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CHALLANGES OF EXTREME ULTRA VIOLET LITHOGRAPHY IN LOW PRESSURE GAS ENVIRONMENT

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ABSTRACT

ASML is market leading supplier of photolithography systems for the semiconductor industry. ASML manufactures machines for the production of integrated circuits such as CPUs, DRAM memory and flash memory. The new generation of lithography machines are capable to produce line features of about 10 nanometer by utilizing extreme ultraviolet light source (EUV) projected onto a mask and then exposing a resist on top of the target wafer. Thereafter by etching away material from the light-exposed-pattern, features can be produced. However EUV light easily get absorbed by all medium including gases. As a consequence lenses have to be exchanged with mirrors and environment has to be at low pressure of light weight gas type. While targeting production of feature sizes of 10 nanometer, specification is made to stack layers which are correct within about 1 nanometer (called overlay). One of many challenges in this scope is to limit uncertainty caused by thermal expansion of the wafer, which is mainly caused by exposure light and heat induced by gas flows. The latter can be induced by 3 identified effect:

- Center heat load: gas purged onto the wafer impinges and stagnates on wafer, obtaining higher temperature than surface causing heat load.
- Gas expansion: gas purged with large pressure drop will expand and cool causing extraction of heat from surrounding solids. This can be predicted by Fourier's law [1].
- Sheer heating: at low pressure domains heat can be induced to surface by slip-sheer heating. This can be expressed as the product of slip velocity and the sheer-stress [1].

Another prominent challenge is caused by resist becoming molecularly volatile while exposed, as depicted in Figure 1. These "molecular contaminants" causes a threat for EUV transmission, by deposition on optics, and has therefore to be purged out of the way of the light path. However the extra purged flow increases the environment pressure and has to be pumped away.

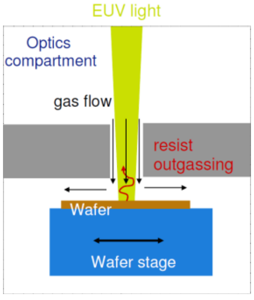

Figure 1: Schematic of EUV lithography light hits the wafer causing molecular contaminants to diffuse in direction of light path, hence threatening light transmission by depositing optical hardware.

Different simulation methods such as network models, CFD, lattice-Boltzman method, direct simulation Monte Carlo (DSMC) and molecular dynamics have been applied depending on complexity, size of simulation domain, Knudsen number range and compressibility. In this presentation ASML will focus on challenges faced when validating DSMC models. Experiments to determine momentum and thermal accommodation factors showed remarkable results, which requires further understanding of underlying physics.

A new wall kernel collision scheme for DSMC is proposed to adhere to the measured results. In addition, literature research states that for gas type of EUV environment the internal energy (rotational) is rarely exchanged in gas-gas collisions. And since the pressure environment is relatively low, negligible effect was found by reducing the Larsen-Borgnakke collision model to variable hard sphere (VHS) and thereby excluding rotational energy exchange all together in gas-gas collisions.
Experiments performed on a simplified axisymmetric geometry, where 3 exchangeable dummy wafers where used designed individually for measurement of pressure, suppression and heat-load, confirmed modelling results of DSMC on four main measurable parameters

- **Flow rate:** case yielded same flow rate over pressure drop as experiment.
- **Matching pressure on wafer:** pressure sensors on wafer target was in good agreement with experiment.
- **Molecular suppression:** released “test contaminants” at center of test wafer caused same degree of contaminant partial pressure at reservoir representing optics compartment.
- **Flow induced heat loads on wafer**: both central heat load as well as peripheral heating due to slip-shear of gas near the surfaces and gas expansion effects in good correlation between DSMC and experiment.

However, DSMC applied in comparisons above is not able to simulate the true geometry due to high computational cost, which is also impacted by inadequate parallelization possibilities.

At ASML we currently face a number of challenges in scope of rarefied gas dynamics, such as:

- Faster simulation technique than current DSMC but with same accuracy.
- Description of tangential momentum accommodation coefficient (TMAC) and thermal accommodation coefficient (TAC) dependency on temperature, surface type, surface treatment & surface coating.
- Finding diffusion coefficients for various compounds which could threaten to contaminate optical compartment.
- Contamination by micrometer sized particles is present. Hence tools and knowledge for predicting stopping power by flow and particle-surface scattering description is highly desired.

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