Numerical Simulations of Inductively Coupled Plasmas for Etching Applications

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High-density low-pressure inductively coupled plasma (ICP) sources are widely used for etching of semiconductors and metals in the microelectronics industry. Plasma uniformity, etch selectivity and anisotropy are important parameters for optimizing plasma etch processes to satisfy the need for continuing downscaling of semiconductor devices. A two-dimensional numerical hybrid fluid Monte Carlo model is being used to investigate the influence of operating conditions such as input power, dc substrate bias, wall temperature and gas pressure on the Ar/Cl_2 plasma used for silicon etching.

Introduction

Inductively coupled plasma reactors which have high input power efficiency and operate under lower gas pressure have been developed for microelectronics fabrication[1,2]. These low pressure systems have less ion scattering which results in a more anisotropic flux to the wafer. Lower gas pressure etching systems must operate at higher plasma densities to achieve the same process rate as conventional high pressure systems. To achieve an efficient power deposition, an ICP reactor geometry is developed. One ICP reactor design is a so called transformer coupled plasma (TCP) reactor where a spiral coil is placed on top of the cylindrical plasma chamber[1]. The bias on the substrate can be varied to control the energy of the ion flux to the wafer. Changing operating conditions such as gas pressure, input power and bias voltage will have an effect on the plasma and the uniformity, anisotropy and selectivity of the etch process. The dependence of the plasma on the operating conditions is investigated with a two-dimensional numerical model.

Description of the model

The model that is being used is the hybrid plasma equipment model (HPEM), developed by Kushner *et al*[2-7]. This model for ICP reactors is a 2D (cylindrically symmetric) hybrid simulation consisting of an electromagnetics module (EMM), an electron energy and transport module (EETM) and a fluid kinetics simulation (FKS). After defining the reactor geometry and conditions, the HPEM calculates the electromagnetic fields in the EMM. When these fields are calculated in every point of the reactor, the electron density, energy and electron impact reaction rates are calculated in the EETM. The FKS uses the electron impact reaction rates as input to calculate plasma species densities, fluxes, source functions and the electrostatic field by solving Poisson’s equation. This electrostatic field is used again as input in the EMM to calculate new electromagnetic fields. The plasma species and reactions that are included in the model are listed in table 1.

Results and discussion

Typical results of the model include the potential and electric field distribution in the plasma, density profiles, fluxes and energies of the plasma species and information on their collision processes and chemical reactions. These results will be presented for a wide range of parameters such as wall temperature, substrate temperature, substrate bias, gas mixture, power deposition, pressure and gasflow. A few results are illustrated below.

Conclusions

The model calculations permit us to predict the best plasma conditions for etching purposes.

References

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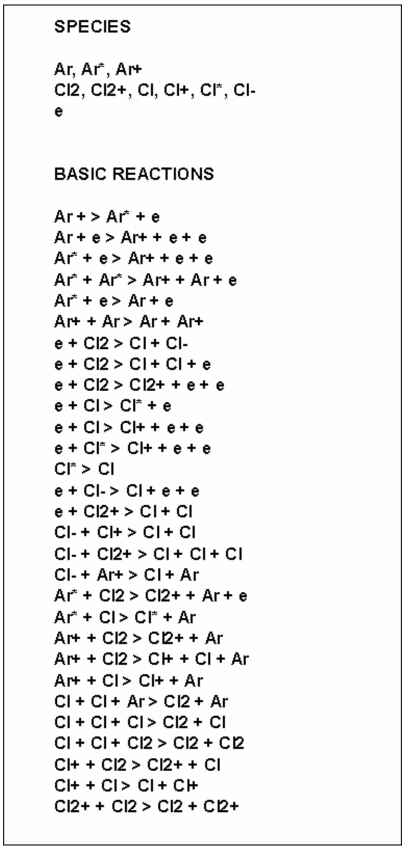
Preliminary results

The predefined reactor geometry is shown in fig. 1. The electron density in the plasma (fig. 2) and the Ar^+ flux to the wafer (fig. 3) were calculated for a substrate bias of 75 V, 110 sccm gasflow, 80% Ar 20% Cl_2 gas mixture, 40 mTorr and coil frequency of 13.56 MHz.

Table 1. Species and reactions included in the model.



SPECIES

Ar, Ar*, Ar+
Cl2, Cl2+, Cl, Cl+, Cl*, Cl-
e

BASIC REACTIONS

Ar + > Ar* + e
Ar + e > Ar+ + e + e
Ar* + e > Ar+ + e + e
Ar* + Ar* > Ar+ + Ar + e
Ar* + e > Ar + e
Ar+ + Ar > Ar + Ar+
e + Cl2 > Cl + Cl-
e + Cl2 > Cl + Cl + e
e + Cl2 > Cl2+ + e + e
e + Cl > Cl* + e
e + Cl > Cl+ + e + e
e + Cl* > Cl+ + e + e
Cl* > Cl
e + Cl- > Cl + e + e
e + Cl2+ > Cl + Cl
Cl- + Cl+ > Cl + Cl
Cl- + Cl2+ > Cl + Cl + Cl
Cl- + Ar+ > Cl + Ar
Ar* + Cl2 > Cl2+ + Ar + e
Ar* + Cl > Cl* + Ar
Ar+ + Cl2 > Cl2+ + Ar
Ar+ + Cl2 > Cl+ + Cl + Ar
Ar+ + Cl > Cl+ + Ar
Cl + Cl + Ar > Cl2 + Ar
Cl + Cl + Cl > Cl2 + Cl
Cl + Cl + Cl2 > Cl2 + Cl2
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Cl+ + Cl > Cl + Cl+
Cl2+ + Cl2 > Cl2 + Cl2+

Fig. 1. 2D reactor geometry.

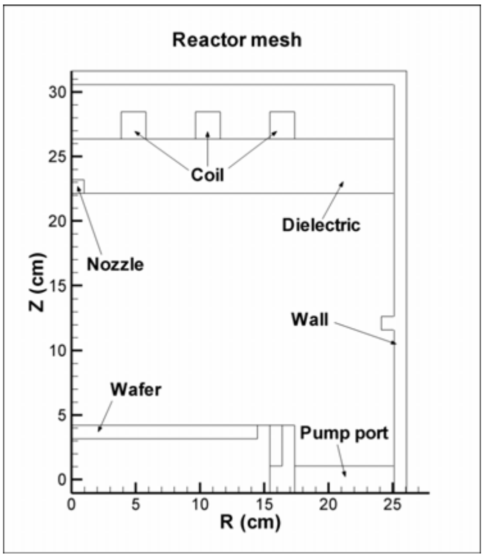

Fig. 2. Calculated electron density in the plasma.

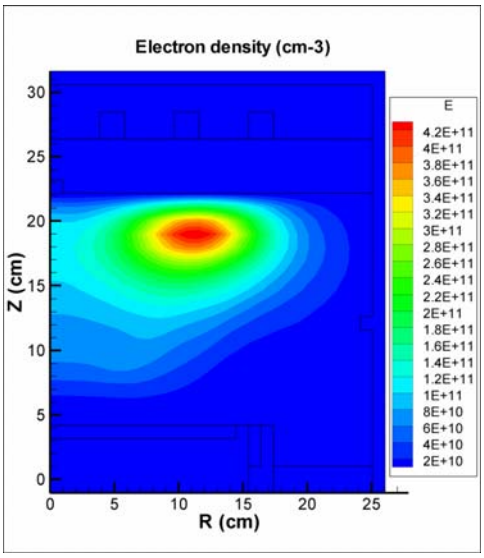

Fig. 3. Calculated Ar^+ flux to the wafer.