RETHINKING THE SYSTEM – FOOD FOR THOUGHT

The fifth edition of the DSPE Conference, on 26-27 September 2023, was held in an inspiring and relaxed atmosphere that facilitated meeting peers in precision mechatronics. The event featured the theme of 'Rethinking the system' and provided ample food for thought, not least about extending the physical boundaries of precision engineering.

JOS GUNSING

AUTHOR'S NOTE

Jos Gunsing is the founder/owner of MaromeTech, a technology & innovation support provider based in Nijmegen (NL), and a DSPE board member.

jos.gunsing@marometech.nl

The 2023 edition of the DSPE Conference attracted over 130 participants (Figure 1) and took place once again in hotel De Ruwenberg in St. Michielsgestel (NL). The relatively warm weather and pleasant countryside environment contributed to the relaxed atmosphere, facilitating social conversations and professional discussions between peers during the breaks (Figure 2).

The two days provided for a rollercoaster of technological highlights, but sadly it is impossible in this report to give all the presentations, demos and posters the attention they deserve. Here, the focus is on the keynotes and the award-winning demonstration, poster and presentation. In addition, two presentations are featured that were aimed at understanding and extending the physical boundaries of precision engineering. Many presenters will appear in forthcoming issues of *Mikroniek* with an elaboration of their conference contributions, to further spread the word on the state-of-the-art in precision mechatronics.

1

The conference attracted over 130 participants. (All event photos: Jos Gunsing)

Impressions of the conference with its relaxed atmosphere.

Conference organisation

Since 2012, the DSPE Conference on Precision Mechatronics has been organised by and for technologists, designers and architects in precision mechatronics. It is targeted at companies and professionals who are members of DSPE, Brainport Industries, Mechatronics Contact Group (MCG), Mechatronic Systems Knowledge Exchange (MSKE), System Architecture Study Group (SASG), and selected companies and institutes. Alongside oral presentations, posters and demonstrations, the conference programme also always features ample opportunities for discussions, networking, and sharing ideas and experiences.

Once again, the organising committee, this time comprising Adrian Rankers, Marc Vermeulen and Annemarie Schrauwen (Figure 3), with strong support from the advisory board, served an excellent programme. For Rankers it was his last DSPE Conference in an organising role, having been at the helm for five full two-day conferences (in 2012, 2014, 2016, 2018 and 2023) and an intermediate one-day conference (in 2021, partly online, due to Covid-19 measures). During the set-up of this 2023 edition, he handed over the organising chair to Vermeulen. DSPE took the opportunity to thank Rankers for his more than ten years of enthusiasm and dedication. At the end of the conference, he was bestowed with an honorary membership of the DSPE Conference.

WWW.DSPE.NL/CONFERENCE

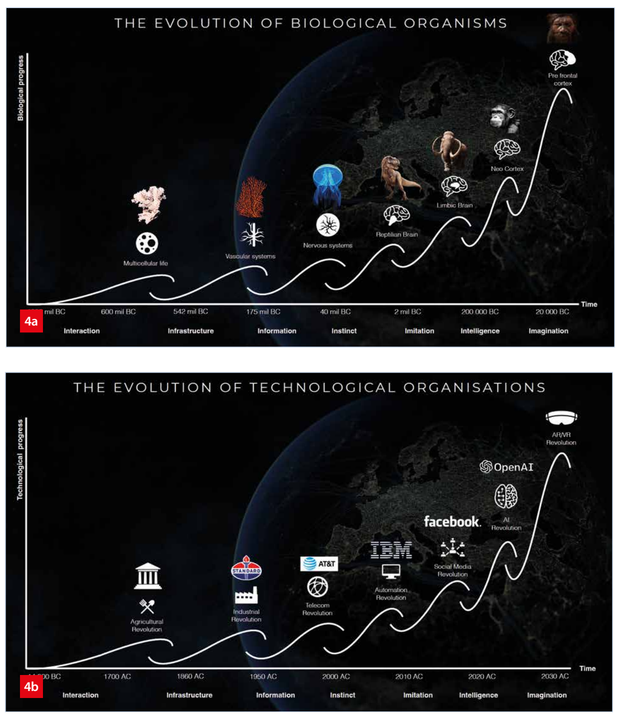
Flanked by Annemarie Schrauwen and Marc Vermeulen, newly appointed honorary conference member Adrian Rankers shows the certificate of appreciation he received for his more than ten years of enthusiasm and dedication in organising the DSPE Conference.

Keynotes

AI

In the first keynote, "Engineering the future; Go digital, stay human", futurist Christian Kromme gave his view of the present and future of AI (artificial intelligence). He compared biological and technological evolution (Figure 4) and concluded that they take similar steps. It is clear then, according to Kromme, that AI is going to play a big role in our future.

Kromme gave examples of how AI will evolve, including many in the engineering field, such as machine learning/algorithmic/generative design and engineering. He stated that many jobs that are linked to well-described procedures and rules will disappear in the near future due to the rise of AI, as well as, for example, physical robots. Smart Industry items such as one-off series production will become much more widespread. Application of AI also implies that soft human skills/qualities



Evolution.
(a) Biological organisms.
(b) Technological organisations.

that are more difficult to replace, such as flexibility, integrity, imagination, ethics, compassion, relationships, emotions, purpose, creativity, empathy, respect and curiosity, will become more and more important. In education, this will have a strong impact on the way we teach precision engineering. Well-balanced systems engineering education and AI-supported engineering tracks can give solution directions.

Lithography

Jan-Jaap Kuit, vice president D&E Mechanical Development at ASML, talked about balancing litho tool complexity within the semiconductor evolution following Moore's law (Figure 5). This issue is not new to the precision engineering community, so it is no surprise that the effort to comply with Moore's law is rapidly increasing with the density of functions/mm^2. Its 'impact', however, is gigantic, as illustrated by this fun fact: the 13-nanometer resolution achieved by a current EUV litho tool means that we could print the entire 'The Lord of the Rings' trilogy (over 1,000 A5 pages) 2,625 times on one side of an A4 sheet of paper.

Along with technological complexity, equipment cost is a huge challenge. To keep the products that are being made by the ASML tools affordable, a lot of measures have to be taken. Imaging resolution, overlay and productivity have to keep pace with rapidly increasing tool costs. Two typical figures illustrate the extremes that have to be reached: the resolution/critical dimension, which is now 8-20 nm, will go towards 2-7 nm; and the overlay, now 2-3 nm, will go towards 1-2 nm.

Topics that have to be considered:

- Shorter wavelength, implying the adaptation of light sources, coatings, etc., while taking into account optics lifetime.
- Larger numerical aperture (Figure 6).
- Higher light-source output power/efficiency.
- Metrology and heating/cooling control.
- High-precision mechanics and vibration control architecture.
- High-speed mechatronics and power electronics.

On the other hand, smart manufacturing, transport, installation and service concepts can help to reduce costs over the total supply chain and lifecycle:

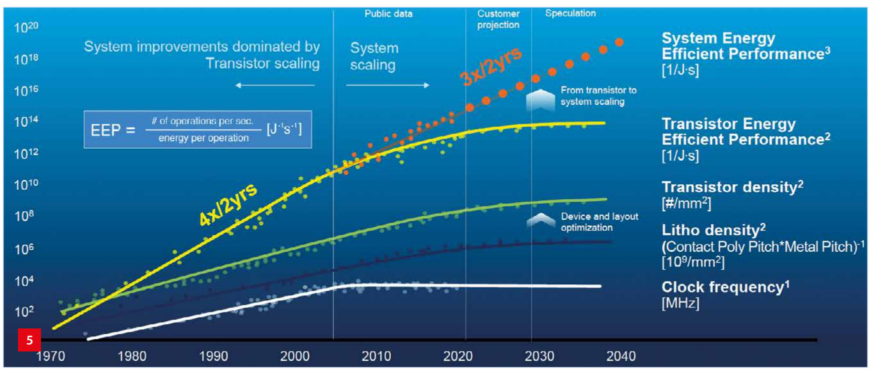
- Machine building and infrastructure
  - Reducing system production and delivery lead times (Figure 7); reducing capital cost in the supply chain; lowering risk with respect to changes and obsolescence.
  - Modularity.
- Transport, tools and service concepts
  - High uptime (reliability and robustness of design).
  - Quick diagnosis of faults.
  - Accessibility and swift swapping of parts.
  - Fast restart without lengthy calibrations.

As a takeaway, Kuit stated, "Simply scaling what made us successful, is not a guarantee for future success. We need to rethink the system to design affordable products by consciously balancing performance, technical complexity and cost at integral level."

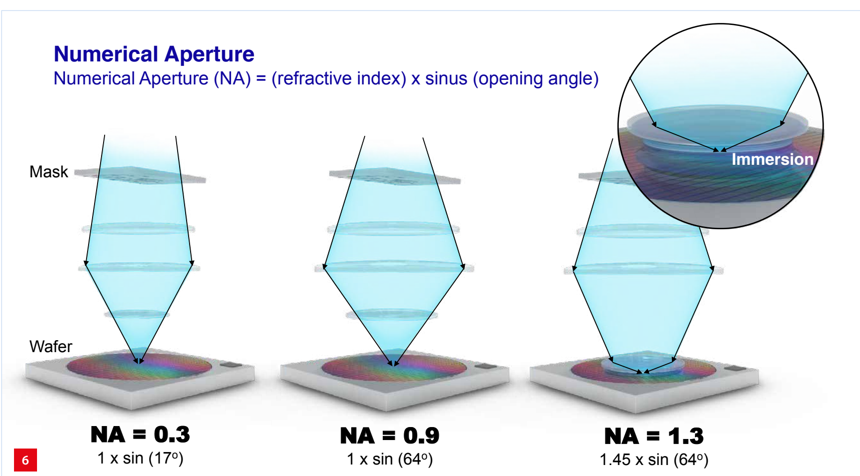
Photonics

Martijn Heck, professor at the Eindhoven Hendrik Casimir Institute of Eindhoven University of Technology, spoke about integrated photonics for a sustainable information society. He showed how photonics (Figure 8) exhibits exponential growth (bandwidth up by factor of two every two years) and can help the world with immediate connectivity and rapid data processing.

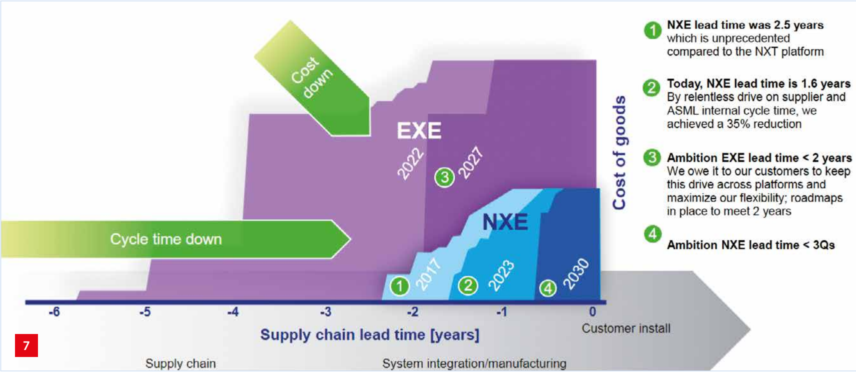
The growth of photonics is supported by progress in the semicon industry, as waveguides, modulators and photo-detectors, for example, can be realised on silicon. However, some important functionalities cannot be realised in CMOS technology: indium phosphide (InP) is crucial as a carrier for some of these, such as lasers and amplifiers. Purely looking at the number of functions/components per chip, photonics seems to be lagging behind on the silicon roadmap following Moore's law (Figure 9). Although that is not an entirely fair comparison, because the functionalities that can be realised in



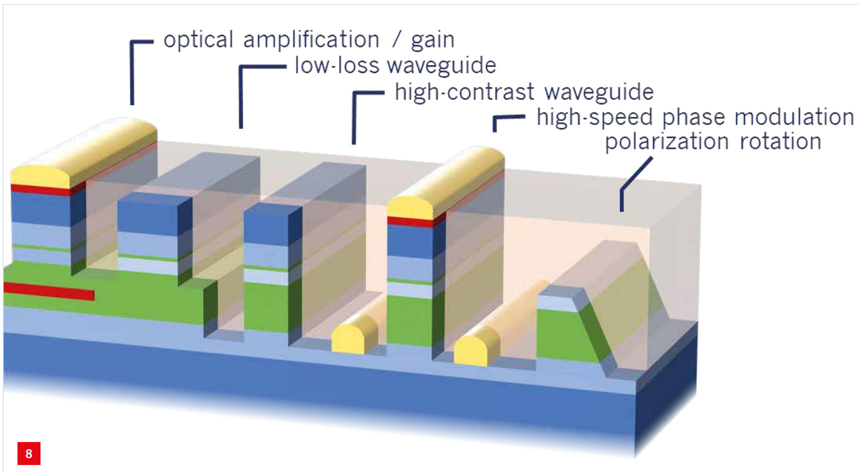
5 Moore's law.



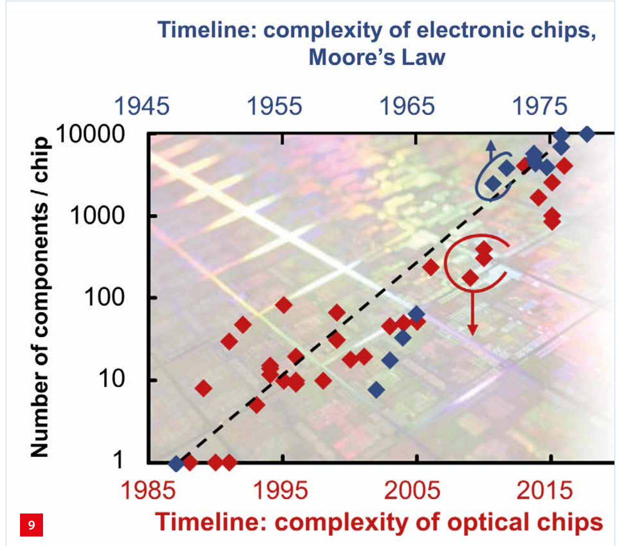
6 Increasing the numerical aperture in lithography.



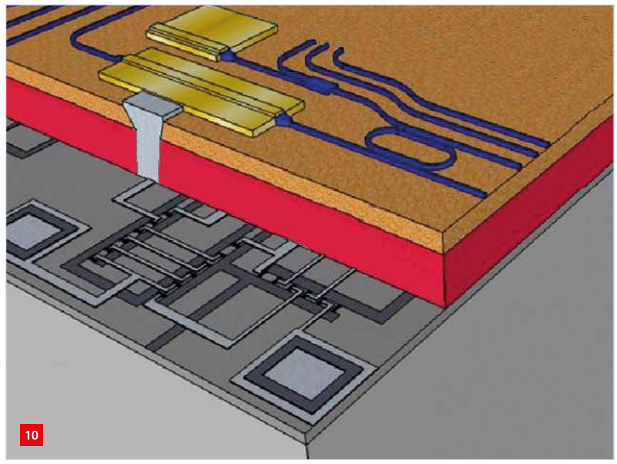
Reducing supply chain lead time.



Photonic functionality on a chip.



Evolution of photonic chips (red) compared to CMOS chip technology (blue). Note the different timescales.



Hybrid chip solution, with an InP chip (top) coupled to a SiGe-based chip.

photonics differ from those in silicon. Heterogenous/hybrid solutions (Figure 10) in which InP chips are coupled to silicon-based chips help to combine the necessary functions to make a complete chip functionality including photonics.

Apart from the obvious applications in data connectivity (telecom, data centres, boards and processors), photonics can be found more and more in applications such as:

- Lasers for sensing/metrology.
- Gas sensing.
- Lidar (automotive; (partly) autonomous vehicles); see Figure 11.
- Wafer alignment sensing.

Further developments in manufacturing and precision engineering, which may include micro transfer printing, will help to improve the performance of photonics, while component size/mass, power consumption and cost will go down.

Awards

At the DSPE Conference, it is a tradition that the best demonstration, poster and presentation receive an award (Figure 12).

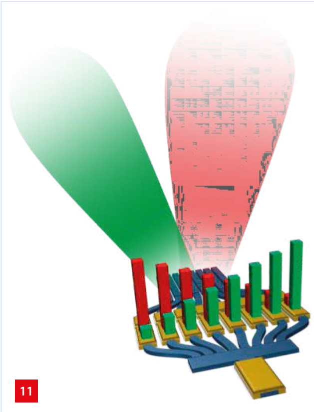
Best demonstration

Rik van der Burg, competence owner Motion Control at Kulicke & Soffa, presented a multi-pipette placement head. Several drivers led to the development of a next-generation pipette placement head for a fast component-mounting system for printed circuit board manufacturing (Figure 13):

- Miniaturisation of the surface-mounted devices to 0.2 mm x 0.1 mm.
- Need for controlled force during component placement.
- Lower cost per placement.

Due to the fact that the currently applied technologies had reached their boundaries, a concept study was initiated. This led to the selection of a multiple-pipette placement head with ten pipettes per head with individual z/phi-controls, featuring:

- Vacuum/air valve for component picking.
- 25 mm z-stroke.
- 10 g acceleration.
- Spring-loaded tool tip for force control.
- Low-cost components.

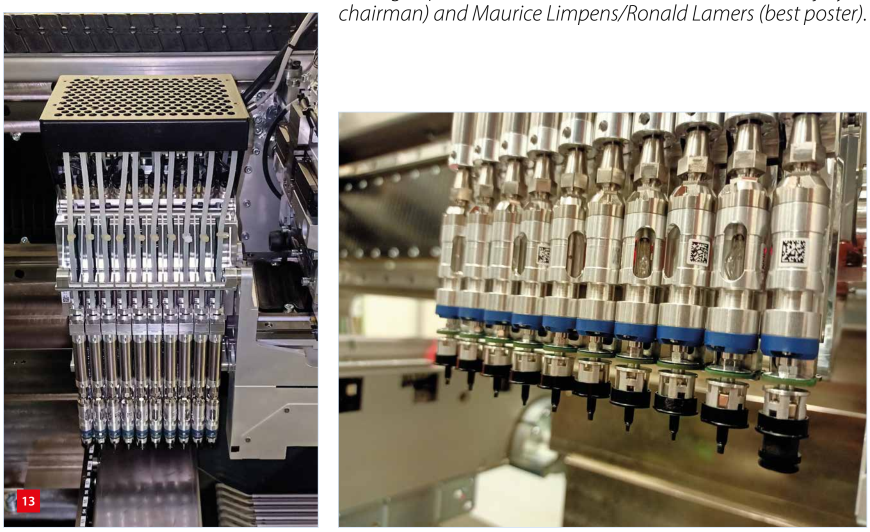


11

Photonics chip with lidar device application.

12

Award ceremony round-up, from left to right: Ron de Bruijn (best presentation), Rik van der Burg (best demonstration), Tom Bijnagte (who received the Incentive award for his design of a high-speed circular nut cracker), Jan van den Brink (jury chairman) and Maurice Limpens/Ronald Lamers (best poster).



13

Part of the placement machine, with a close-up of the 10-pipette placement head.

Thermal aspects and the very tight footprint required the custom design of a PCB-integrated z-motor with capacitive encoder, and an AC phi-motor. Overall control is managed by a 128-axis controller from ACS Motion Control that is able to control several 10-pipette placement heads separately to all the other machine axes.

Best poster

Maurice Limpens, thermo-mechanical architect at MI-Partners, and Ronald Lamers, thermal dynamic design engineer at Thermo Fisher Scientific, presented a poster about a 20-K vibration-free cold battery. Specifically in analytical equipment when looking at samples with extremely high resolution under cryogenic conditions, the imaging process can be disturbed easily by vibrations due to the cooling system. For example, when the cold 'finger', which is linked to the sample, is connected to a bottle with boiling fluid as a source of vibrations.

A cold battery (Figure 14) was developed that can be cooled down to temperatures between 5 and 20 K, and has sufficient capacity to keep the temperature at a controlled low level.

There were no obvious choices for the materials to be used for this battery in this extremely-low-temperature area. Their specific heat capacity near 0 K is very different from that at ambient temperatures. Figure 15, taken from the patent application for this cold buffer device, shows a graph for the specific heat capacities.

With reference to Figure 15, the material chosen for the inner (coldest) buffer was erbium. What also helped was that due to several phase transitions over the temperature curve, the specific heat capacity of erbium is relatively high at extremely low temperatures. The inner layer consists of approximately 100 kg of erbium, which is embedded in the outer buffer layer of approximately 100 kg of copper (which in turn is linked to other parts around the sample that is to be cooled). The cold finger leading towards the sample can be controlled using heating elements. The inner and the outer buffer can be cooled with a cryo cooler connected to the buffers by a thermal switch.

Best presentation

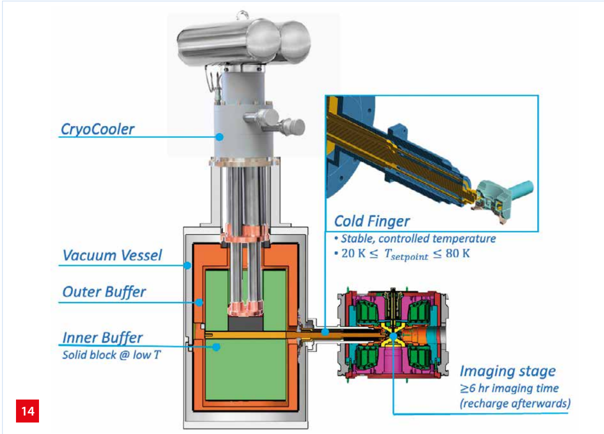
Ron de Bruijn, Ph.D. candidate at TU/e, gave a presentation about piezoelectric wafer stages provided with a highly variable stiffness device for next-generation semicon equipment. Based on a comparison of two actuator types (Table 1), he decided to apply piezo actuators as short-stroke actuators in a long-stroke, short-stroke actuator set-up for moving wafer stages.

Table 1
Comparison of actuator types.

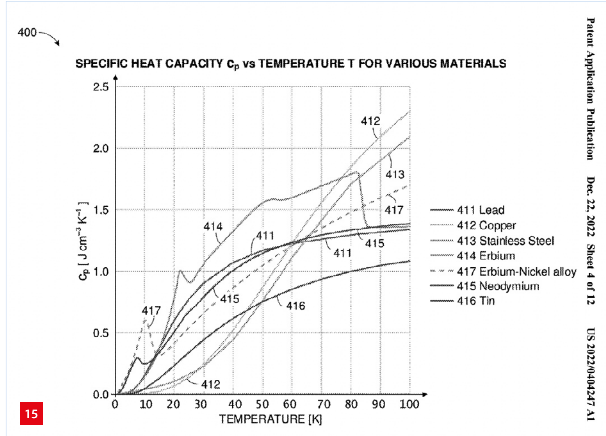
	Lorentz	Piezo
Disturbance transmissibility	Low	High (high intrinsic stiffness)
Electromagnetic fields	Yes	No
Power dissipation	High	Low
Power density	Low	High

For moving wafer stages, piezo actuators can be applied successfully in different ways, such as advanced model-based control and mechanical stiffness switching. The latter was presented at the conference. De Bruijn proposed a concept with a piezoelectric actuator moving the wafer table and an internal balance mass/intermediate body connected with variable stiffness to the long-stroke frame (Figure 16).

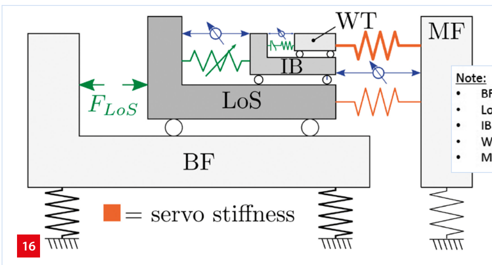
For the variable stiffness, a rubber cone enclosed in a cone-shaped metal component with a small clearance (Figure 17) will give high stiffness during high-acceleration phases and low stiffness during standstill or constant velocity. Modelling demonstrated that comparable results can be obtained for both the Lorentz- and the piezo-actuator set-ups, while preserving the piezo-actuator benefits in terms of high force density and absence of electromagnetic fields. An experimental set-up is being prepared to verify modelling results.



Cold battery concept, for keeping a sample at an accurate 20 K for more than 12 hours.



Specific heat capacity for several materials in the low temperature range; specifically erbium and copper are relevant for the cold battery. (Source: US patent US-20220404247-A1)



Long-stroke, short-stroke concept with internal balance mass/ intermediate body.

Physics backgrounds

Taken from the vast amount of very interesting presentations, here we will feature two. They involved work concerned with fundamental understanding of particle transport under vacuum conditions and heat transfer in contact surfaces, respectively. Both presentations provided valuable insights for the engineering of precision equipment.

Particle contamination transport

Dmitri Shestakov, senior functional analyst at VDL ETG, discussed the importance of modelling contamination transport at low pressure. Contamination is harmful in the manufacturing of chips; see Figure 18. Particle sources can be such things as 'clean' air flows and wear due to moving parts. Heat flow can also induce particles to get moving. To give an indication of the particle dynamics: at 1 Pa pressure a 10-micron particle can fall down with 20 cm/sec.

The forces that act on a particle can be seen in Figure 19:

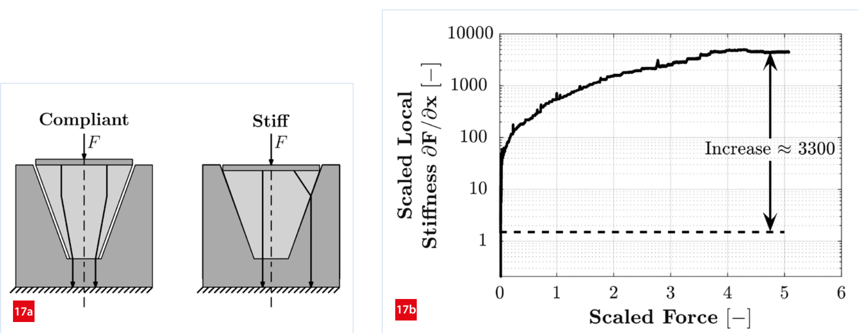
- F_{drag}, in flow direction.
- $F_{turbulent}$, also in other directions.
- F_{el} ($F_{electrostatic}$), electrostatic forces.
- $F_{gravity}$.
- $F_{brownian}$ (molecules bumping).
- $F_{thermophoretic}$ (gradient in temperature; heat flow due to, for example, a heating bottom and cooling ceiling, gives rise to pressure/force exercised on the particle; see Figure 20).

Shestakov focused on $F_{thermophoretic}$, both in an experimental set-up and with theoretical research including Monte Carlo simulations, to gain first insights in the transport behaviour of contamination particles in low-pressure environments. He shared the following conclusions:

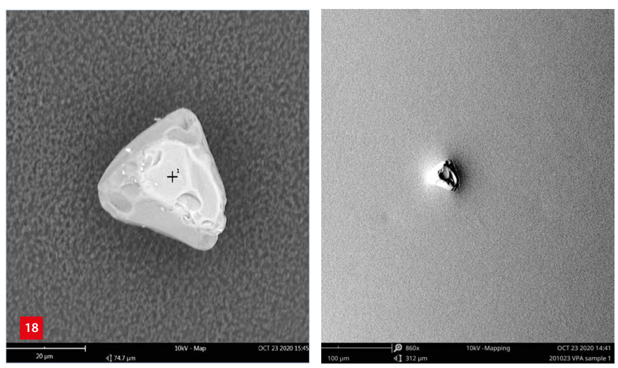
- Knowledge of fine particle dynamics is essential for understanding the contamination transport in systems.
- This type of work – theoretical/simulation research in combination with experiments – is only possible in close collaboration between industry and academia.

Thermal contact conductance

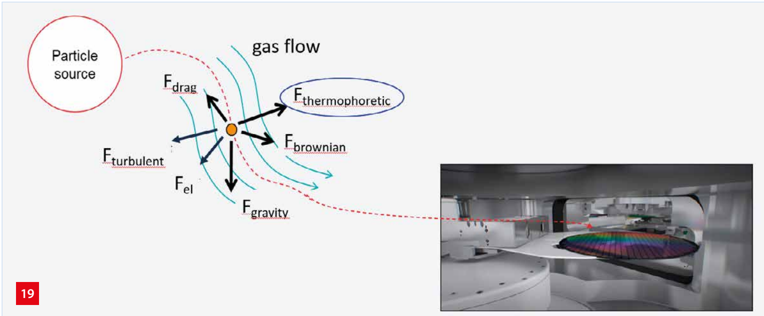
Joris Oosterhuis, now at ASML, discussed work conducted



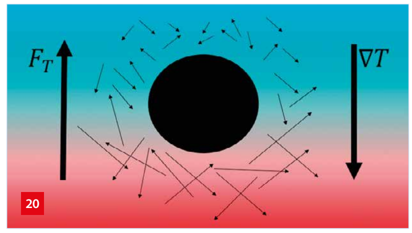
Variable-stiffness concept.
(a) Rubber cone with defined clearance in metal housing.
(b) Stiffness increases with applied force.



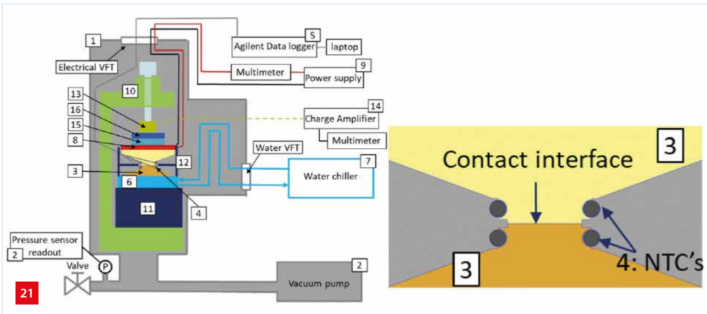
Examples of defects/particles on wafers in chip manufacturing.



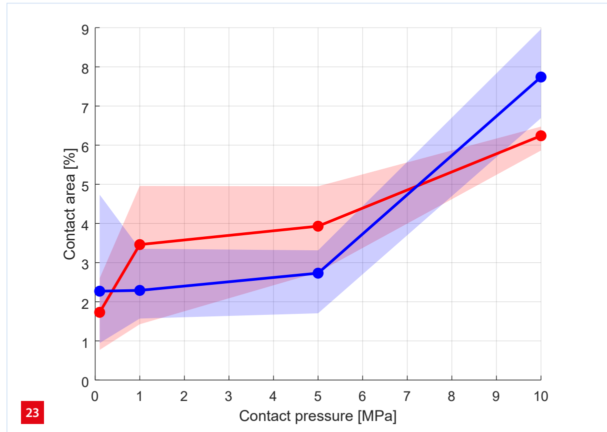
Forces acting on a particle that threatens to contaminate a wafer.



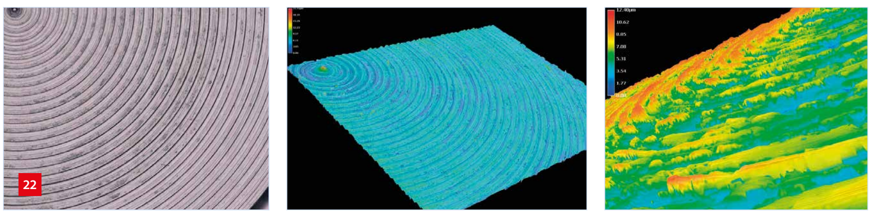
Thermophoretic forces acting on a particle.



Experimental set-up for studying thermal contact conductance; on the right, the two samples in contact.



Estimated real contact area for aluminium samples with R_a = 0.4 μm (red) and R_a = 1.6 μm (blue). Lines indicate average real contact area, while bands show spread due to different directions of tilt.



Example of a microscopic image (left) and 3D surface profiles of one quarter of a sample.

at Philips Engineering Solutions. This concerned the thermal energy transfer through the contact between two objects, as characterised by the thermal contact conductance. This quantity is highly dependent on material properties, surface roughness, geometrical topography, recontacting, etc., which leads to a high level of non-reproducibility. Especially for vacuum systems, where thermal contact conductance is important in the heat transport mechanism, the predictability needs improvement.

A test set-up (Figure 21) was designed in which several parameters could be varied:

- Heat flow:
  - temperature of heated zone, water cooling at 22° C;
  - temperature measurement with NTCs.
- Contact area:
  - size;
  - material;
  - roughness;
  - surface topography.

The real contact area for a given surface pressure was predicted to be an important feature. The surface topography before and after the experiments was reconstructed with help of a Keyence 3D microscope (up to 1,000x magnification) combined with low-pass filtering, denoising and detrending to rule out factors such as edge and tilting effects (Figure 22).

It was clear that increasing the penetration depth of roughness peaks increases the real contact area. More work must be done to predict the relation between topography/peaks, plastic and elastic deformation, and the real contact area. It was also shown that in many test cases the average roughness value increased after contact.
Oosterhuis concluded that the estimated real contact area as a percentage of the nominal contact varies greatly and will be between 1 and 9%, depending on the contact pressure, which ranges between 0 and 10 MPa. Thus the thermal contact conductance varies as well, with more or less similar percentages (Figure 23). Rougher surfaces seem to conduct better due to more asperities in local contact. However, more work will have to be carried out to improve the predictability of the thermal contact conductance; think of effects such as surface topography, roughness, elastic and plastic material properties, oxidation, manufacturing procedure, and the effects of recontacting.

Conclusion

The conference featured a loaded programme under the motto 'Rethinking the system.' Participants had the opportunity to absorb a great deal of knowledge, ideas and insights for rethinking and reconsidering. Thus, after two days they had consumed enough food for thought to last until the next edition, on 23-24 September 2025. The committee and everyone else involved in the organisation, as well as the actively participating attendees, deserve a warm thank you for a fantastic event.