A global plasma and surface model of a hydrogen/methane inductively coupled discharges for the Extreme-Ultra-Violet lithography machines

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Abstract: A global model of hydrogen/methane inductively coupled plasma with 469 homogeneous reactions is developed to investigate the plasma-surface interaction in Extreme-Ultra-Violet lithography machines. The model is self-consistently coupled with a surface deposition/etch model of 42 heterogeneous surface reactions for the net deposition/etch rates. An agreement is obtained between the simulation results and a wide variety of measurements e.g. electron density, electron temperature and hydrogen atom density. The deposition rate for a varying methane impurity level is provided.

Keywords: EUV plasma, methane plasma-surface model, hydrocarbon deposition/etch

1. General

Extreme-Ultra-Violet (EUV) lithography plays an essential role in the modern integrated circuit (IC) technology. The number of transistors on ICs double in value once in two years, empirically predicted by Moore's law. However, the feasibility to reduce the size of the transistors has recently become extremely challenging as the length-scales shrink down to orders of a few nanometres. The introduction of the EUV lithography process in the last decade facilitates this, reducing the size to a minimum value ever achieved to date.

The IC development recipes involve a series of deposition, etch and lithography processes. They commence with a photoresist layer covering a deposited film on a substrate. During the lithography step, light with a desired pattern illuminates the photoresist and creates the associated structure onto the surface. The wafer then goes through etching process to obtain the patterned film. The limiting step to achieve a minimum transistor size is the lithography and here EUV lithography is essential.

The lithography machines involve two distinct plasma phenomena. The EUV light in the machine is created by a laser-produced tin plasma. In the process, tin droplets are introduced into a vacuum system, which are irradiated by a CO_2 laser. This produces a tin plasma generating EUV light at a wavelength of 13.5 nm. Then the light is collected within the EUV source and transmitted through a series of mirrors to a reticle (or mask). The reticle creates a desired pattern to be printed on the photoresist to manufacture the IC structures in consecutive steps. The light pattern illuminated on the wafer finalizes the photo-lithography step. An overview of the process is depicted in Fig. 1.

An additional EUV-induced plasma is created in the lithography machines other than the tin plasma due to the high-energy light waves travelling through a low-pressure hydrogen medium. For further details on the properties of this plasma, we refer to [1,2]. The EUV-induced hydrogen plasma changes the interior surface by a flux of various reactive plasma species. Especially gaseous hydrocarbon species, being present as an impurity in the system, can induce the growth of hydrocarbon layers on optically sensitive surfaces. This hydrocarbon deposition in lithography machines due to the exposure to EUV-induced plasma reduces the lifetime of optical elements by affecting the transfer of the EUV-light onto the wafer. In order to understand the role of this EUV-induced plasma on the hydrocarbon deposition/etch rates a global and surface model is developed for a hydrogen/methane inductively coupled plasma as a reference case.

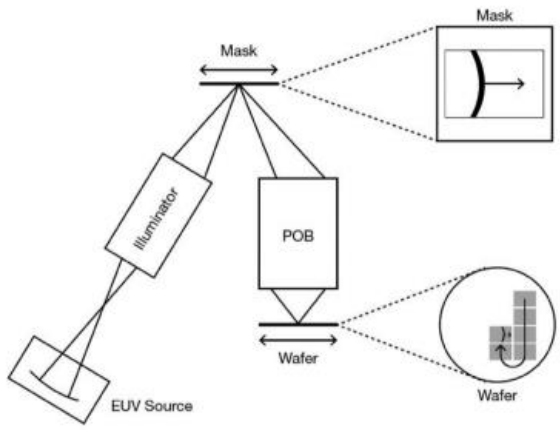

Fig. 1. Working principle of EUV lithography; the EUV source generates the EUV by Sn (tin) plasma and illuminates onto reticle (or mask). The reflected light passes through the Projection Optics Box (POB) and printed on the wafer. The wafer has a large number of IC structures. (source: ASML)

2. Global and surface model

Zero-dimensional global models [3-6] are often preferred to probe a detailed chemical kinetics of molecular plasmas. They involve a volume-averaged particle balance equation for each species and a volume-averaged electron energy balance equation. The volume-averaged particle balance equation of a plasma species i is

$$\frac{dn_i}{dt} = S_i \,,$$

where n_i represents the species density and S_i the source. The source is due to either homogeneous gas-phase reactions among plasma species or heterogeneous reactions occurring on the solid surface – in contact with the plasma. The source also involves effective transport terms due to diffusion and convection. The volume-averaged electron energy balance equation is

$$\frac{d(\frac{3}{2} n_e T_e)}{dt} = Q_e \,,$$

where T_e is the electron temperature under the assumption of a Maxwellian electron energy distribution function and Q_e is the energy source. The energy source for the electrons is the absorbed electrical power and the energy loss is due to various elastic and inelastic collisions in the plasma volume and at the surface.

Additionally, a surface model [7] is self-consistently coupled to the system of equations. The surface reaction set is adapted from earlier studies of hydrocarbon deposition, etch processes [7-9]. In addition, radical adsorption coefficients are updated in this study with more recent values. The etching by hydrogen ions – important for a large hydrogen to methane ratios - are also included in the surface reaction set. The surface density of the adsorbed species *i* in the model is

$$\frac{dN_{(ads)i}}{dt} = \sum_j \Gamma_{ji}$$

where $N_{(ads)i}$ is the surface density of the adsorbed species denoted by the subscript *i* and the flux of a species due to a surface mechanism *j* is represented by Γ_{ji}.

3. Results

The simulation results are validated against electron density, electron temperature, hydrogen density and deposition rate measurements and an agreement is obtained in hydrogen as well as hydrogen/methane inductive discharges [9,10]. The comparison of the electron density is shown in Fig. 2.

A deposition rate of about 400 (A/min) is calculated by the model in an inductive methane plasma. The value is in agreement with the measurement by Vanhulsel et al [11]. The deposition rate decreases as more hydrogen is introduced into the system. The rate for the hydrogen dominated plasma including only impurity level of methane is calculated and the simulation results are discussed.

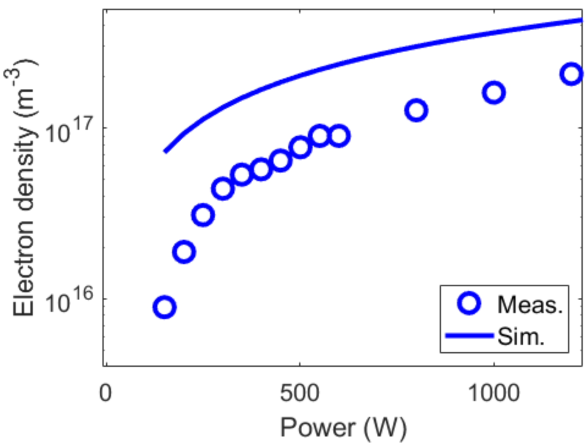

Fig. 2. The comparison of the electron density calculations and Langmuir probe measurements [8] in a hydrogen plasma for a variation of the input power. The plasma has a length of 8 cm and a radius of 5 cm.

4. References

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