ACCESS TO CLEANLINESS

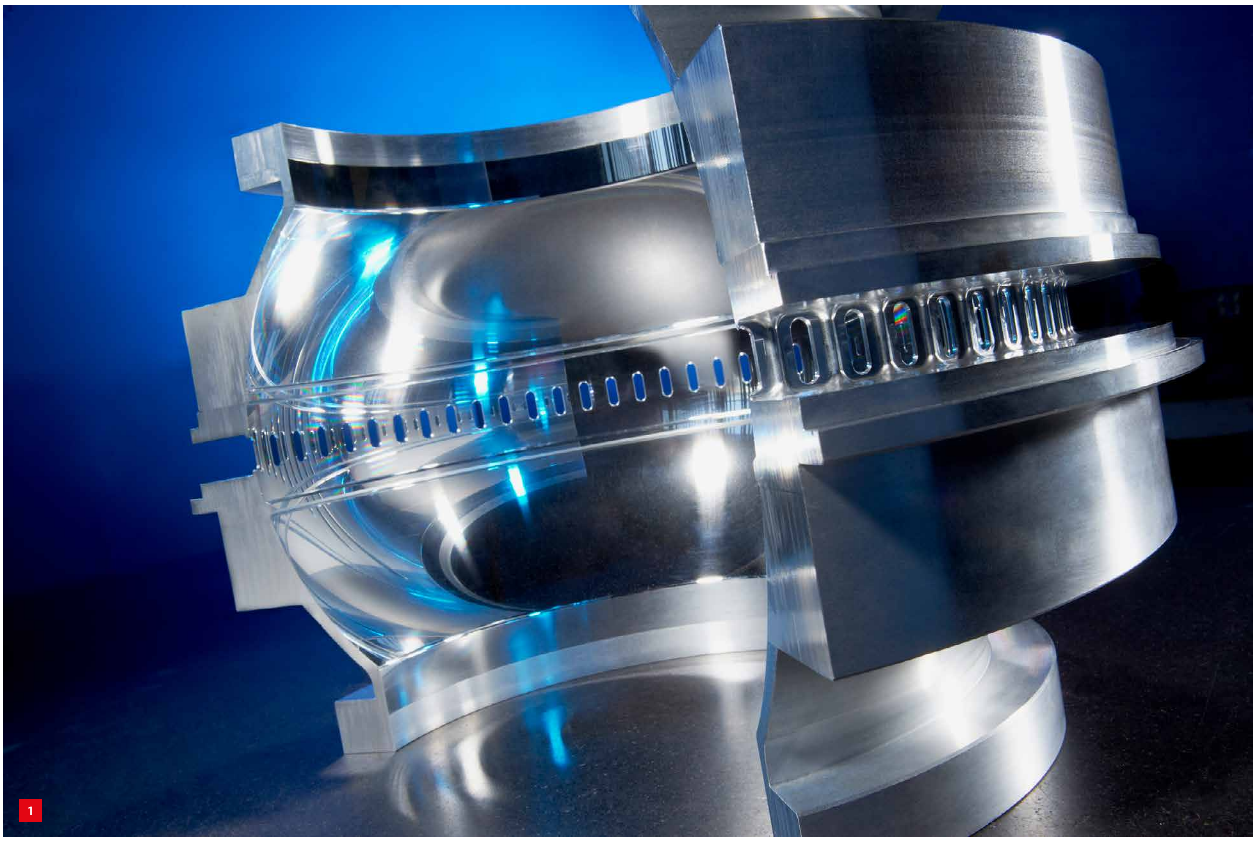
Contamination control is critical for the operation of high-end manufacturing equipment. In the ACCESS project, VDL ETG and various research groups from Eindhoven University of Technology (TU/e) collaborate to deepen their fundamental understanding of generation, transport and removal of particle contamination. During a mini-symposium organised at the TU/e campus on 1 February 2024, results were presented and a follow-up was launched to raise the gained knowledge and expertise to a higher level of understanding as well as bring practical application within reach.

High-end manufacturing equipment has to support increasing levels of cleanliness. The scale of contamination influences processing of current- and next-generation semiconductor devices, which is why semiconductor manufacturing increasingly involves vacuum environments (Figure 1). Various kinds of analytical techniques, such as electron microscopy, mass spectrometry and spectroscopy, are also affected by the need for cleanliness. First-tier high-tech system supplier VDL ETG is pro-actively developing capabilities in product design as well as in production process design to support increasing requirements on cleanliness.

Where knowledge gaps exist, VDL ETG supports research to further the state-of-art, for example in the ACCESS project: Active Contamination Control for Equipment and SubstrateS. In this project, VDL ETG and Eindhoven University of Technology (TU/e) work together as a multidisciplinary team, to deepen the fundamental understanding of generation, transport and removal of particle contamination.

Introduction of a key enabler

A symposium was organised to mark the end of the first round of the ACCESS project, which had started in 2019. The event, jointly organised by VDL ETG and TU/e HTSC (High Tech Systems Center), attracted an audience of over 100 people and was opened by chairman of the afternoon Ton Peijnenburg, CTO of VDL ETG. Next, Paul Blom, senior system engineer at VDL ETG, gave an introduction to the ACCESS project. He declared that contamination control is a key enabler for high-tech equipment. "All our



1 To mitigate contamination, semiconductor manufacturing increasingly involves vacuum environments such as vacuum chambers.

EDITORIAL NOTE

This report was based on input provided by VDL ETG and the TU/e HTSC.

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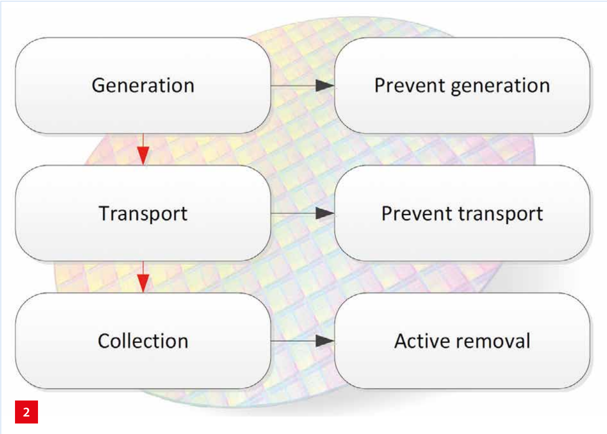

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Three stages of contamination control.

main accounts identify contamination control to be one of their future challenges."

In semiconductors, Blom showed, the presence of contaminants such as particles can cause major defects in devices affecting yield, performance and reliability. Contamination is introduced, for example, during wafer handling under vacuum conditions, and involves three stages: generation of particles, their transport and their collection by critical wafer surfaces. Hence, contamination control also covers three stages (see Figure 2): the prevention of particle generation, the prevention of particle transport, and the active removal of particles.

Three research presentations

Following this introduction, the main course of the symposium was a set of three oral presentations by researchers, featuring particle generation, transport and removal, respectively.

Scratch experiments
Tom Bertens, EngD candidate, discussed the generation of wear particles on silicon wafers. Contact between lithography machine components and mono-crystalline silicon wafers has been identified as an instigator of the formation of wear particles. The primary objective of this research was to understand the complexities of the wafer-machine contact and characterise the interaction at the micrometer level. A thorough examination through in-situ scratch experiments was conducted on the micro- and nanometer scale.

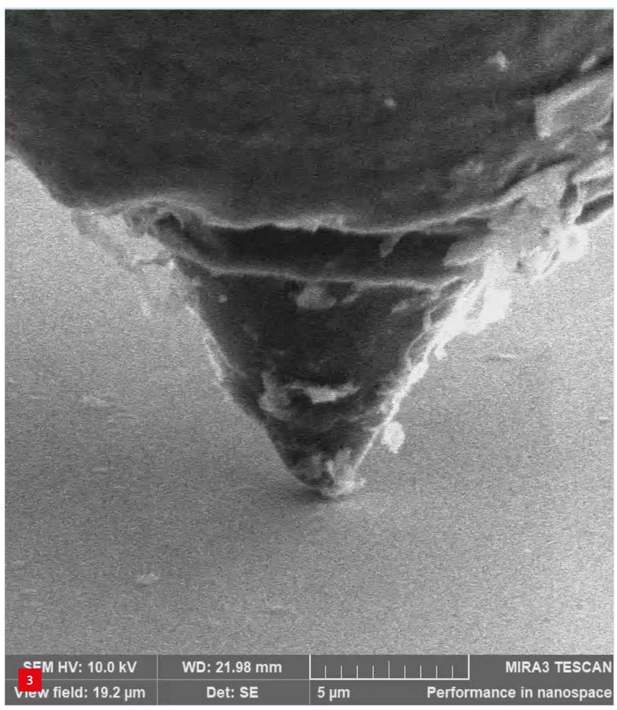
The machine parts, coated in a diamond-like-carbon coating, exhibit surface irregularities known as asperities. Indentation tests were conducted with an indenter probe specifically manufactured to the asperity geometry, to assess the loading conditions under which phase transformations occur in the mono-crystalline silicon. Building on the insights gained, scratch testing (Figure 3) commenced, with the goal of mimicking the wafer-machine interaction. The observed scratch topography was successfully compared to the numerical outcomes of the material scratch model (Continuum Bond Model, CBM) that was also developed in the ACCESS project.

Follow-up research will focus on expanding the CBM model with damage and fracture law effects, further validating the model, and ultimately unravelling silicon material behaviour.

Temperature gradients
Ralf Reinartz, PhD candidate, talked about the contribution of the thermophoretic force to particle transport in a rarefied gas. This force, due to a temperature gradient, was studied for a finite-size spherical particle in rarefied-gas conditions using both experimental and numerical methods. For the numerical simulations, the Direct Simulation Monte Carlo (DSMC) method was used and the computational efficiency was greatly improved. For studying particle transport phenomena such as levitation due to thermophoresis, a particle visualisation set-up was realised.

The influence of particle thermal conductivity and gas properties on the thermophoretic force was investigated and comparisons between the two methods were made, concerning the influence of particle properties such as shape and accommodation coefficients.

Further research will be devoted to deepening the understanding of the thermophoretic force and the effect of particle shape and other gas and particle properties.



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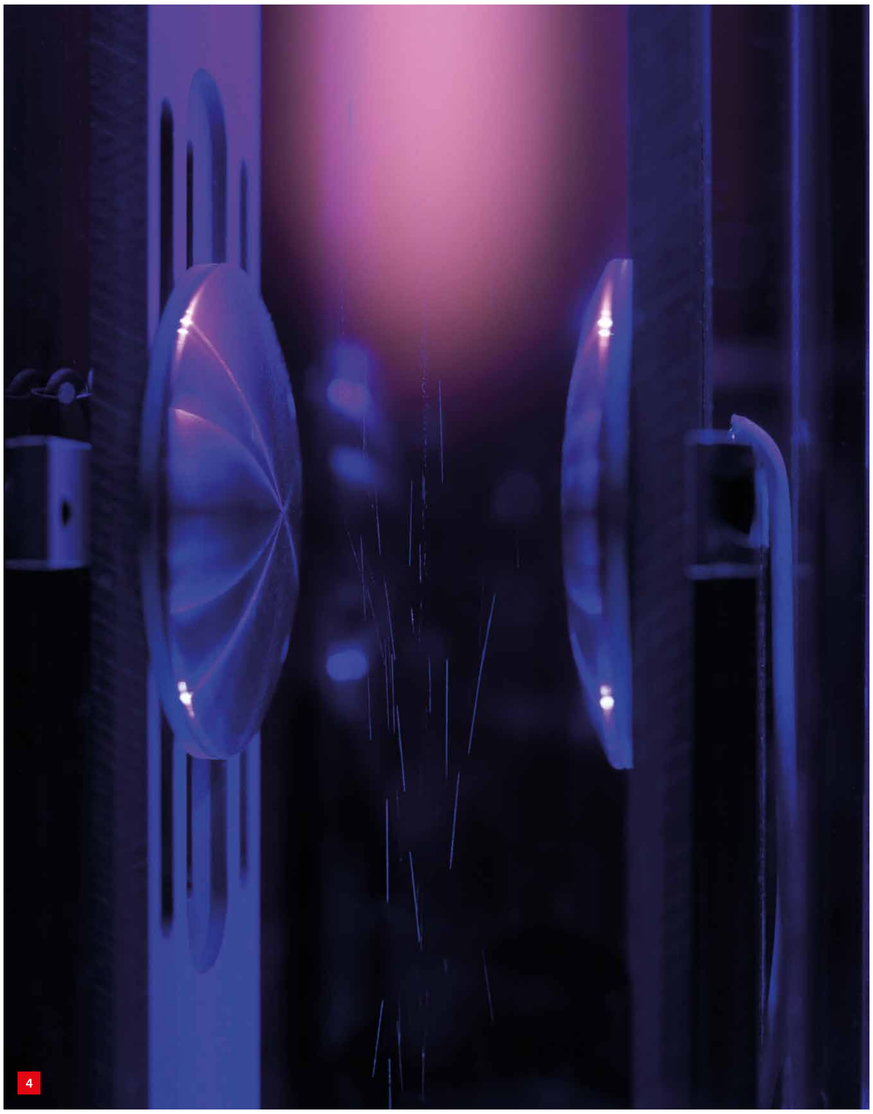
SEM image of a scratch experiment with a diamond indenter tip.



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Vacuum particle charging set-up for plasma cleaning. (Photo: Bart van Overbeeke, TU/e)

Plasma cleaning

Judith van Huijstee, PhD candidate, presented the use of a plasma-based dust filter for particle removal. This can take advantage of the property that dust particles become electrically charged when they are immersed in plasma. Electrically charged particles can then be filtered by application of an external electric field.

The fundamental research in this project was concerned with the interaction between dust particles and afterglow plasmas, specifically the charging of dust in this type of plasmas (Figure 4), as the dust particle charge is a key parameter for the effectiveness of a plasma-based dust filter. Demonstrators that were developed included a high-voltage source for plasma generation and a prototype particle seal.

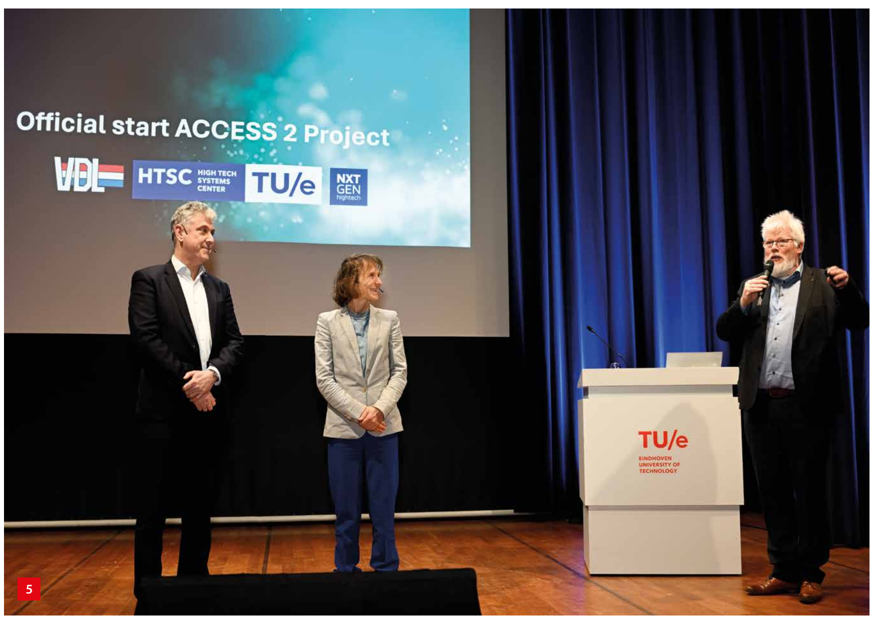
In the follow-up of this project, the plasma seal will be demonstrated and further developed. Ultimately, understanding the cleaning process as applied to electron-beam systems has to lead to a complete plasma-cleaning solution.

Conclusion, kick-off and reflection

Following the three research presentations, Kasper van den Broek, tribology expert & contamination control architect at VDL ETG, shared the conclusions of the ACCESS-1 project. New insights into particle generation, transport and removal have been obtained, using analytical and experimental methods, demonstrators have been realised and models have been validated.

Further research now has to raise the gained knowledge and expertise to a higher level of understanding as well as bring practical application within reach, as described above for the three topics. This will be the objective of the ACCESS-2 project, which will receive funding from the NXTGEN HIGHTECH National Growth Fund programme. The symposium was then officially concluded by VDL ETG CEO Geert Jakobs and TU/e rectrix magnifica Silvia Lenaerts, who praised the partnership and kicked off ACCESS-2 (Figure 5).

In the aftermath, chairman Ton Peijnenburg reflected on the symposium: "The researchers also presented their work through posters, which sparked lively discussions with the audience. They demonstrated that this research requires a close collaboration between theory and experiment, and that the combination of PhD and EngD students is ideal for this purpose. Moreover, they showed that studying particle contamination is not only important, but also fun."



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Official start of the ACCESS-2 project, with VDL ETG CEO Geert Jakobs and TU/e rectrix magnifica Silvia Lenaerts; on the right, chairman of the afternoon Ton Peijnenburg, CTO of VDL ETG. (Photo: Bart van Overbeeke)