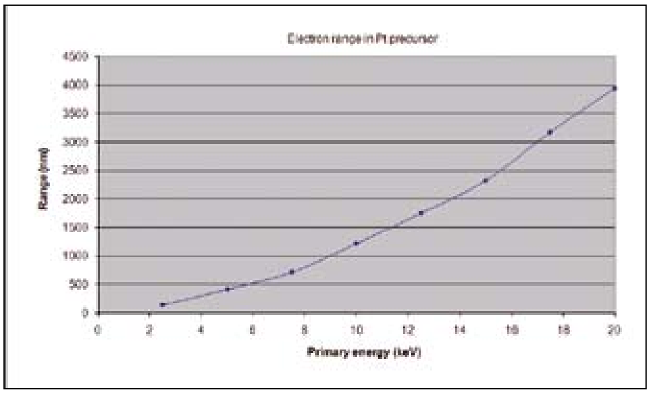

Figure 5. The average distance from the impact point that electrons can travel in frozen platinum precursor, as a function of the initial energy.

In addition to the 3D possibilities this technique offers another benefit: the speed is two to three orders of magnitude higher than normal EBID (leading to the name MaxEBID). The reason is that normally the precursor is activated by secondary electrons escaping from the surface, which only represent a fraction of the number of electrons that are released in the material. Because now the entire interaction volume is inside the frozen precursor, all released electrons will contribute to the decomposition process. The disadvantage is that the interaction volume, not the probe size, determines the lateral resolution. It is not known yet how the purity (and other properties) compare to normal EBID.

NanoBuilder

Until recently, the DualBeam microscopes were mostly used interactively: the user defines one or two patterns, sets a few properties (material type, depth) and controls patterning manually. While this is fine for cross-sections and basic modifications, it fails when creating more

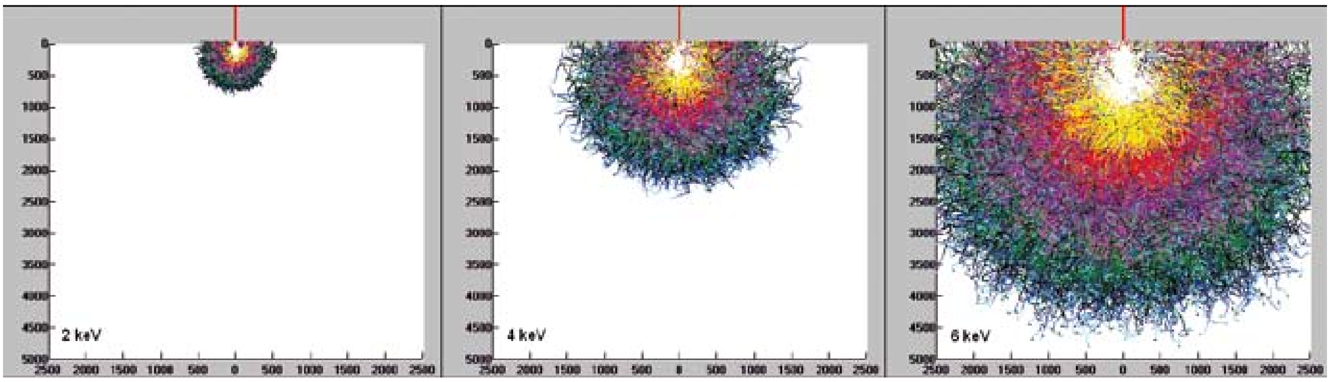

Figure 4. Simulated paths of electrons entering SiO_2 with energies of 2, 4 and 6 keV (left to right). Horizontal and vertical scales are in Ångström.

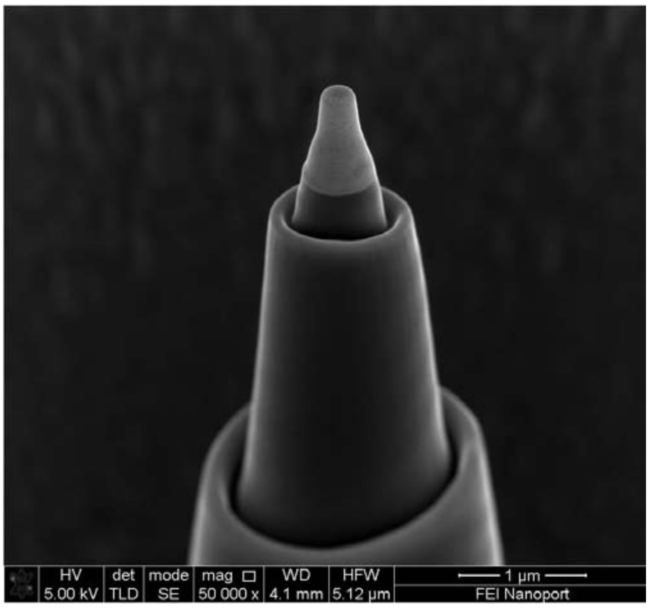

Figure 6. Detail of a nano-tip created with NanoBuilder, using successively smaller beam currents to switch from high milling rates to high precision. The white top is Pt deposition. (Image courtesy Chengge Jiao)

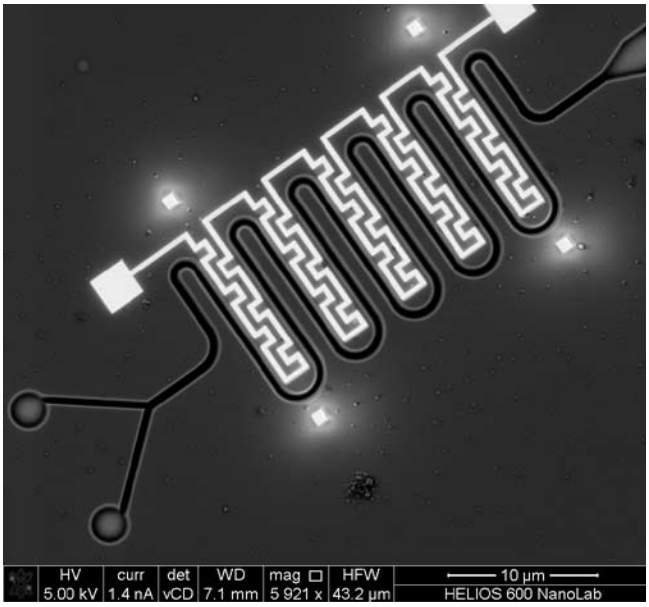

Figure 7. Micro-fluidics channel (dark line) milled into Si substrate with a deposited platinum heater (white line). This structure was created using NanoBuilder.

complicated structures: the process is slow, error-prone and hard to reproduce, there is no coupling to the more complex CAD-designed structures, and it exposes the entire field of view (damaging existing structures) when an image is needed to correctly align the patterns.

To solve the above limitations the NanoBuilder software was created. It imports designs as GDSII files (a standard format in the semiconductor industry, supported by many CAD editors). Designs consist of one or more layers; in NanoBuilder each layer is assigned a 'Process' that specifies how the 2D shapes on that layer need to be patterned: beam (electron or ion), beam settings (energy and current), patterning parameters (dwell time, overlap, …), and optionally a precursor gas. In other words, the 'Process' defines how material needs to be removed or added. Similarly, 'Alignments' can be added to define how the layer must be aligned to the substrate: either by taking an image and searching for a known feature, or by scanning just a few lines over existing dedicated alignment structures (exposing only those lines). With a 'site list' it is possible to create the same design at multiple locations.

As a result it is now possible to use the microscope overnight to create one or more nano-structures, the results are much more reproducible, and the alignment allows more accurate placement (at low dose). See Figures 6 and 7 for examples of structures created with NanoBuilder.

Conclusions

- ALD with EBID combines the advantages of both techniques: site-specific, fast depositions of high purity.
- MaxEBID allows the creation of true 3D structures such as bridges, is several orders of magnitude faster than normal EBID, but suffers from worse lateral resolution (defined by the interaction volume).
- NanoBuilder makes nano-prototyping practical by automating the entire process, allowing unattended, reproducible creation of nano-structures.

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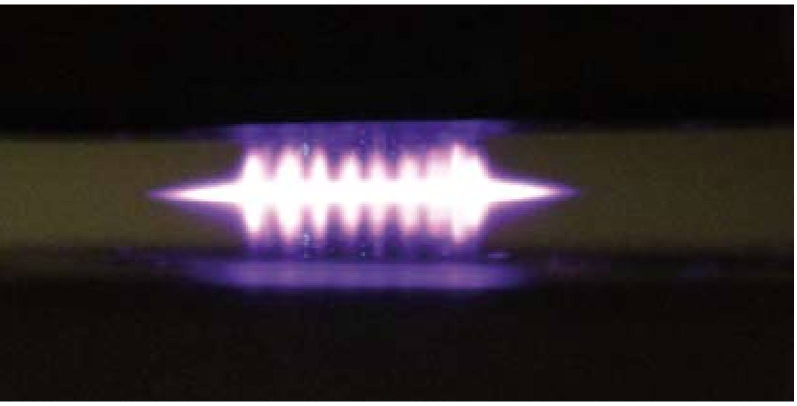
[1] R. Feynman, "There's plenty of room at the bottom", www.zyvex.com/nanotech/feynman.html.
[2] A.J.M Mackus, J.J.L. Mulders, M.C.M. van de Sanden, and W.M.M. Kessels, "Local deposition of high-purity Pt nanostructures by combining electron beam induced deposition and atomic layer deposition". *J. Appl. Phys.* 107F, 116102, 2010.

Towards plastic

Electrical discharges – or plasmas – have fascinated mankind for centuries, because of their aesthetical beauty and uncontrollable behaviour. It has only been for a few decades that plasmas are being used abundantly in industry for a myriad of applications, mostly in the controlled environment of vacuum chambers. In recent years it has become possible to operate plasmas under atmospheric pressure in a controlled manner, opening up the possibility of plasma treatment of surfaces that cannot withstand heat and/or are difficult to use in vacuum. InnoPhysics has developed an atmospheric plasma source that can deliver plasma in a patterned manner, such that the benefits of digital printing now apply to plasma treatment as well. Instead of ink droplets, dots of activated gas are being printed. Presently, the main target market is plastic electronics.

• *Wouter Brok, Alquin Stevens, Ed Bos, Tom Huiskamp, Nico van Hijningen, and Hugo de Haan* •

"… this stream often divides itself into a variety of beautiful rivulets, which are continuously changing their course, uniting and dividing again in the most pleasing manner …"
Joseph Priestley, *History of Electricity*, 1769



Plasmas are gases in which a fraction of the atoms or molecules is ionised. One can achieve this by simply heating a gas to a sufficient temperature, but it is more effective to apply electric fields and couple energy directly into the charged species that for a large part define the

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characteristics of a plasma: electrons and ions. Especially electrons are, due to their low mass, easily accelerated in an electric field. When they collide with neutral atoms or molecules, they transfer some of their energy to these heavier species. This can result in excitation or in ionisation of the species. In the case of excitation, the energy is often released again in the form of light (giving the plasma its appearance) or it stays available for chemical reactions. In the case of ionisation, another electron and an ion are created and thereby the plasma sustains itself [1].

Plasma physics

An important parameter in the physics of plasmas is the number of atoms that an electron encounters on its way through an electric field from one electrode to the other; this is easy to understand if one considers that electrons multiply themselves by ionisation. For that they need to pick up sufficient energy between collisions and meet the right number of atoms. The product of pressure and distance is the quantity that describes this. If it is too low, there are not enough atoms on the electron's path to be ionised. If it is too high, the electron cannot pick up enough energy between collisions to ionise and the plasma will be hard to ignite as well. In the Paschen curve [2] shown in Figure 1, the minimal voltage is shown that is required to ignite a plasma between the canonical parallel plate geometry often found in textbooks [3]. This breakdown voltage has a minimum at a specific value of pressure times distance and it is usually around this value that plasma sources are designed. If one considers the numbers, it can be seen that the convenient engineering sizes of some centimeters require sub-atmospheric pressures and that if one wants to operate plasmas at atmospheric pressures, one needs to decrease the distance between electrodes to tens of micrometers.

Of course, one can choose to operate a discharge on the right hand side of the minimum of the curve by applying a sufficiently high voltage. This has the downside that plasma development becomes uncontrollable: at atmospheric pressure small filamentary discharges develop that are reminiscent of lighting, with their destructive effect on contacting surfaces. There is one trick that can mitigate this: introducing a dielectric barrier between the two electrodes. Any current that runs through the discharge from one electrode to the other hits this surface, charges it and thereby counteracts the electric field of the electrodes.

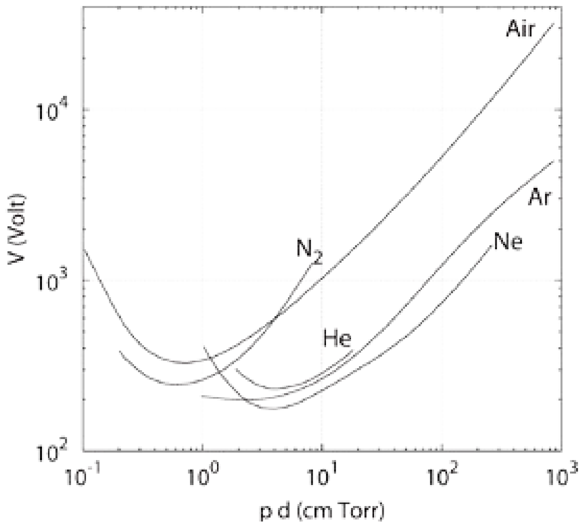

Figure 1. The Paschen curve describes the breakdown voltage *V* of a discharge between two parallel plates, as a function of the product of the distance *d* between the plates and the pressure *p* of the gas [2, 3] (1 cm Torr = 1.333 cm mbar).

While the field diminishes, the discharge dies out before it can become destructive. So-called dielectric barrier discharges (DBDs) have become a common design for plasma sources that operate at atmospheric pressure. The materials, manufacturing capabilities and power supply technology of recent years have allowed large steps to be made in the development of well-controlled atmospheric pressure gas discharges [4]. As an additional bonus, these plasmas can be chemically active, while remaining relatively cold (i.e. some tens of °C).

Applications of plasma treatment

By means of plasmas, we have a way of creating specific molecules efficiently, or to deliver chemical energy to surfaces without heating them. This was realised a long time ago and plasmas found their applications in deposition of layers and in etching. Both are essential steps in the production of semiconductors nowadays. By being able to create controlled plasmas at atmospheric pressure, the versatility of plasmas can be applied to materials that cannot stand vacuum (such as biological tissues) or to materials that are unwieldy for vacuum equipment (such as big rolls of plastic sheets). As such, plasmas are finding applications in the emerging field of plasma medicine [5], in which they are tested for disinfection and stimulation of

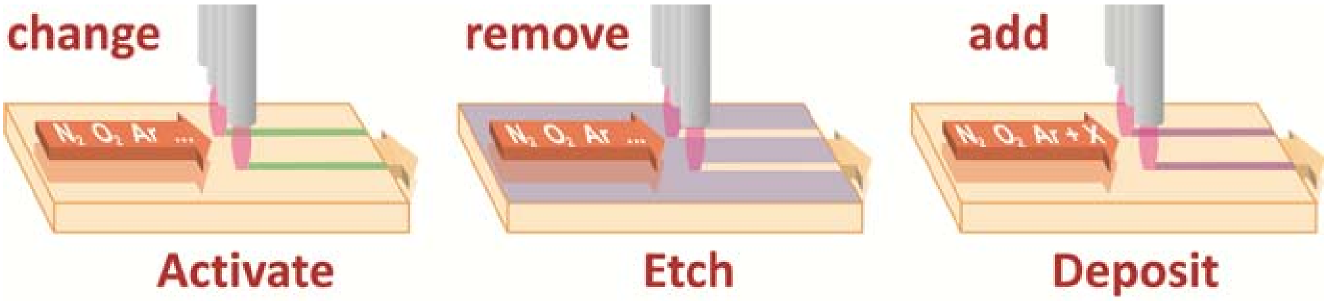

Figure 2. Process capabilities divided in three categories.

wound healing. Already more established is their capability of functionalisation of surfaces: the wettability of substrates can be altered substantially and surfaces can for example be prepared before they receive a layer of ink or glue that would otherwise not hold [6]. In the textile industry, plasmas are used as a pre-treatment before dyeing, or – using different chemistries – to render textiles water repellent.

Surface modifications can be categorised in three types: activation, etching and deposition; see Figure 2. The type of modification realised with a plasma depends largely on the gas in which it is ignited. It is therefore possible to make tools that can do any of the three of the operations by changing the gas supply and choosing the right settings for the power supply. In the following, the focus will be on activating the surface, although the equipment described is indeed not limited to this application.

'Changing', 'activating' and 'functionalising surfaces' are terms that are typically used when one talks about changing the surface energy of materials, or adding molecular groups to surfaces in order to change the adhesive properties of specific chemical compounds to the surface. Plasmas achieve this via the reactive particles that are created in the collisions that happen between electrons, ions and neutral atoms and molecules. If oxygen and nitrogen are present, many radical species can be formed, such as O_3, OH radicals and ions, H_3O^+, singlet oxygen, NO species, and many, many more [4]. The chemically energetic particles are capable of opening bonds of surface molecules, establishing new bonds and assembling molecules at the surface of the material.

In general, all these activation effects add to the surface energy of the material. This surface energy is important in the way the surface interacts with other, solid or liquid, surfaces. If a surface already has a low energy, creating a joint interface with another material is generally not energetically favourable; the individual components are energetically better off on their own and this shows for example by liquids forming beads on the low-energy surface, rather than wetting it. If a surface is treated, bonds are broken and the resulting surface energy is higher, it might become favourable for liquids to create a common interface with the treated surface, thereby wetting it.
In Figure 3 this is illustrated: in the middle one can see a trace where the plastic has been plasma-treated and where the fluid spreads. Around it, the liquid forms beads.
Surface energy and wettability are quantified by so-called water contact angle (WCA) measurements: the angle between the solid surface and the meniscus of the droplet is measured and if one knows the surface energy of the test fluid, one can calculate the surface energy of the solid via Young's law. High surface energies lead to low contact angles and vice versa.

Figure 3. Illustration of the wetting of a surface. In the middle a 2 mm line was treated with plasma. The liquid there forms a snug interface with the plastic, whereas around the treated area, it minimises the contact with the interface and forms beads.

Contact angles do not tell much about the specific surface chemistry though. If one wants to know this, one can use ellipsometry to determine the energy of molecular bonds at the surface and x-ray photoelectron spectroscopy (XPS) for the stoichiometrical composition of the surface. Atomic force microscopy (AFM) can be used to quantify the texture, which is another property that can have its effect on the contact angle. Such more detailed data about the surface can become important if one has certain specific applications in mind. For example, the presence of –NH groups at a surface is very interesting from the viewpoint of living cell adhesion to the surface; therefore, their density is an important quantity in bio-engineering.

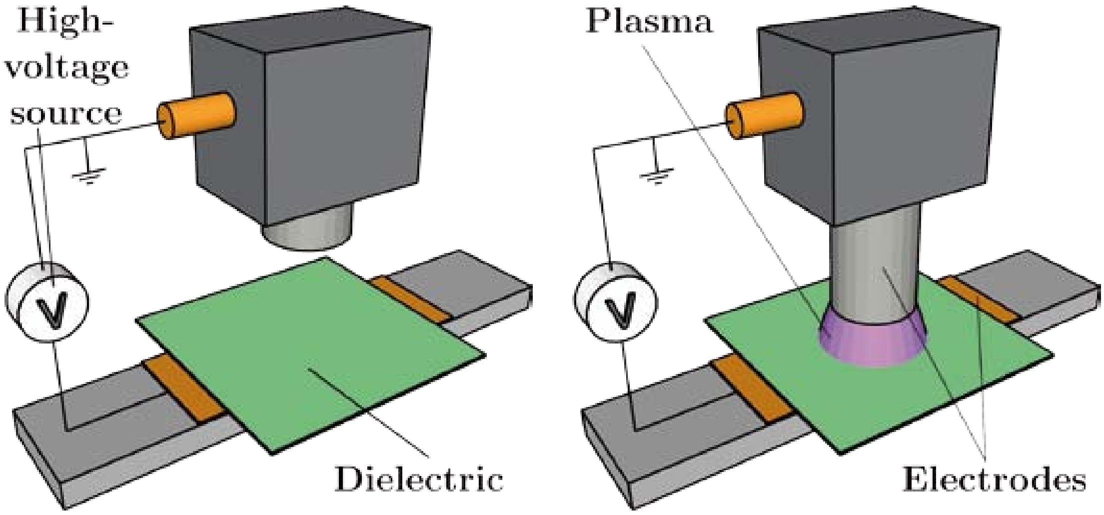

Figure 4. Schematic illustration of the working principle behind plasma printing technology: a plasma is ignited by varying the distance between a needle and the substrate behind which the counter electrode is placed.

Plasma printing equipment

Most atmospheric plasma treatment systems that are available on the market are either meant to homogeneously treat surfaces (such as is common for textiles) or generate plasmas of a centimeter in diameter (for example for wound healing). InnoPhysics has developed a plasma printing technique that combines plasma treatment with digital printing. Instead of the droplets that are for example delivered at a specific place on a substrate by an inkjet printer, a plasma is briefly ignited at the desired spot. Referring to the Paschen curve model in Figure 1 again, one can see that there are three parameters that determine whether a plasma ignites or not: the gas pressure, the distance between electrodes and the applied voltage. The gas pressure is typically hard to control on small time scales. The applied voltage is reasonably easy to control on a small time scale, so this could be a convenient parameter to vary. We chose the unconventional third: the distance between the electrode and the substrate.

The technology behind this can be most easily explained by referring to traditional impact printing techniques in which a needle is mechanically displaced, impacts an ink ribbon and thereby transfers ink to paper. By moving a needle down towards the substrate, the Paschen curve is crossed and a plasma can ignite. This is illustrated in Figure 4.

It was decided to first make this technology available in a laboratory set-up. For this OTB Solar's Pixdro LP50 inkjet tool [7] was selected as a platform. The modification kit that InnoPhysics provides for this platform consists of a printhead assembly, substrate table and high-voltage power supply. With these additions, the LP50 delivers the functionality for plasma printing on the scale of R&D level development; see Figure 5.

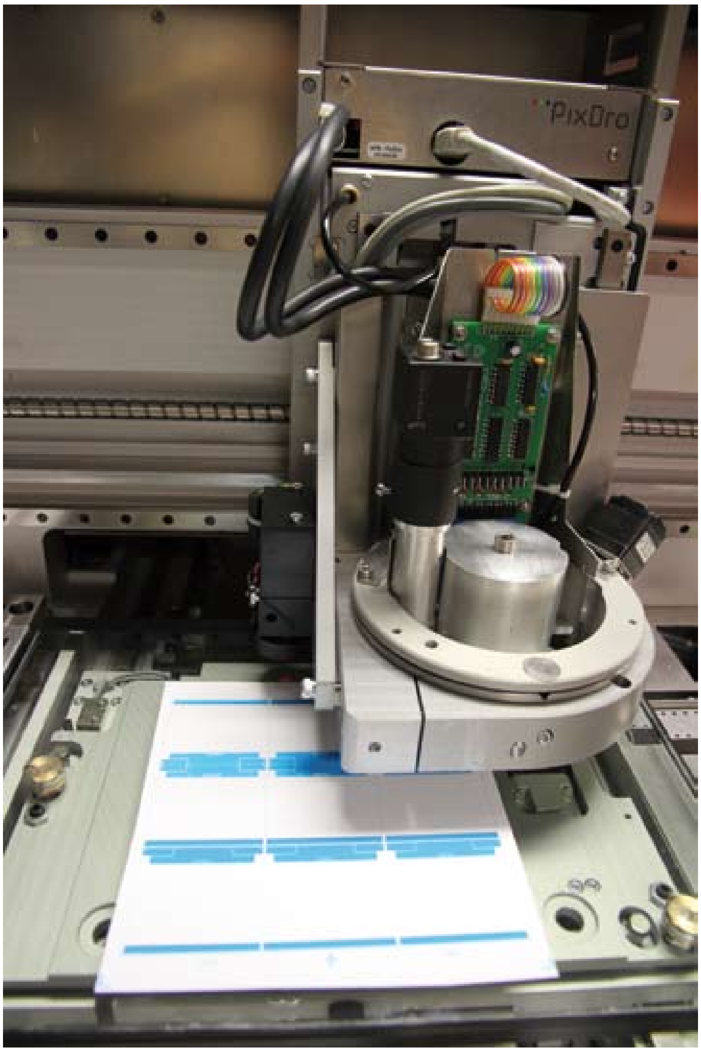

Figure 5. The plasma printhead mounted in Pixdro's LP50 desktop printer [7].

The printhead consists of two arrays of twelve needles that can be independently moved towards the substrate. The frequency at which this happens is typically half a kHz per needle. Between the substrate table and the printhead an alternating potential is applied with a frequency in the order of tens of kHz. When a needle moves close enough to the substrate table (when *d* in the Paschen curve decreases), the electric field becomes sufficiently large for the plasma to ignite. Figure 6 shows side and bottom views of the plasmas when all needles are activated. Precise needle control and precise voltage control allow for accurate plasma treatment. In Figure 7 the effect of these two parameters on the energy delivered per plasma pulse is plotted.

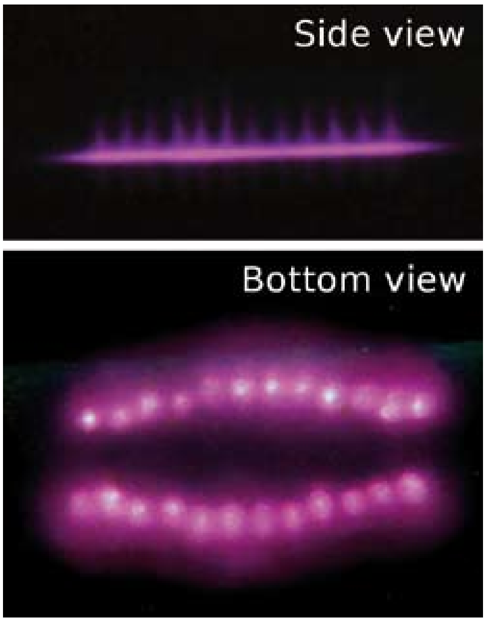

Figure 6. The plasma printhead in action: side view of a single row (12 needles) and bottom view of the two rows (24 needles) operated simultaneously.

Since the printhead is mounted on an XY-stage, motion of the head with respect to the substrate allows to switch the plasmas at specific locations, thereby creating a pattern area that is plasma treated. While the LP50 system is ideal for research and development work, it does not have the speed required for most production processes. Knowing this, InnoPhysics is working on production-scale equipment, which can be integrated in roll-to-roll processing tools.

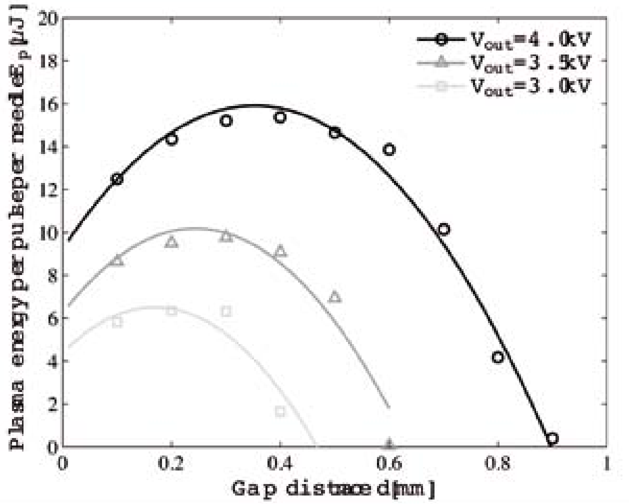

Figure 7. The energy dissipated in the plasma as a function of the gap distance.

Process capabilities

Above, it was already mentioned that plasmas can be used for a number of surface modifications: activation, etching and deposition. Below, some examples are given of processes that can be demonstrated with the plasma printer. The first one is illustrated in Figure 8. The substrate was a plastic foil with two layers on top. The first layer was hydrophilic and on top of it was a hydrophobic layer with a thickness of a few nanometers. By plasma printing in an environment of oxygen and nitrogen, the top layer was selectively removed (etched). As the figure shows, this can be made visible with a regular text marker pen: the ink only transfers to the substrate where the hydrophobic layer has been removed. This effect is highly durable and can be made visible time and time again.

This process example has been developed in collaboration with the Holst Centre [8]. The idea behind it is to use the

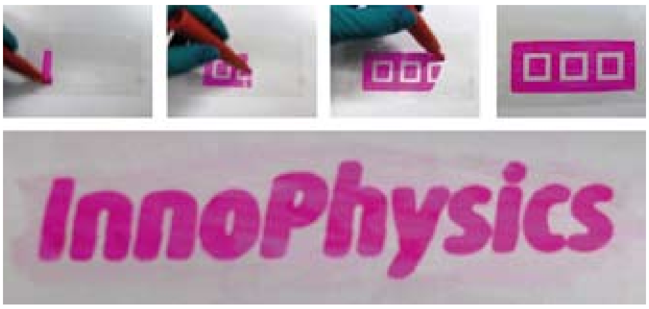

Figure 8. After plasma printing on a substrate, the effect is often not visible, as it would be with inkjet printing. In this case, a large contrast was created between hydrophobic (original surface) and hydrophilic (treated surface), which can be made visible with a marker pen. The ink only sticks on the hydrophilic surface and shows the pattern that was printed.

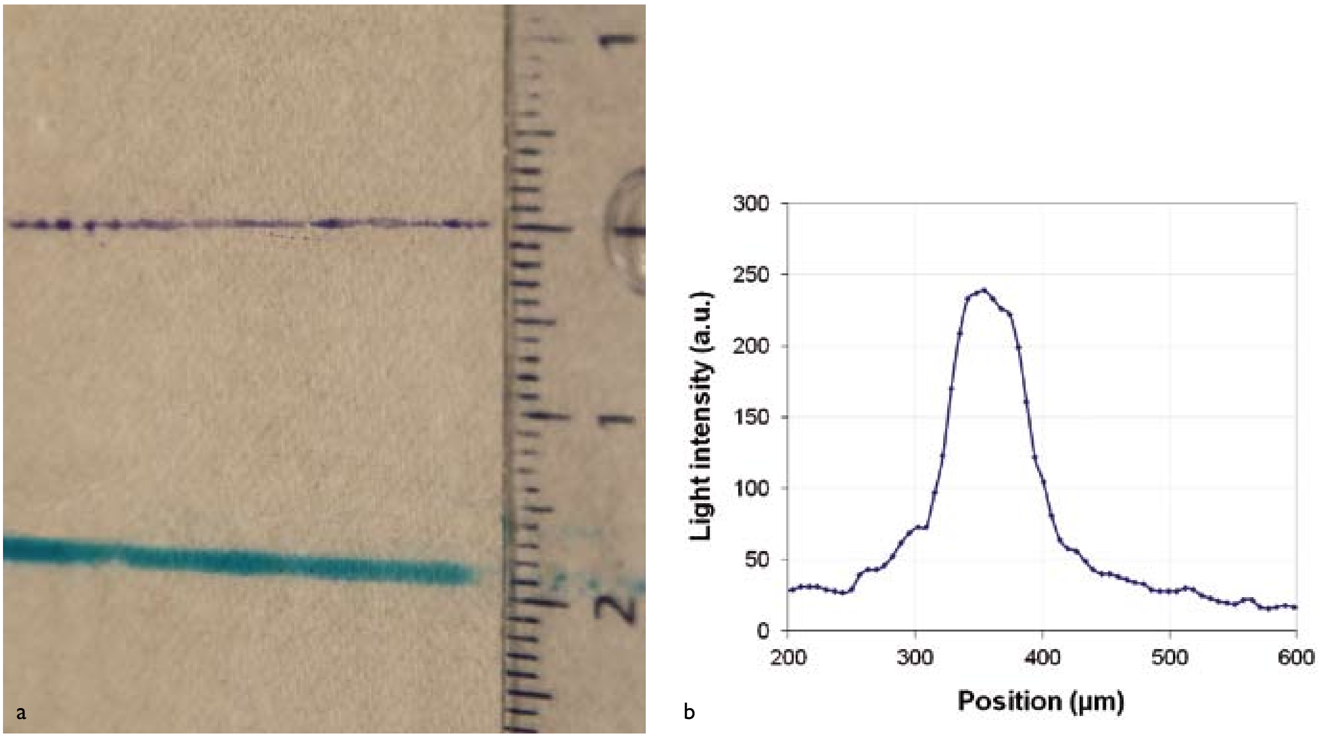

Figure 9. Example illustrating the resolution that can presently be obtained with plasma printing.
(a) Line widths 1 mm and 300 µm; the visualisation is done in the same manner as in Figure 8.
(b) The light intensity measured across a plasma that was optimised for small size. The intensity profile shows a 80 µm FWHM (full width at half maximum) plasma channel of a printhead presently under development.

large surface energy contrast to selectively deposit functional materials by combining plasma printing with slot-die coating techniques. In this way, patterns of functional inks can be created in a controlled manner. This can be used for customisable printed, organic electronics, such as custom-shaped thin-film OLED devices. Being selective at the nanometer scale without damaging the substrate, by using a maskless technique, is relatively unique. Lasers are the next best alternative; in terms of feature size, lasers are still one step ahead of the plasma print technique. However, operating without damaging the substrate or creating debris in the process, and scaling towards production sizes at an acceptable cost of ownership is difficult to achieve with lasers.

The second example illustrates the resolution that can presently be obtained with plasma printing. Figure 9a shows two lines made visible with a marker. These lines were printed on a regular plastic foil (i.e. not having the layer stack of the previous example). One can see that 1 mm and 300 µm wide functionalised areas could be realised. Smaller line widths are more difficult to visualise in this manner. Figure 9b shows a light emission profile that has been measured for a specifically sharp needle geometry. Although the link with surface functionalisation is not direct, it indicates that there are ways to increase the resolution beyond our present standard solution.

The third example (Figure 10) follows from a joint research effort with the Functional Polymers group at Fontys University of Applied Sciences [9] in Eindhoven, the Netherlands. They are active in the field of fluid dynamics and their research involves all aspects of fluid behaviour on a variety of substrates. Their specific interest

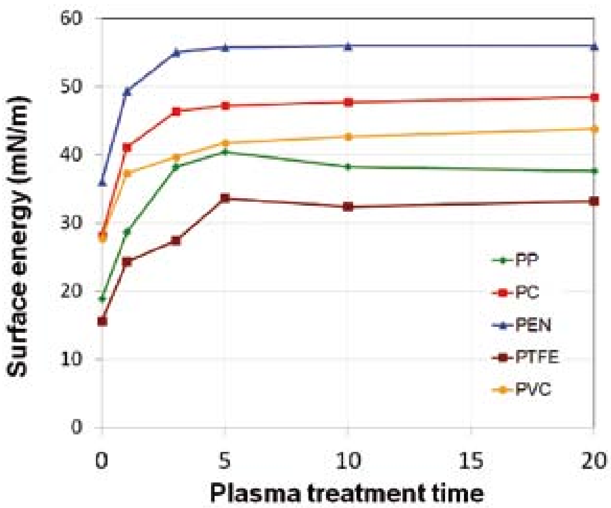

Figure 10. The change in contact angle for a number of different plastics as a function of the treatment time. One can see that the largest effect is obtained between the first two data points of each curve.

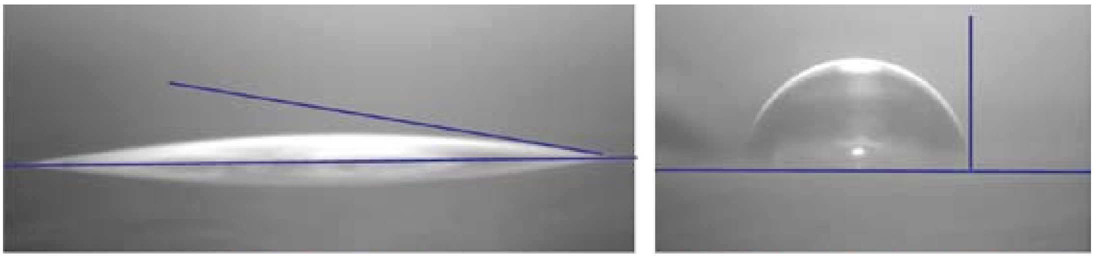

Figure 11. By feeding HMDSO in to the plasma region, methyl-rich silicon oxide deposition can be realised. This new top layer has a lower surface energy than the original surface and the droplet does not spread as well anymore.

is to understand and control the flow behaviour of functional inks, such as conductive organic inks, that are jetted with digital inkjet techniques. Preparing the substrates and thereby improving the controllability of the droplets on substrates is a research subject in which plasma printing is playing a major role.

Figure 10 shows how different plastics react to plasma treatment as a function of time. On the horizontal axis the treatment time of one location is given and on the vertical axis the surface energy, which has been calculated from contact angle measurement. The largest change happens in the first few seconds of treatment. In fact, faster than was anticipated, as otherwise we would have chosen the time intervals differently. Future work will show exactly how steep the change in surface energy is in time. One can furthermore see that surface energy increases of roughly 20 mN/m are obtainable for all the materials that were tested. This change depends strongly on the gas that is administered to the plasma region. For specialty gas mixtures, changes in surface energy of 40-50 mN/m have been demonstrated in the lab, which corresponds to roughly 70° in water contact angle differences between treated and untreated areas.

The fourth example (see Figure 11) is a very preliminary result, but one shown for completeness. In this example, a precursor gas (hexamethyldisiloxane or HMDSO) was fed into the gas nozzle of the printhead. This material is often used in the semiconductor industry to create oxide layers. Notice that the contact angle now changes from small to high; i.e., in the opposite direction as it did in the activation examples given before.

Markets

To conclude, a small outlook on the market envisioned for this new technology is presented; see Figure 12. Currently, the main target market is plastic electronics. This is an expanding market with a large variety of different applications that use printing technologies for devices or components on polymer films such as organic LEDs, (organic) solar cells and displays, organic sensors, biomedical chips and RFID tags. For the volume production of many applications in printed electronics, very thin, patterned layers of (semi-)conducting and/or insulating polymers need to be created with high precision and extremely uniform thickness. Printing of such patterned layers can result in significant cost reductions compared to homogeneous deposition techniques that require subsequent patterned removal.

Accurate control of surface energies is required in order to achieve the desired thin-film accuracies and uniformities. As described above, plasma printing enables maskless patterning of surfaces or coatings on thin, insulating substrates. It can thus be used for surface energy controlled slot-die and/or inkjet printing but also for direct etching of thin organic layers. Many emerging applications demand hybrid manufacturing utilising both slot-die coated patterns and inkjet for which etching and activation in one machine are mandatory.

Acknowledgements

The authors would like to acknowledge the following people for the fruitful and pleasant collaboration: Ronn Andriessen, Juliana Gabel and Jaap Lombaers from the Holst Centre; Jan Bernards, Martijn van Dongen, Renée

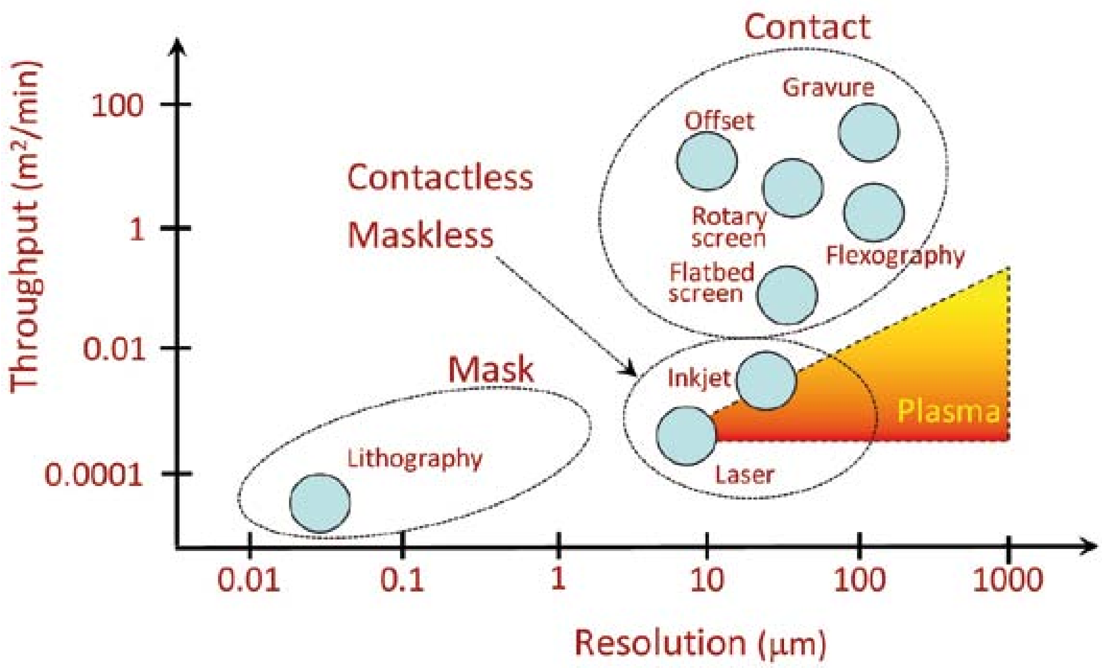

Figure 12. The positioning of plasma printing with respect to other printing techniques. Please notice the discrimination between contact and contactless, which is important for fragile substrates, and between with mask and maskless, which has clear implications for the workflow of production.

Verkuijlen, Richard Janssen, Richard van Hout, Kevin van de Wiel and Merel Eland from Fontys University of Applied Sciences; Peter Brier, Peter Diepens and Klaus Schiffer from Pixdro/OTB Solar; Gerrit Kroesen, Guus Pemen and their colleagues from Eindhoven University of Technology; and finally, all partners in the R&D programmes HTT PrintValley, PiD Printing for Inkjet Applications and RAAK Pro Inkjet printing.

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Bringing µSLA to

Increasingly, integrated packages of ICs, sensors and other functional parts form the central part of consumer products like iPads, cell phones and hearing aids. Moreover, production series will become smaller, so manufacturing should become more flexible. Traditional IC-packaging and PCB technology cannot cope with these demands. Maskless digital, additive manufacturing technologies such as microstereolithography (µSLA) may address many of these challenges. TNO has brought µSLA to a resolution and building speed that show good industrial feasibility of generating integrated 2D and 3D chip packages. On top of that, integration of electrical interconnects with µSLA has been realised.

• *Gerrit Oosterhuis, Hessel Maalderink and Ben van der Zon* •

Integrated packages of ICs, sensors and other functional parts (Figure 1) form the central part of consumer products like iPads, cell phones and hearing aids. To achieve smaller form factors as well as improved performance, these packages will become smaller and more flexible in form.

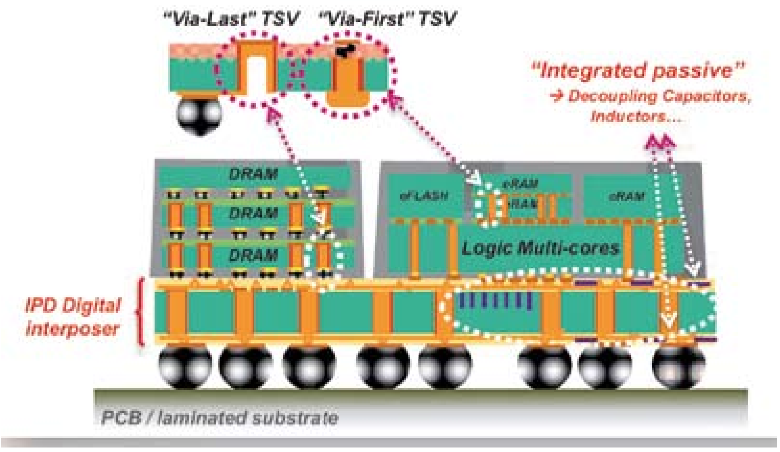

Figure 1. Example of an integrated chip package as published in the 3D Packaging newsletter [1].

Also, production series will become smaller, so manufacturing should become more flexible. Traditional IC-packaging and PCB technology cannot cope with these demands.

Maskless digital, additive manufacturing technologies such as microstereolithography (µSLA) bear the promise to address the manufacturing challenges concerned. TNO has

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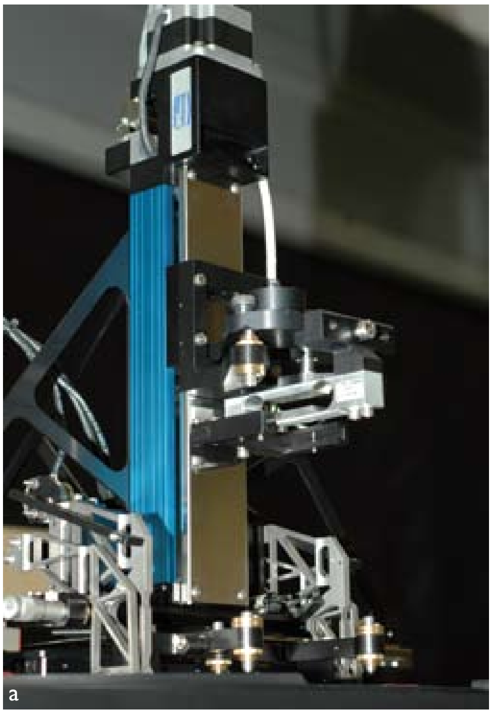
industrial feasibility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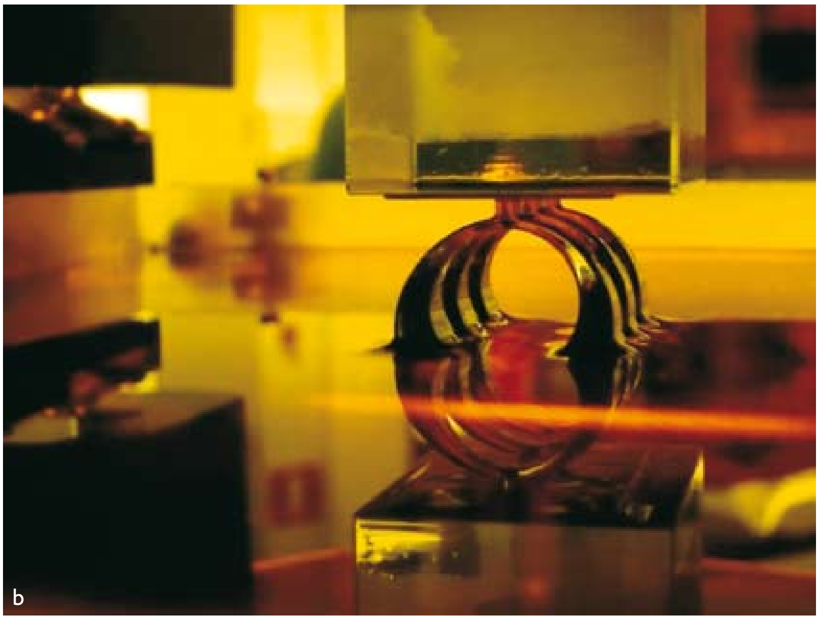
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Figure 2. Microstereolithography as developed by TNO.
(a) The tool is capable of building parts with 5-10 µm resolution.
(b) µSLA at work; layers are formed below the liquid surface.

brought µSLA to a resolution and building speed that show good industrial feasibility for chip packaging [2, 3, 4, 5]; see Figure 2. One of the major challenges is to incorporate conductive structures into the insulator building material. Therefore, a µSLA-based manufacturing process was designed at TNO to produce 3D-interconnect structures (patent pending). Using this process, a demonstrator was built to illustrate the potential of digital, additive processes for chip packaging and interconnects. The process will be outlined here and experimental results will be shown.

Microstereolithography

The basic µSLA process is depicted in Figure 3.
A maskless projector (in this case a Digital Light Projector, DLP) projects a series of images through a glass plate onto the bottom surface of a photo-curable resin. The images correspond to consecutive intersections of a CAD representation of the object to be built. Triggered by the incident radiation, the resin locally polymerises to form a layer of the object. After each projection, the z-stage (holding the object) moves up to separate the product from the glass plate, and down again to form a new thin layer of resin.

The final voxel (3D pixel) size is not only determined by the projector resolution and the magnification of the image. The microfluidic properties of the resin as well as the photochemical characteristics of the curing reaction also influence the resolution of the cured resin pattern [6]. Equipment developed at TNO is capable of producing parts with details down to 10 µm.

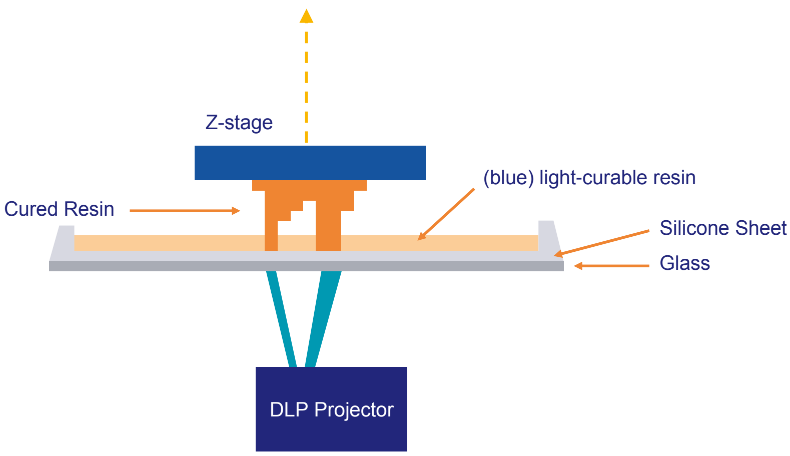

Figure 3. The basic principle of µSLA. Layer by layer, resin is selectively cured to form a freeform object.

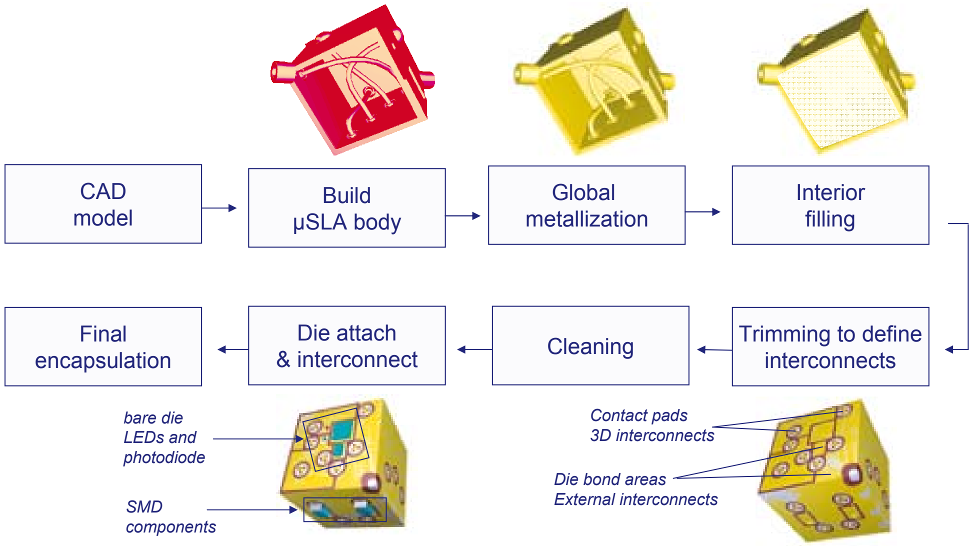

Figure 4. Overview of the µSLA-based process to manufacture 3D interconnects. The steps are described in detail in the text. As an illustration, drawings are shown of the demonstrator cube that was built to proof the concept.

Typical materials for this type of technology are acrylics and acrylic-epoxy hybrids. These resins may also be filled with thermal conductors, adhesion promoters or ceramics. Electrically-conductive structures, directly produced through µSLA, are currently under development at TNO.

Process description

To investigate what can be done in terms of chip integration and packaging using µSLA, the challenge was taken up to produce a 3D conductive structure that combines electrical interconnects and mechanical support with other functionalities. The target was to use existing µSLA and metallisation technology. Thus, a process has been developed that starts by building a 3D structure in insulator material, followed by a number of global processes to add conductor material and to define the interconnect structure. Figure 4 shows an overview of the process flow. Each of the steps is explained in more detail below.

Build µSLA body

As a first step, the body is built layer-by-layer directly from CAD using the µSLA process. The material is an electrical insulator like the epoxy-acrylic compositions typically used for prototyping. The shape is designed in such a way that arbitrary interconnects can be made between any of the faces of the structure. The structure of the demonstrator currently presented is a cube. Principally, this can be any freeform shape.

Global metallisation

The complete structure is metallised. Typically this is done using an electroless plating process that is preceded by an adhesion-promoting step. For most applications, the preferred material for the metal layer is copper with a thin nickel-gold finish to allow wire bonding directly on the µSLA surface. For electrically and thermally less demanding applications, nickel can also be used for the bulk metal, as it grows easier on acrylics using electroless chemistry.

Interior filling

Mainly to support the fragile interconnect structures, the interior of the cube is filled with an electrical insulator material. The filling material must match the thermal expansion of the material used for the µSLA body. Further, additives may be used to influence bulk properties of the filling material, like thermal expansion, thermal conductivity or stiffness.

Trimming to define interconnects

The outside surface of the body contains ridges as well as domes that are located at the ends of the internal interconnects. These are shaped in such a way that machining these structures separates the different metal parts of the structure, rendering an electrical 3D circuit. Thus, the metal surfaces on the outside are separated from the interior 3D interconnects.

Cleaning and die connect

After the grinding step, the contact areas and the end-pads of the interconnects are cleaned prior to die attach and interconnect formation. To connect the chips, wire bonding or flip chip using conductive adhesive is straightforward. However, more advanced technologies like printed interconnects using for instance nano-inks or laser-induced processes are also very suitable to be incorporated in this process.

Demonstrator design

To demonstrate the potential of this technology, a pulse-oximetry sensor has been built. This is an optical sensor to determine heart rate and oxygen saturation in human blood. It consists of two LEDs, a photodiode and an amplifier, which need to be positioned close together. The

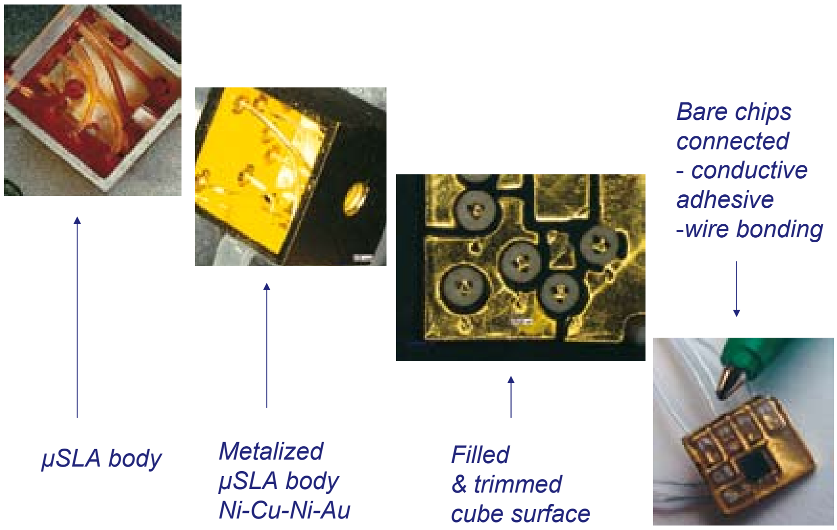

Figure 5. Overview of the experimental results of the developed process, showing the µSLA 3D body built in epoxy-acrylic photosensitive resin, which is subsequently covered by 0.5 µm nickel, 5-10 µm copper, 1-2 µm nickel and 100-200 nm gold. The size of the cube is 10x10 mm^2. On the inside of the cube, the internal interconnects of about 300 µm cross-section can be seen. The picture of the filled and trimmed surface shows the opened contact pads of the 3D interconnects. The µSLA insulator material appears black, the shiny yellow color is the gold finish on the copper layer, the mould material is white. Finally, chips are assembled on this surface.

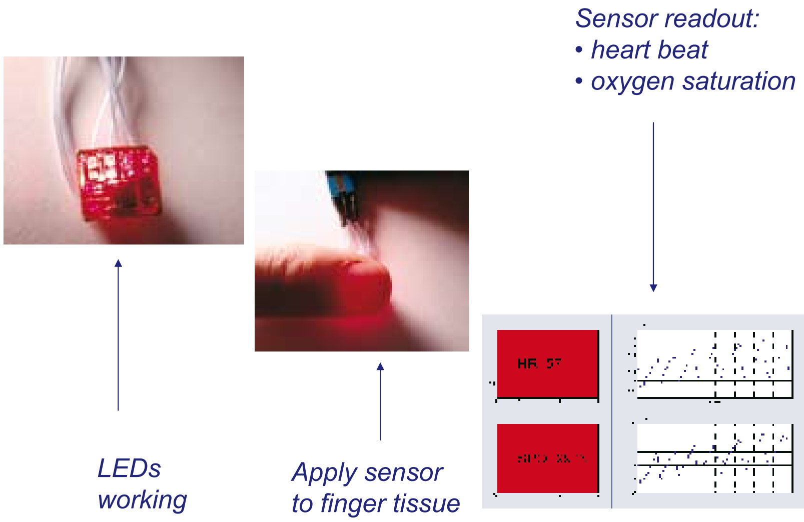

Figure 6. The assembled chips together form a working sensor that is placed against finger tissue to measure the heart rate as well as the oxygen saturation of the blood.

demonstrator is designed as a cube with the LEDs, photodiode and amplifier integrated in bare die on one face, SMD resistors on another face, and the external wiring connected to a third face.
For demonstration purposes and ease of handling, the cube was built using 200 µm as the smallest detail. However, the designed process can be scaled down to details in the order of 10 µm rendering dimensions well applicable to chip packaging.

Experimental results

Figures 5 shows the experimental results of the presented process step-by-step. Figure 6 shows that a working sensor could be fabricated. The LEDs and the photodiode worked well and heart beat as well as oxygen saturation could be detected. The electrical resistance of the 3D interconnects (vias) was measured using a probe station and was found to be in the range 0.1-0.4 Ω, which is well sufficient to act as an electrical interconnect.

Conclusions and outlook

Based on the µSLA process, it is possible to generate integrated 2D and 3D chip packages. The 3D-interconnect conductivity is more than adequate for building electrical systems. An important process result is the metallisation of µSLA surfaces with a quality that complies with common chip-interconnect technologies such as wire bonding.

Using this process, it will become possible to quickly and cheaply produce small series down to single products by changing nothing but a software file that describes the interconnect structure and inserting the corresponding chips and devices.
The developed manufacturing method allows for real heterogeneous integration and functionally-shaped packages like antennas, nozzles or mechanical functions. Also, the developed technology is an eminent candidate for building reconfigurable wafers as used in 3D wafer-to-wafer stacking.

Next steps in the further development of this technology will include material compliance and reliability, thermal management and digitally-printed interconnect structures to ensure industrial maturity. The final goal is to arrive at a digital, additive production platform that produces these smart products regardless of the specific product application, at the highest achievable value of ownership for the process, i.e. lowest cost per package.

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Metallic coatings presented at RapidPro

During the RapidPro, a new event on additive manufacturing, rapid prototyping, rapid tooling and other 3D technologies, to be held om 2 March 2011, the results of a technology cluster organised by TNO will be presented. The topic of this technology cluster is metallic coatings on rapid manufacturing parts. See also the RapidPro announcement elsewhere in this issue (page 55).

www.rapidpro.nl

Huub Janssen and Tim Nai honoured

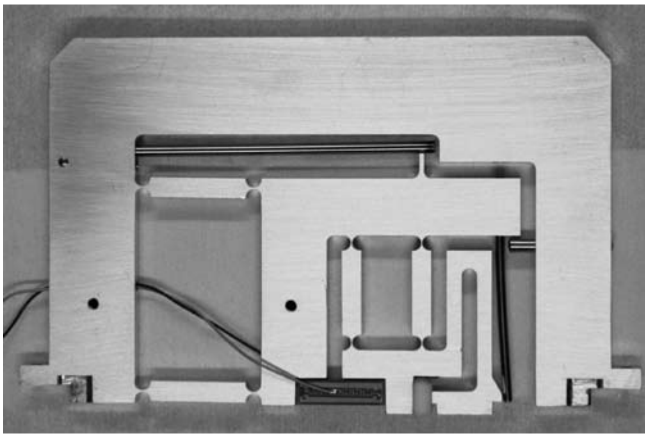
During the 2010 Precision Fair in Veldhoven, DSPE presented two awards that are both named after legends of precision engineering in the Netherlands. The biennial Prof. M.P. Koster Award went to Huub Janssen of Janssen Precision Engineering, and the annual Wim van der Hoek Constructors Award was given to Tim Nai for his graduate work at Delft University of Technology.

On Wednesday, 1 December, the two-yearly Prof. M.P. Koster award was presented for the fifth time. This prize is for deserving mechanical engineers/designers in the field of mechatronics and precision technology. On behalf of the jury, chaired by the Twente professor Herman Soemers, Rien Koster, who gave his name to the award, handed out the prize after explaining the jury's considerations.

Oeuvre prize

Huub Janssen, director and proprietor of Janssen Precision Engineering at Maastricht Aachen Airport, was awarded the prize for all his work in designing constructions for use in such developments as machines for chip manufacturing and the world's largest optical telescope. His work mostly concerns imaging systems where the challenge lies in precisely positioning and manipulating light or ion beams, for example. According to the jury, each of Huub Janssen's designs is an innovative and beautiful example of the combined mechanical, electronic and control engineering way of thinking. This enables Huub Janssen to not only create high-quality employment within his own company, JPE, but to also contribute to the progress of IC technology and astronomical research. The jury also praised the way in

Winner of the Prof. M.P. Koster award 2010 Huub Janssen flanked by the two doyens of Dutch precision engineering: Rien Koster, the man who gave his name to the award (left), and Janssen's graduate professor Wim van der Hoek. (Photo: Mikrocentrum)



One of the highlights of Huub Janssen's precison engineering career so far has been the work with Janssen Precision Engineering on the development of a specific and extremely compact drive and measuring system for cryogenic and vacuum application in the 'Grand Telescopio de Canarias' (GTC). This work has led to the realisation of a demonstration model of the so-called Configurable Slit Unit (CSU) for the GTC infrared instrument. The CSU comprises 110 bars that can be positioned arbitrarily within the instrument's image field. On the left the actuator mechanism of a single bar.

which JPE is open to young people who want to learn the trade. Work placement opportunities are always available for students from all types of technical education programmes and the company regularly welcomes school excursions. The professionalism that Huub Janssen and his company demonstrate by sharing their expertise and experience with others was regarded very highly by the jury.

Janssen Precision Engineering

After graduating from Eindhoven University of Technology under the doyen of Dutch precision technology, Prof. Wim van der Hoek, Huub Janssen worked for ASML and Philips. Twenty years ago, he set up his own company JPE (Janssen Precision Engineering) situated at Maastricht Aachen Airport. JPE designs and builds high-precision appliances for use in the semiconductor industry, space travel, astronomy, biotechnology and the medical industry. It specialises particularly in high precision, vacuum applications, handling and measurement. JPE currently has twelve employees. A pleasantly surprised Huub Janssen expressly thanked them in his acceptance speech. "Without them, I would never have been able to achieve this. Sometimes it's one of them who inspires a new design and sometimes it's another."

Wim van der Hoek Constructors Award winner Tim Nai (left) and chairman of the jury Jos Gunsing. (Photo: Mikrocentrum)

Rien Koster

With the Prof. M.P. Koster award, DSPE wants to highlight the importance of designing for the precision industry. The Netherlands plays a leading role internationally in this field of industry, which in a broader context is dubbed 'high-tech systems'. The man who gave his name to the award, M.P. (Rien) Koster, has contributed to this role as a group leader at Philips CFT (Centre for Industrial Technology) and as a professor at the University of Twente. Koster also wrote the 'bible for mechanical designers', "Construction principles for precision movement and positioning". His successor as a professor in Twente and chairman of the jury Herman Soemers recently published an English-language sequel to this book called "Design Principles for precision mechanisms".
The M.P. Koster award comprises a sum of money from The Institute – leadership in precision engineering & mechatronics, and a trophy made by students at the Leidse Instrumentmakersschool.

Wim van der Hoek Constructors Award

On Thursday, 2 December, the Wim van der Hoek Constructors Award was presented to Delft student Tim Nai. On behalf of the jury the prize was handed over by DSPE board member Jos Gunsing, business development technology manager at NTS-Group in Eindhoven and lector in Mechatronics at Avans University of Applied Sciences in Breda, the Netherlands. First, Gunsing commemorated the demise of Ad Weeber, one of the initiators of this award, which was created on the occasion of the 80th birthday of the grand old man of design principles, Wim van der Hoek. The prize is awarded annually for the best graduation project in the field of construction in mechanical engineering; it comprises a certificate, a trophy and a sum of money granted by the 3TU Centre of Competence High Tech Systems.

Conceptual work

The 2010 issue was awarded to Tim Nai for his graduate work on the design of a compliant steerable arthroscopic punch, an instrument to be used in minimally-invasive knee surgery. The jury commended his conceptual work, the combination of constructing and testing, and the clever use of a compliant rolling contact element. In the Interactive Mechanisms Research group at Delft University of Technology, Tim Nai's design is part of further investigations aimed at reducing the twenty something different instruments required nowadays to two or three, making knee surgery simpler and more effective. More on this subject in a forthcoming issue of Mikroniek.

Tim Nai being congratulated by Wim van der Hoek. (Photo: Mikrocentrum)

Information

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compliantmechanisms.3me.tudelft.nl

Passing the 1000

Additional results have been obtained using the new line-scale calibration facility at VSL Dutch Metrology Institute. In the original paper [1], the calibration of the VSL Zerodur line scale was presented as the first result. Since this scale was 300 mm long, it could not be used to evaluate the performance of the setup over its full range of 1000 mm in one run. Also because of the low thermal expansion coefficient of Zerodur, the calibration procedure is not suitable to validate the material temperature compensation used in the software to reduce all measurement values to conditions at 20 °C.

• *Richard Koops, Ancuta Mares and Jan Nieuwenkamp* •

In order to check the compensation in the software and to explore the behavior over the full 1000 mm range, a scale was required of at least this size with a thermal expansion of the order of 10^{-5}/K. As a national metrology institute VSL still owns one of the Platinum-Iridium x-meter bars that were in use as national standards until the early 1960s.

Historical background

Next to the fact that this artifact had an appropriate length and thermal expansion coefficient to be used for our purpose, the historical background is worth mentioning briefly. This particular Pt-Ir x-meter from VSL, number 19C, was manufactured in 1884 and originally only had markers at the zero position and 1 m position until it was refurbished in 1957. At that time, additional millimeter markers were added to the scale as well as numbers at the centimeter positions. Because in the early days of length metrology it was not yet decided at which temperature the results should be obtained, Pt-Ir meter standards had two markers at the 1 m position; one valid for measurements at 0 °C and one valid for measurements at 20 °C; see Figure 1. The adoption of 20 °C as the default temperature for dimensional measurements took place at the CIPM meeting in 1931 and was written down in the first standard (ISO 1) of the International Organization for Standardization in 1951 [2].

Calibration

Just prior to becoming obsolete VSL's x-meter 19C was calibrated in 1959 and a certificate was issued stating the errors for the 1 meter interval both at 0 °C (actually measured at 0 °C) and at 20 °C and the errors at the centimeter positions. Since these were the last calibration results and more recent information was not available, we

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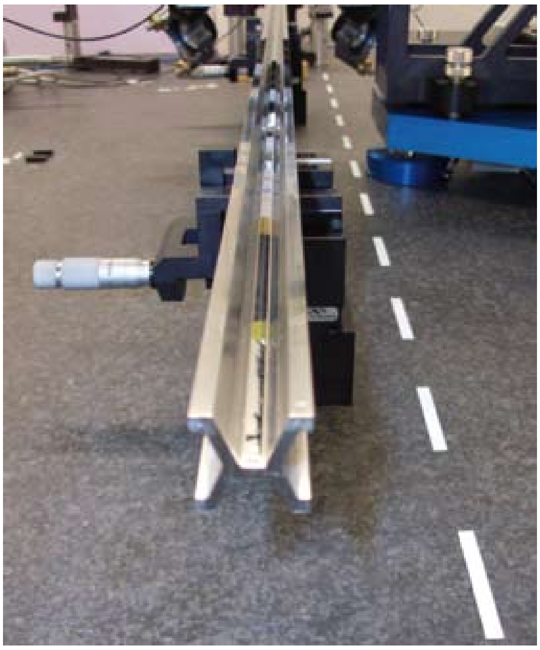

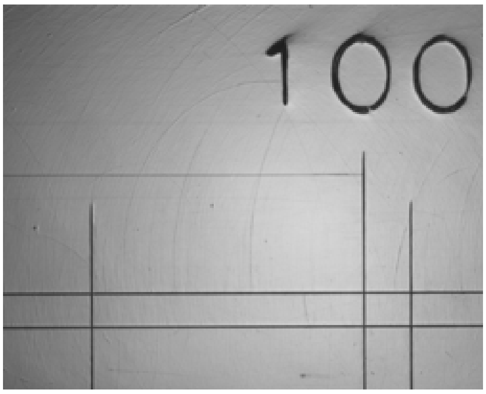

Figure 1. The Dutch x-meter, the former national standard of length, aligned in the new calibration setup. On the right, a close-up reveals two markers at the 1 m (100 cm) position since in the early days of length metrology several temperatures values were considered as default. In this case the left marker is valid for calibrating at a temperature of 20 °C and the right one for calibrating at 0 °C.

did not use the x-meter results for a formal validation but only to check the performance of our new setup over the full range. Also, the less than ideal quality of the markers and the flatness deviations of the x-meter provided nice challenges for the automated edge detection.

Results

The results of the calibration and the results from 1959 are displayed in Figure 2. The error bars indicate the measurement errors, at 95% coverage, that were established for this calibration. Even though the calibration certificate from 1959 does not state a measurement uncertainty, the results are in good agreement except for a few points at the beginning of the scale that could be attributed to the quality of the scale in this region. The agreement also indicates a correct compensation in the software for the material temperature.

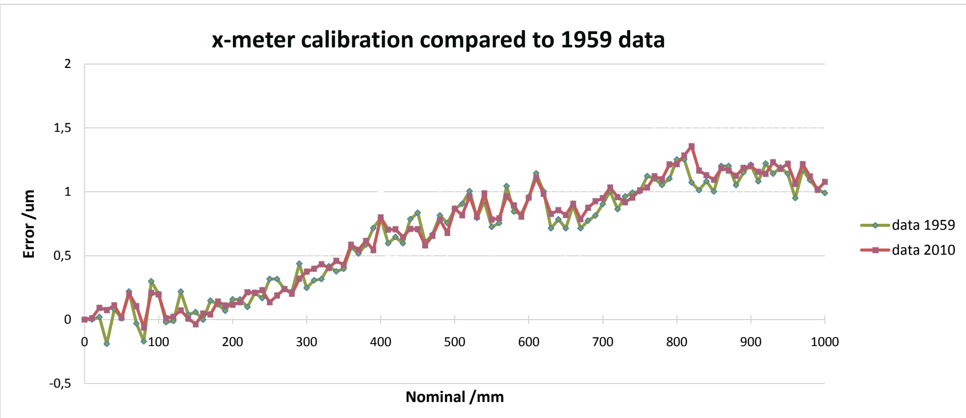

Figure 2. The first measurement over the full range of 1000 mm. The results obtained with VSL's new setup of the x-meter compared to the calibration performed in 1959 are in good agreement, given the measurement error that was evaluated for this calibration. The quality of the surface at the beginning of the scale is responsible for the mismatch in this area.

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"New printing technologies possibilities and

New printing technologies offer new opportunities – for new applications, for contributing to a better environment, for cheaper production processes and for new markets. The PrintValley project sees 23 Dutch high-tech organisations exploring the boundaries together – with surprising results that could lead to many new jobs in the future. Agentschap NL supports this Point-One project with contributions as part of the High Tech Top Project scheme.

PrintValley sees small and large Point-One associated companies such as Océ, Validus, OTB Solar, Liquavista and OLED Technologies working together with other Dutch partners on new digital printing technologies. PrintValley is an open innovation project supported with 20 million euros from Agentschap NL.

Industrial printing

The initiative for PrintValley came from Océ, two years ago now. Project leader Marcel Slot, Technology Planning Director: "There are many growth opportunities for industrial printing. It is for that reason that we launched this open innovation project back then. There are various ongoing sub-projects that are looking at digital printing technologies for new graphic applications, for example. At Océ, we are making our environmentally friendly CrystalPoint printing technology and other advanced inkjet technology suitable for higher speeds and printing on a wider variety of paper types and other substrates. Other companies, however, are conducting research into printing technologies for putting electrically conductive patterns on solar cells, for example, or for printing pixel patterns on displays."

OLED displays

In relation to that last point, OLED Technologies is expecting to make a breakthrough. "The new printing technologies make it possible to apply perfect-quality thin layers to OLED displays, allowing us to significantly lower

Inside view of one of the world's fastest 'small-size' inkjet printers, the Océ Jetstream 2200. Capacity: 2,200 A4 print-outs per minute.

offer unprecedented work opportunities”

the cost price of these displays. OLED displays are found in many mobile phones and tablet PCs and demand will, therefore, only increase in the future. Thanks to the PrintValley project, we will soon be even stronger in this growth market”, says Jerry Hillman, OLED Technologies CEO.

‘Functional inks’

PrintValley is working closely with the Delft and Eindhoven Universities of Technology as well as the research institute TNO. This collaboration primarily involves research into systems that can print environmentally friendly inks or so-called ‘functional inks’. These are inks whose colour does not convey graphic information on paper, but that fulfil a physical or chemical role. An example is an electrically conductive ink for producing electrical connections. Maarten Steinbuch, Professor in Systems and Control at Eindhoven University of Technology (TU/e)*:* “PrintValley’s aim is to bring new products to market using the research results. In that respect, the first results are very promising, but follow-up is still required.”

The Colorwave 600: this is the first printer manufactured using the new Océ CrystalPoint inkjet platform technology for printing wide-format drawings and posters. (See also the article on page 5 ff.)

Point-One

Point-One is an open association of and for high-tech companies and knowledge institutes in the Netherlands that are involved in research and development in the fields of nano-electronics, embedded systems and mechatronics. The Point-One innovation programme has been funded with 900 million euros of public and private investment (2009-2012). Point-One members enjoyed sales of 29 billion euros in 2009, and together they invested 1.7 billion euros in R&D. All of Point-One’s activities are jointly financed by the project members and Dutch government agency Agentschap NL, with a supplementary contribution for international R&D from the European Commission.
This article was based on a Point-One press release.

www.point-one.nl

Labels for medicine

A good example of printing ‘ink’ with a specific role is currently being developed by new firm Validus Technologies, a TU/e start-up. This shows how open innovation within projects such as these leads to extraordinary results. Robert Vrancken, CTO and co-founder of Validus Technologies: “Using TU/e expertise and Océ technology, we are currently working on a printer prototype for printing anti-counterfeit labels for medicine packaging, for example. Thanks to our patented technology, these labels are given unique optical traits allowing consumers, manufacturers and the government to determine authenticity in a quick and trusted manner. There is serious market interest in our products already.”

The provisional estimate is that with the PrintValley project results in 2015, at least 1,000 additional jobs will be created in the Netherlands.

TNO demonstrates manufacturing

TNO Science and Industry in Eindhoven made significant use of the DSPE PiB-day to demonstrate its skills in rapid manufacturing and micro-milling. Of course, rapid manufacturing got a lot of attention in the October 2010 issue of Mikroniek, but looking at the TNO RM and LayerWise set-ups and products in reality provided better insights into this promising technology for producing complicated products. And the lecture and high-speed video about micro-milling aroused a kind of amazement, because of the achievement to machine a workpiece with an endmill of not more than 100 micrometer diameter in practice and even 25 μm in research.

• *Frans Zuurveen* •

The Precision-in-Business (PiB) day is held at TNO's in Eindhoven, the Netherlands, on 18 November 2010. Chairman of the day Henk Buining of TNO starts his lecture about rapid manufacturing (RM) by showing a model of a large gearbox casing from paper, produced by the oldest RM process. This used to be called rapid prototyping and was based on the stacking of cut-out paper sheets. The resulting product is vulnerable, however this example showed the wrong positioning of one hole, because of the impossibility to insert a fixing bolt. Such a design fault would be more difficult to detect on a two-dimensional drawing.

Today, other designations for modern RM are 3D printing and additive manufacturing, with the important difference that these technologies provide products that really fulfil their function in practice without the necessity to make expensive tools; see Figure 1. Complex-shaped parts with integrated functions can be produced, so reducing the number of parts required. In contrast to conventional production processes, the price remains the same irrespective of extra complexity.

The processes start with a CAD-file controlling a laser beam that produces solid voxels – volumetric pixels – in a powder or fluid. The materials used are plastics, a.o. some ABS-like. Also foamy products can be made, to be applied

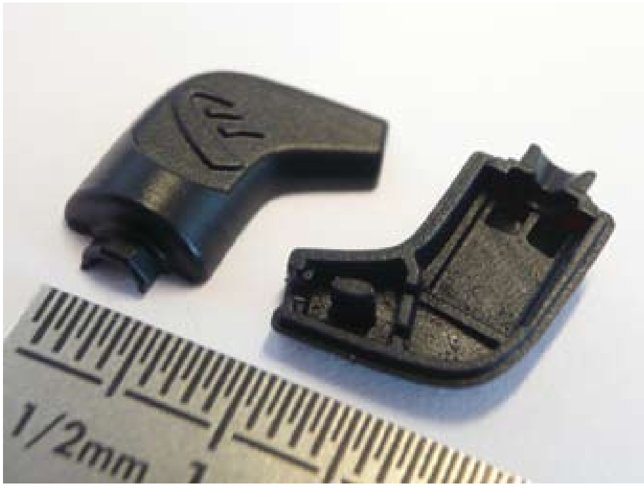


Figure 1. A miniature housing produced by rapid manufacturing without expensive tools.

rapid and micro-milling

as models for investment or lost-wax casting, to accurately produce complicated metal products. Interesting and cost-saving application areas are teeth corrections, hearing-aid ear pieces and machine part integrations.

Stereolithography

Many basic processes are available for the sheet-wise hardening of RM base material. Bart van de Vorst of TNO explains the ins and outs of stereolithography (SLA), see Figure 2, and even microstereolithography (see also the article on page 40 ff.). The characteristic of micro-SLA is the application of blue-light curable resin. This is an acrylate that is sensitive to light with a wavelength of 450 nm. A vertical stage moves the cured resin one step of about 25 μm upwards after a new layer has been formed on a glass sheet. To that end, an optical system projects a blue-light image on the glass sheet in the fluid, which corresponds with the appropriate product cross-section. The process differs from earlier RM processes in imaging a complete cross-section, instead of scanning an image with a laser spot, with time saving as a valuable result. Often an extra structure is needed to support the product during the formation process.
SLA rapid manufacturing machines are commercially available; however, TNO succeeded in improving their

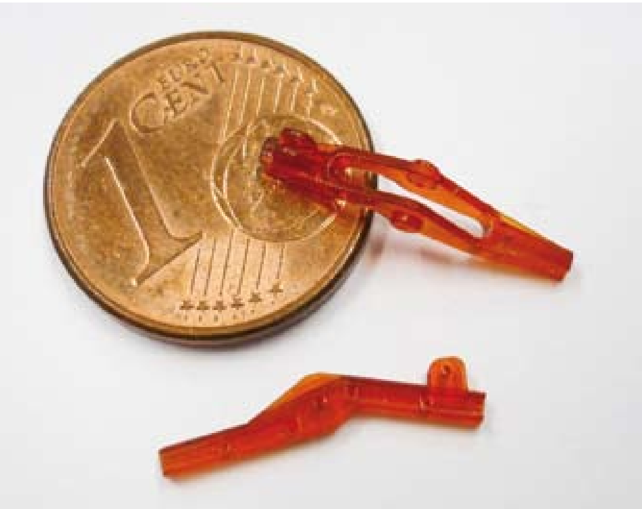


Figure 2. A tiny hinge realized by stereolithography.

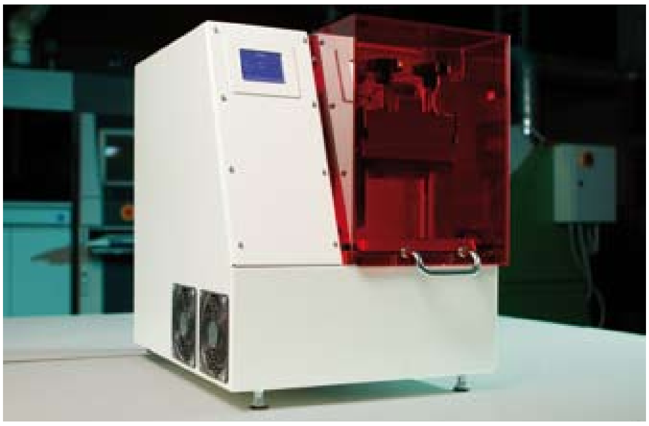


Figure 3. Prototype of a DLP printer (Digital Light Processing), developed by TNO, for producing ceramic and plastic parts.

Figure 4. A ceramic part made by the new TNO DLP printer.

speed and resolution. The modified machine projects 1,920 x 1,080 pixels in HD-mode. The corresponding resolution of less than 100 μm can even be halved by moving succeeding images across half the resolution value. The speed gain is achieved by using a surface area dependent step time, instead of working with a fixed time for each imaging and curing step. TNO delivers a set for upgrading a commercial RM machine.

TNO also developed a DLP printer (Digital Light Processing) for producing ceramic and plastic parts with the SLA-system; see Figure 3. Key for producing ceramic parts is the application of a plastic fluid with an extremely high mass percentage of ceramics, up to 85 mass %. After producing a part with this high ceramics content it is being

Figure 5. A complicated burner head produced by LayerWise.

Figure 6. Measuring the runout at the cutting edge of a micro-endmill with a diameter of 0.5 mm.

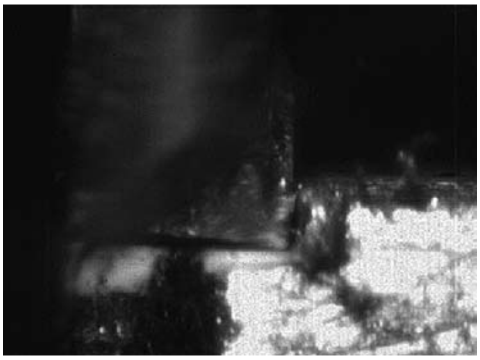


Figure 7. A high-speed image of the micro-milling process with an endmill of 0.5 mm and a speed of 30,000 min^{-1}. The unsharpness is due to the short exposure time at a speed of 6,000 frames per second.

heated, with the aim to sinter the ceramic particles and to burn out the unwanted plastic; see Figure 4. A main benefit of the DLP-system is the improved building speed. TNO wants to get in contact with parties that are interested in bringing the prototype into series production.

RM in metals

Tom de Bruyne makes clear that the metal rapid manufacturing process of his firm LayerWise, based in Leuven, Belgium, produces highly complicated parts from ‘difficult’ materials like titanium and CoCr steel. This additive process is based on layer-wise local laser melting of metal powder with a grain size of 20-30 µm. Locally, the high-power laser reaches a maximum temperature of 3,000 °C. The porosity varies from 95% to even 99.98%, which means that the product can be regarded as completely solid in some cases. When making use of aluminium powder the porosity may be rather large.

De Bruyne states that the revolutionary LayerWise SLM-process (Selective Laser Melting) is neither fast nor cheap. But it already has proved its value for making dental structures, burner heads (see Figure 5), complicated machine parts and miscellaneous freeform products with a minimum wall thickness of 0.2 mm and a resolution of 5 µm.

Micro-milling

Han Oosterling of TNO explains the difference between standard milling and micro-milling. Besides the difference in tool dimensions – minimum endmill diameter 25 µm in micro-milling research – the cutting angle for micro-milling is negative instead of, normally, positive; see Figure 6. This negative cutting angle is due to the small rounding of a micro-milling cutting edge.

Micro-milling differs from HSM (High-Speed Milling) in the cutting speeds. Of course, the rotational speeds of micro-milling tools are high – up to 60,000 min^{-1} – but the extremely small tool diameter limits the cutting speeds. During the guided tour in the laboratories and workshops, TNO demonstrates the micro-milling process on a Hembrug Nanofocus precision machine.

A high-speed video film appears to be very illustrative for the micro-milling material cutting process; see Figure 7. Occasionally, every five to ten tool revolutions, a material chip released. This phenomenon is obviously due to the gradual building up of a sideways force between tool and material.

To conclude

Of course, the speakers on this PiB-day are kindly prepared to answer questions and to help solving problems when applying the new technologies dealt with. But probably still more promising is the statement that the TNO RM Demonstration Centre is commercially available for introducing RM techniques in practice.

Author’s note

Frans Zuurveen is a freelance text writer who lives in Vlissingen, the Netherlands.

Information

www.tno.nl/rm
www.layerwise.com

New Event: RapidPro

On 2 March 2011, Mikrocentrum will be organising the new RapidPro event. This combined trade fair and congress will highlight the possibilities of additive manufacturing, rapid prototyping, rapid tooling and other 3D technologies for multiple industries. Because the free-entrance RapidPro focuses on the entire Benelux, the Koningshof in Veldhoven, the Netherlands, has been chosen as the venue.

After decades of development, various additive manufacturing technologies can now finally be considered mature. Thanks to breakthroughs in materials science and production systems, products and prototypes manufactured using additive technologies measure up to their conventionally manufactured counterparts. End products are strong and accurate, manufacturing capacities have increased considerably and manufacturing speeds have also improved a great deal. Moreover, the decrease in cost price of both the machines and the end products make additive technologies an attractive alternative for numerous applications.

Nevertheless, the possibilities of additive and related 3D technologies are still not very well known. Having organised various theme days on the subject since 2004, Mikrocentrum feels that the time is ripe for presenting a comprehensive overview of all the ins and outs. "Too few people realise that the future isn't on the doorstep, but it's there already", says seminar manager Els van de Ven. "A missed opportunity, because these technologies can considerably shorten the time to market as well as offering a solution for low production volumes and/or complex shapes."

Large playing field

With RapidPro, Mikrocentrum targets a large number of participants and visitors from a wide variety of industries. "We work closely together with knowledge institutes such as TNO and Sirris, but can also rely on contributions from providers of additive manufacturing technologies, specialists in 3D measurement and scanning, and CAD/CAM/CAE experts to structure the interrelationships between these disciplines", explains Van de Ven. As regards visitors, she sketches a rich palette of industries and job descriptions: "The medical sector and the dental industry have, of course, been using additive manufacturing for some time now, as have model construction and architecture. But the options are also becoming increasingly attractive for machine and equipment building, automotive, aviation and aerospace, and the production of special tools. And it won't be long before consumers can hook up their computer to their own 3D printer, with which downloaded parts can be printed directly."

Information

www.rapidpro.nl

Solar technology

Engenia, top training for professionals, organises an academic-level introductory course on solar technology. The two-day course will be held on 21/22 April, 26/27 May, and 23/24 June 2011, and comprises four half-day sections:

- Market and Technologies (overview)
- Technology (working principles)
- Crystalline solar cells (the production cycle)
- Thin film solar cells (the second generation)

www.engenia.nl

"Seeing nano for

On 17 and 18 November 2010, the 6th Netherlands MicroNanoConference took place in the Waaier conference centre, located next to the University of Twente's brand new nanolaboratory. This annual event enabled industry and academia in the Netherlands to present the latest developments in microsystem- and nanotechnology research and technology development. Although the scientific research programmes MicroNed and NanoNed formally have ended and subsidised researchers were no longer obliged to attend, the organising committee surpassed the 2009 edition with over 450 participants.

• ***Richard Bijlard*** •

Some interesting plenary sessions at the MicroNanoConference featured a range of renowned international speakers, like professor Paolo Dario of the Italian Scuola Superiore Sant'Anna. Dario showed the next step in modern surgery: utilisation of miniature robots that can be swallowed and form a self-assembling operation structure inside a patient's stomach to accurately and effectively perform operations inside the body. Jean Marc Triscone of the University of Geneva showed the progress in the studies of oxide interfaces that might form the basis for new electronic components in the near future. Developments in manufacturing high-volume electronics (roll-to-roll fabrication of organic LEDs) were covered by TNO's Paul Blom.

Themes

Besides the plenary sessions, participants could select lectures from four parallel streams, comprising approximately twenty lectures each. The themes were clearly following the current Dutch research programmes and directions. Their societal impact was reflected by the title of the plenary presentation by the brand new TU Delft professor and dean, Rob Fastenau, former executive vice president at electron microscope manufacturer FEI's Eindhoven branch: "Seeing nano for a better world."

- "Towards a Safe and Sustainable Society"
  This theme focused on environmental and social issues like clean water, food, energy, risk analysis, and policies and politics dealing with the responsible use of technology.
- "Innovations in Fabrication and Instrumentation"
  Starting with lectures about probes, sensors and actuators, topics such as specific nano-equipment and molecular machines, modeling and fabrication were covered.
- "Enabling Lifescience with Micro- and Nanotechnology"
  The upcoming multidisciplinary fields of bio-nano, nanomedicine and nano- and microfluidics were covered in a variety of subjects.
- "Photonics, Electronics and Materials"
  Last but not least an interesting theme, dealing with all

Author

With his company Technogation, Richard Bijlard is actively helping technology companies to develop international partnerships and sales channels. Key to this are his experience in technology marketing and sales and his large international technology network.

www.technogation.com

a better world"

aspects of light (including space applications), electronics and materials properties.

Valorisation

In between the lectures, conference participants could visit the tabletop exhibition area, where thirty manufacturers showed their latest products and services in instrumentation, flow measurement, optics, fabrication, and life sciences. They also could network, or view a variety of interesting scientific posters. Focussed on the valorisation of micro- and nanotechnology research, this 6th MicroNanoConference really showed the value of combining the inputs of both the academic and the industrial community. Looking forward to this year's issue!

Information

www.micronanoconference.nl

Networking in the exhibition area of the MicroNanoconference.

The hidden use of

On Wednesday, 1 December 2010, Applied Piezo chairman Jan Peters presented the first copy of a new Applied Piezo publication to Mikrocentrum director Geert Hellings. The booklet, "The hidden use of piezo technology in applications all around us", was meant to show the everyday use of piezo applications and the importance of further development of this technology. For example, piezoelectric actuators and sensors play an important role in high-tech systems as well as in in high-tech manufacturing technology. The Dutch Applied Piezo foundation promotes research and industrial application of this technology, with Geert Hellings and Mikrocentrum among the first to support the foundation when it started in 2004. The presentation took place at the 2010 Precision Fair, organised by Mikrocentrum.

Chairman Jan Peters (right) has presented the first copy of the Applied Piezo publication to Mikrocentrum director Geert Hellings. (Photo: Mikrocentrum)

Piezoelectric materials are among the 'invisible' materials that are widespread around us, although they are unknown to the public at large. Mobile phones, automotive electronics, medical technology and industrial systems are only a few of the application areas where 'piezo' is indispensable. Echos to capture the image of an unborn baby in a womb make use of piezo. Even in a parking sensor at the back of our car piezo is present.
The 'piezo' phenomenon can be applied so abundantly because of the very nature of the material itself: its capability to change shape – for example become shorter or wider – when an electric voltage is applied. This change in shape – generally in the micron range – occurs very fast, within milliseconds. Furthermore it is highly reproducible, and accurate in the nanometer range. Piezo also works the other way around: compressing or otherwise deforming the material generates an electric charge.

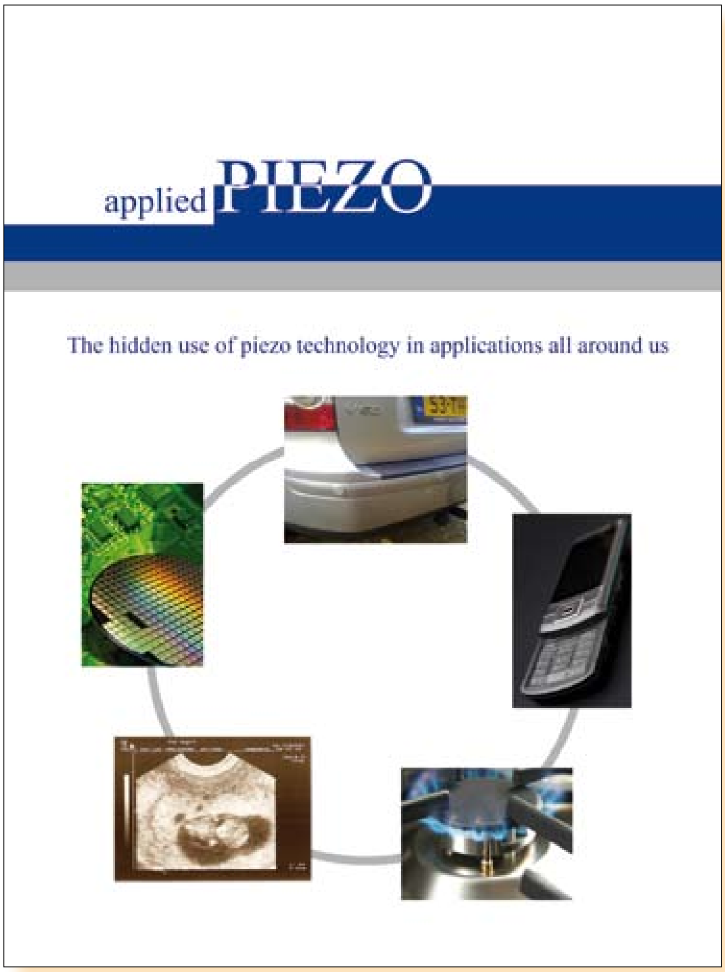
Actuators and sensors

Piezoelectric actuators – devices that convert an electrical signal into an 'action' such as a physical displacement – play an important role in high-tech systems, and also in high-tech manufacturing technology. As do piezoelectric sensors – devices that convert a mechanical action into an electrical signal. Applications range from inkjet printers and loudspeakers to scanning tunneling microscopes

(STMs) and wafer steppers for making integrated circuits (ICs).

Future

An intrinsic shortcoming of piezoelectric devices is due to the (brittle) ceramic nature of the piezo material (commonly PZT, lead-zirconate-titanate) itself, and to their manufacturing technology. So, a big step in piezo device performance may be achieved by combining silicon technology for making integrated circuits with piezo technology. For example, by using novel laser-based deposition techniques for locally depositing piezo films. In this way, MEMS (micro-electromechanical systems) can be created comprising exceptional functionality in a single device. The integration of piezo in MEMS allows the fabrication of very small devices that have electronic, mechanical and chemical components, and communicate by sensing and actuating with their surroundings.



"The hidden use of piezo technology in applications all around us", Applied Piezo, 2010, ISBN 978-90-79926-03-9, by Eddy Brinkman of Betase, an independent company engaged in knowledge transfer in the areas of chemical engineering and materials science, www.betase.nl.

Applied Piezo

The aim of the Applied Piezo foundation is to facilitate the access of industry to utilisation of piezo technology. Applied Piezo is a group of companies and universities that provide complementary piezo expertise. The goals of their collaboration include:

- creation of new business in piezo actuators and sensors;
- promotion of piezo technology;
- stimulation of knowledge development and innovation;
- providing a network where knowledge, expertise and products can be exchanged.

In 2007, Applied Piezo took the initiative of the SmartPie research programme ("SMART systems based on integrated PIEzo"). SMARTPIE research is aimed at strengthening the innovative position of the Dutch high-tech industry by generating new piezo-based technology. This research programme, funded by the participating companies and universities as well as by the Dutch government through the SmartMix programme, will provide new piezo materials and applications, through which a total paradigm shift will occur in the type of basic technologies being used.

www.applied-piezo.com
www.smartpie.nl

Free booklet

The Applied Piezo foundation makes available free copies of the booklet to the first twenty applicants for membership of the Applied Piezo LinkedIn group. In the application, please state "Mikroniek" and the address to which the free booklet should be sent.

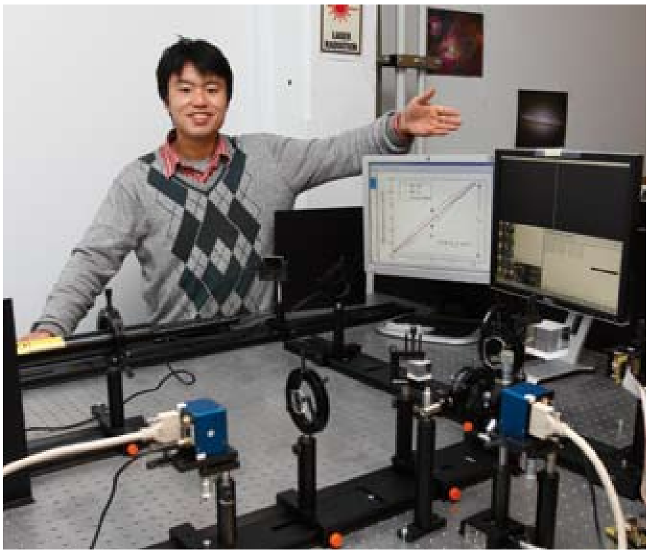
www.linkedin.com/groups?mostPopular=&gid=49032&trk=myg_ugrp_ovr

Mechatronics and microsystems open up their doors

On 4 November 2010, the Delft Centre for Mechatronics and Microsystems (DCMM) organised a Customer Day. The main purpose of the day was to present DCMM's ongoing research in the domains of mechatronics and microsystems. The scope of this second edition of the Customer Day was extended to the nano-domain and included a tour of the new Van Leeuwenhoek Laboratory for Nanoscience.

The Customer Day attracted over 200 visitors, amongst whom 125 researchers, managers and policy makers from industry, research institutes and government. "Inspiring", "informative", and "OK for a university to open up its doors", these were just a few of their comments. The ultimate goal was to set up new collaborations and to strengthen existing ones. To promote technical education in general, a KidzScience Event was organised as well, in which eight primary

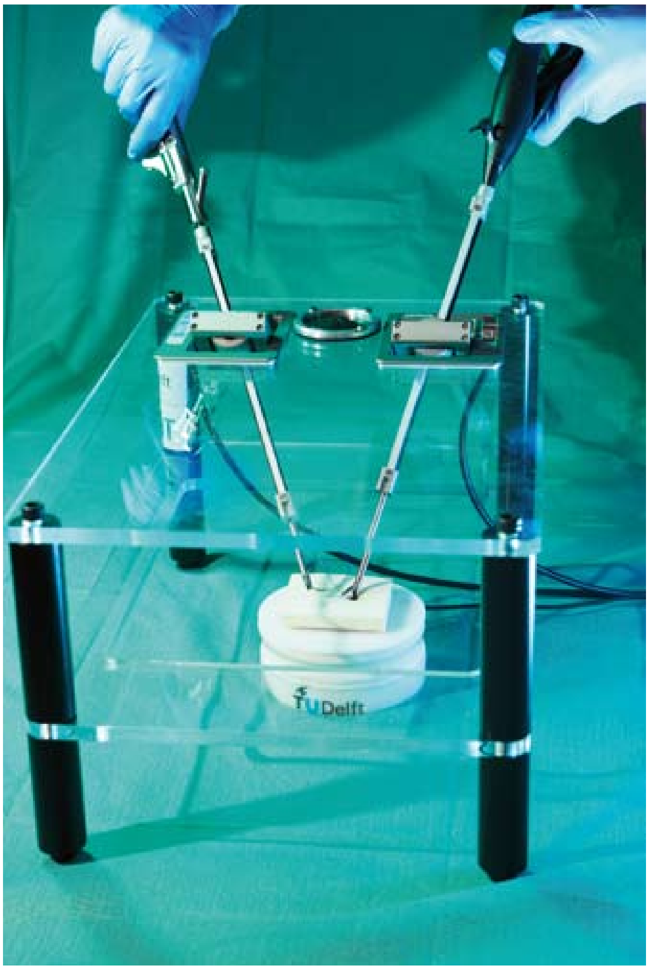
Impressions of the DCMM Customer Day. (All photos: Bram Saeys)



Ph.D. student Hong Song presented a poster on adaptive optics: "I have met quite some people who were interested or curious about adaptive optics. Most of them are from TNO, NOVA, Astron or ASML. Some of them are new to adaptive optics and some are already experts in this field. They were interested in the experimental setup in the lab, especially when they saw the images from the camera and how the deformable mirror improves the image resolution."

schools with over 200 children from the Delft area participated.

In a fair-like set-up, DCMM research groups presented a total of fifty projects by means of posters and demonstrations, concerning the following topics: Adaptive Optics; Automotive/Vehicle Mechatronics; Biomedical Instruments; Mechanics, Dynamics and Optimisation; Micro/Nano Electronics and Sensor Systems; Micro/Nano Engineering & Manufacturing; Mobile Robots and Humanoids; and Precision Mechatronics. In forthcoming issues of Mikroniek some of the individual projects will be described in more detail.



One of the most complex tasks in endoscopic surgery is suturing. The TrEndo system, presented by the Minimally Invasive Surgery and Interventional Techniques group, is currently being validated for its ability to objectively classify the level of skills of surgical residents. Combined with a custom-made force platform the system allows for both motion and force tracking

Ph.D. student Emine Eda Kuran presented an experimental set-up for investigating chip-to-foil self-assembly of ultra-thin chips (UTCs), i.e. the magnetic force field supported self-alignment of UTCs for their high-speed placement.

Delft Centre for Mechatronics and Microsystems

The Delft Centre for Mechatronics and Microsystems (DCMM) is part of Delft University of Technology. It deals with the fundamental aspects of the design, modelling, optimisation and production of miniaturised electro-mechanical systems. DCMM aims to research and explore the possibilities of small-scale functions and the benefits generated at macro level. DCMM comprises research groups from three Delft faculties and the research is focused on four interdisciplinary research themes:

- Medical Instrumentation
- Intelligent Automotive Systems
- Adaptive Optics
- Micro and Nano Engineering

m.tichem@tudelft.nl (Marcel Tichem)
www.dcmm.tudelft.nl

DSPE announces register for Certified Precision Engineers

DSPE has been assigned a project by the Point-One innovation programme to create a register for Certified Precision Engineers. DSPE has been working on this initiative for quite some time. The main goal is to focus more on the post-academic education of employees at companies, institutes and universities. The initiative is also linked to the activities of technology road mapping in the ecosystem of the high-tech industry, which are being carried out in collaboration with Brainport Industries.

Certification points can be earned by following selected courses, and once participants have collected a total of 45 points (one point per course day) they will be certified and added to the register of Certified Precision Engineers. They are then allowed to use the title CPE. In the (near) future DSPE will outline a lifelong learning programme, which is a prerequisite for maintaining the CPE accreditation.

There is a historical difference between post-academic education today and that of 20 years ago. In those days, large companies like Philips invested a great deal in educating their technical personnel. Today, that's all gone and not enough attention is paid to employee education. There is no time for education when times are busy and no money in an economic downturn.

DSPE wants to use the certification programme to highlight post-academic technical education to management. DSPE will be marketing the value of this title and how it can help a CPE's career and to do this, HR management and line management will be updated on the CPE programme on a continuous basis.

It is unacceptable for precision engineers that post-academic education is seen as something time-consuming during busy times and as a money drain during an economic downturn. On the contrary, post-academic education saves money and lead-time for the company as designs are improved by well-qualified engineers. DSPE wants to showcase this and convince the industry that we should care about post-academic education.

Programme with courses selected by DSPE

Basic courses ('mandatory')
- Mechatronics
- Control Systems Tuning
- Dynamics & Modelling
- Systems Architecture and Engineering
- Design Principles

Other courses
- Optics
- Opto-mechanics
- Opto-mechatronics
- FEM
- Actuators and Electromechanics
- Sensing, Calibration, Measuring Principles
- Vision
- Advanced Motion Control
- Multi-body Dynamics
- Applied Optics
- Exotic Materials
- Connection Techniques
- Manufacturing Techniques
- Coating, Corrosion
- Thermal Design (Mechanics)
- Tribology
- Vacuum Technology
- Noise & Vibration Control
- Contamination Control
- Methodic Design
- Electronics for the Precision Engineer
- IT for the Precision Engineer
- Experimental Techniques

Obituary:
Simon van de Graaf (1923-2011)

Simon van de Graaf played a major role in the growth and significance of Mikroniek as a specialist precision technology journal. Siem was Mikroniek's editor-in-chief for years (until 1999), while working at Philips and also after he retired. Together with the other volunteer members of the editorial team, he invested a great deal of time and energy professionalising the journal.

Siem took his job seriously, was very precise and personally checked the logic, formulas and calculations postulated in the articles. As soon as he found something unclear, he would discuss it with the author and try to resolve the issue. Good-natured, but resolute, he wanted to have things explained to him in detail. Although authors were initially not happy with his 'feedback', they were later able to appreciate how Siem helped them to correct their texts. This also enabled them to prevent the same mistakes appearing in their other (scientific) publications.

Siem was also an expert in choosing the right word. Articles submitted often lacked the suspense which drew the reader into the story. In a number of places, he would very subtly replace one word with another word that had practically the same meaning, but just another connotation. This would create a certain suspense and make the article much more enjoyable to read.

He did a great deal to improve the readability of the journal, such as breaking up long sentences. Press releases were pared back to their essential message and turned into brief announcements, ensuring that the reader was informed quickly.

He was very involved in NVPT (DSPE) and did his bit to give the precision engineering profession a face with Mikroniek. He only decided to stop in 1999, at the age of 76. Siem died on 16 January 2011 at home in Nuenen at the age of 87.

Jaap Verkerk

This photograph of Simon van de Graaf was taken in 2009.

15-18 March 2011, Ede and Veenendaal (NL)
Demoweek 2011

Nine companies offer a comprehensive overview of milling technology, including machines, tools automation, software, measurement equipment, control, drive technologies, and auxiliary machines. Participants are Bemet International, BenderTechniek, Cellro, DMG, Dormer Tools, Dymato, Heidenhain, Mitutoyo and 3D Worknet.

www.demoweek.com

Heidenhain is one of the participants of the Demoweek 2011.

24 March 2011, Veldhoven (NL)
Hightech Mechatronica

The fifth edition of this high-tech mechatronics event, organised by Techwatch, publisher of Bits&Chips and Mechatronica Magazine. Research, development and implementation of mechatronic systems are the main themes of the conference and exhibition.

www.hightechmechatronica.nl/en

29-30 March 2011, Nieuwegein (NL)
Fotonica Evenement 2011

This photonics event comprises a conference, an exhibition, a brokerage event and other knowledge transfer activities. The conference programme includes (social) themes such as Healthcare & Life Science, Lighting, Industrial Photonics, Solar, and Fundamental Research Photonics. Technological topics include Microscopy, (O)LEDs, Integrated Optics, Lasers, and Optical Sensing and Imaging.

www.fotonica-evenement.nl

7 April 2011, Woudschoten (NL)
The Sense of Contact 13

Workshop on sensor technology, showcasing the potential of sensors to solve current issues and challenges. Dutch universities, institutes and industry will present their recent sensor research and development according to challenges in natural environment and medical aspects of the human body. Another important theme is the inspiration that nature provides for the development of sensors.

www.fhi.nl/senseofcontact

19 April 2011, Enschede (NL)
TValley 2011

The Mechatronics Valley Twente Foundation organises its eight TValley conference, focusing on innovation and business in the high-tech industry. This time, the central theme is 'High-tech systems in medical devices'.

www.tvalley.nl

20-21 April, 's-Hertogenbosch (NL)
Mocon 2011

Tenth edition of this trade show for the Dutch motion & control branch. Companies will exhibit: Drive techniques as a function of motion control; Measurement and sensor systems; Machine control & operating software; Production automation; and Services. The seminar programme includes lectures on robot safety and high-efficiency electric motors.

www.easyfairs.com/mocon-nl

Impression of the previous Mocon.

23-26 May 2011, Como (Italy)
Euspen 11th International Conference

Conference and exhibition on precision engineering and nanotechnology, addressing the latest advances and market developments in precision processes and manufacturing, as well as fabrication, metrology, sensing applications and cutting-edge materials.
This year's conference topics will include:
- Ultra Precision Replication Techniques
- Nano & Micro Metrology
- Ultra Precision Machines & Control
- High Precision Mechatronics
- Ultra Precision Manufacturing & Assembly Processes
- Important/Novel Advances in Precision Engineering & Nano Technologies

www.como2011.euspen.eu

25-26 May 2011, Eindhoven (NL)
Materials Engineering

This trade exhibition offers a synoptic and transparent business-to-business platform for material, product, and design technology. This year's theme is "Smart and functional materials". In this context, for example, attention will be paid to piezo technology, in a special pavilion. Another special topic is devoted to aluminium.

www.materialsengineering.nl

26-27 May 2011, Aachen (Germany)
Aachen Machine Tool Colloquium

International meeting place for specialists and managers from industrial production companies. Over 1,000 experts from industry and research institutions are expected for an exchange on production technology.

www.awk-aachen.de

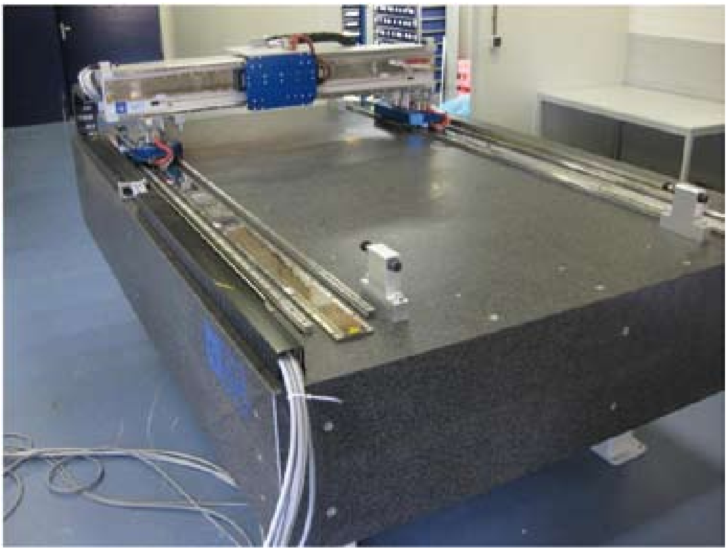
RoboNed database and inventory

Since April 2010, in the Netherlands robotics activities are coordinated by RoboNED. This Dutch Robotics Platform, chaired by Twente professor Stefano Stramigioli, aims to stimulate the synergy between the robotics fields and to formulate a focus. The goal of RoboNED is threefold: bringing the various fields and disciplines involved in robotics together; stimulating the Dutch innovation ecosystem by uniting stakeholders from research, education, industry and society; and stimulating the social acceptance of robotics in the Netherlands.

Recently, RoboNed has developed a database for producing a clear survey of Dutch robotics. Each party can add its own activities. Also, an inventory was made of the RoboNED community.

www.roboned.nl
www.robodb.org

Platform for high-speed PV film scribing



Q-Sys, headquartered in Helmond, the Netherlands, recently developed a granite-based gantry-style platform delivering high-performance XY motion over the full footprint of the machine. The platform was designed for the laser scribing of flexible photo-voltaic film, offering 2 g and 3 m/s across the table, with 1 g and 2 m/s along it. Unmapped accuracy is better than 20 μm with 2 μm repeatability. The gantry beam is driven and encoded at both ends to enable full gantry-mode control, ensuring optimum performance over the entire 2 x 1 m^2 machine bed.

www.q-sys.eu

VSL acquires ten new EMRP projects

Last year, EMRP projects calls were issued for ‘Industry’ and ‘Environment’. Out of 45 project proposals, all submitted by consortia consisting of European national metrology institutes, 26 projects will most probably be funded. Dutch VSL will participate in ten projects in the next three years:

- Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures
- Metrology for manufacturing of thin films
- Optical and tactile metrology for absolute form characterisation
- Metrology of small structures for manufacturing of optical and electronic devices
- Metrology for ultra-fast electronics and high-speed communications
- High-temperature metrology for industrial applications
- Metrology for chemical pollutants in air
- Emerging requirements for measuring pollutants from automotive exhaust emissions
- Traceability for surface spectral solar UV radiation
- Spectral reference data for atmospheric monitoring

The European Metrology Research Program (EMRP) is jointly supported by the European Commission and the participating countries within the European Association of National Metrology Institutes (EURAMET).

www.vsl.nl
www.emrponline.eu

New generation of angle encoders

The absolute angle encoders from Heidenhain with integral bearings and hollow shafts have long been used for angular measurement in the range of a few angular seconds. Particularly on rotational axes, such as rotary tables and tilting axes on machine tools, they are an adequate solution for position and speed control. Now the existing RCN 200 and RCN 700/800 series have been completely revised. The angle encoders were improved with new scanning technology, evaluation electronics and revised mechanical design, and are now offered in the RCN 2000 and RCN 8000 series, with EnDat 2.2 interface.

The new scanning method permits a very high signal quality and at the same time even greater resistance to contamination. Thanks to the new scanning and evaluation electronics, it became possible to greatly reduce the influence of the rotational speed on the generation of position values. This ensures that, even at high speeds, the scanning signals are of high quality and continue to interpolate well.

www.heidenhain.com

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