Topic number: 4.

Modeling Ar/Cl_2/O_2 and Ar/SiH_4/O_2 Inductively Coupled Plasmas used for anisotropic etching of silicon and deposition of SiO_x

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The etching behavior of a Cl_2/O_2/Ar inductively coupled plasma (ICP) on a *p*-Si substrate, as used in Shallow Trench Isolation (STI) is investigated through simulations in comparison with experimental results. A similar simulation method is reported for investigating Ar/SiH_4/O_2 ICPs applied for SiO_x deposition in the silicon trenches for the production of electronic devices.

The model that is applied is the hybrid plasma equipment model (HPEM), developed by Kushner *et al* [1]. This model for ICP reactors is 2D (cylindrically symmetric) and consists of an electromagnetics module (EMM), an electron energy 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 as a function of space in 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 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 until convergence. Two additional Monte Carlo simulations are performed to predict the fluxes, angles and energy of the plasma species bombarding the *p*-Si substrate, and the resulting surface processes such as etching and deposition.

Typical results of the model include the potential and electric field distribution in the plasma, density profiles, fluxes and energies of the plasma species as well as information on the substrate level such as etching and deposition rates. The influence of the gas fractions on the properties of the plasma and the plasma etching or deposition process will be discussed. Fig. 1 shows half cross sections of the cylindrically symmetric reactors used in the general plasma calculation of the model for the etching of silicon (left) and for the deposition of SiO_x (right).

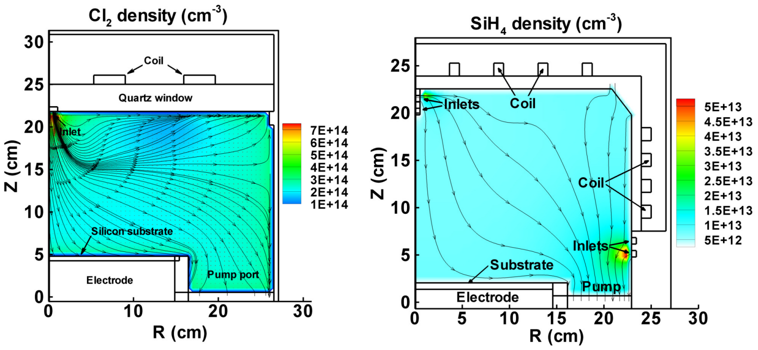

Fig. 1: 2D geometry of the ICP reactors used for etching of Si (left) and for SiO_x deposition (right). The density profiles of the precursor gases (Cl_2, left) and SiH_4 (right), as well as the gas flow lines, are plotted.

Fig. 2 (left) shows a calculated silicon trench profile after etching. Fig. 2 (right) shows the calculated and measured etch rate as a function of oxygen fraction in the $Cl_2/O_2/Ar$ gas mixture. If the oxygen fraction exceeds a certain threshold value, formation of SiO_x surface layers becomes dominant and the etch rate is drastically reduced [3]. This is due to the fact that silicon can be chemically etched by chlorine, while SiO_x products cannot. Therefore, a small fraction of oxygen is typically added to the chlorine based plasma to protect the sidewalls of the trench from lateral etching. However, if this fraction becomes too high, chemical etching becomes negligible, reducing the etch rate significantly. In the transition region where the etch rate drops abruptly, a rough surface with local oxide islands is formed, making it difficult to measure the overall etch rate. These experimental results are in good agremeent with the calculated surface processes.

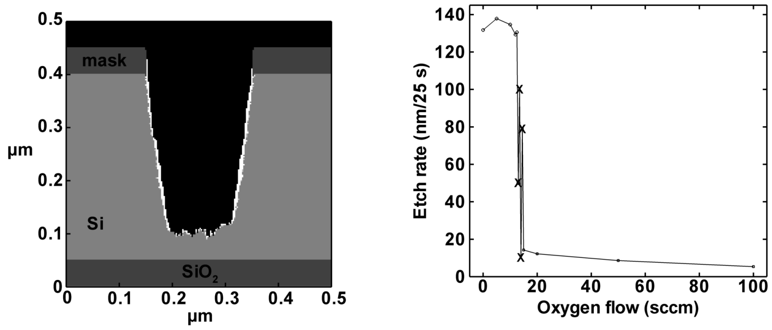

Fig. 2: (Left) calculated trench profile after $Cl_2/O_2/Ar$ exposure. The white material is deposited SiO_x. (Right) calculated and measured etch rate as a function of oxygen fraction.

$SiH_4/O_2/Ar$ inductively coupled plasmas are applied to deposit SiO_xH_y products onto the substrate (and into the trenches). O_2 is added to oxidise the deposited silicon species. During this deposition process, a bias is applied to allow sputtering of the surface for an efficient trench filling process without undesirable side effects such as void formation. This surface process is investigated under different operating conditions by means of modelling.

Reference

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