

Conceptual Design of Advanced Inductively Coupled Plasma Etching Tools Using Computer Modeling

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Abstract—Inductively coupled plasma (ICP) reactors for semiconductor etching are attractive in that the location of plasma generation and the plasma density can be controlled by placement of the inductive coils. This feature has been used to perform a conceptual design of an ICP etching tool having two plasma sources which provide additional control over the magnitude and composition of the reactive fluxes to the wafer. Images of plasma properties in the reactor are presented.

INDUCTIVELY coupled plasmas (ICP) are being developed for etching of dielectrics and metals for semiconductor microelectronics fabrication [1]. ICP reactors operate at low gas pressures (<10 – 20 mtorr) and high plasma densities (10^{11} – 10^{12} cm^{-3}). The inductive electric field is generated by solenoidal or spiral coils while a separate radio frequency bias is applied to the substrate to accelerate ions anisotropically into the wafer. This arrangement allows the magnitude of the ion flux and energy to the wafer to be independently controlled. However, the composition of the radical and ion fluxes in conventional ICP reactors can only easily be controlled by choice of the feedstock gases or gas flow rate. In this paper, we present images generated with a plasma equipment computer model of a conceptual design for an ICP etching tool, which has two separately powered plasma zones, for 300-mm wafers. This design provides additional control of the composition of the radical and ion fluxes to the wafer by isolating regions of radical or ion production.

The model used here, called the hybrid plasma equipment model (HPEM) is similar to that described in [2]. The HPEM is two-dimensional (2-D) (r, z) cylindrically symmetric simulation. It is composed of a series of linked modules which are iterated to a converged solution. The modules used here are: 1) electromagnetics (propagation and power absorption), 2) electron kinetics (Monte Carlo simulation which generates electron transport and source functions), and 3) fluid-kinetics (solves for all neutral and charged particle densities, and Poisson's equation for the electric potential). We investigated p -Si etching using an $\text{Ar}/\text{Cl}_2/\text{BCl}_3 = 1/1/1$ gas mixture at a pressure of 10 mtorr. The species included in the simulation are Ar , Ar^* , Ar^+ , Cl_2 , Cl_2^+ , Cl , Cl^* , Cl^+ , Cl^- , BCl_3 , BCl_2 , BCl_3^+ , BCl_2^+ , SiCl_2 , SiCl , SiCl_2^+ , and SiCl^+ .

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The raw data for the images were generated by the HPEM on a Digital Equipment Corporation (DEC) Alphastation 200 4/233 workstation. The data were postprocessed on a DEC VAXstation 3000/95 using a menu-driven monochrome graphics program (INTER_ICP) based on the Visual Numerics DI3000 library of graphics primitives. INTER_ICP generates x - y line, contour, and vector plots, equipment schematics, and HDF files (a standard graphical exchange protocol). The HDF files and line/contour/vector plots were transferred to an Apple Centris 650 microcomputer where Spyglass Transform v2.11 was used to generate color intensity plots from the HDF files. The line/contour/vector and color intensity plots were combined in CA-Cricket Draw III v1.0.

The ICP etching reactor, shown schematically in Fig. 1(a), uses two sets of independently powered coils. Solenoidal coils surround the upper plasma zone and gas inlet. A flat spiral coil sets on top of a dielectric window for the lower plasma zone. Ar/Cl_2 (120 sccm) flows through the top inlet port. BCl_3 (60 sccm) is injected through circular metal nozzles in the lower plasma zone. Ions which are produced in the upper zone are largely confined to that region by large diffusion losses to the walls. Radicals produced in the upper zone, however, flow to the lower chamber due to low loss rates to the walls. The only significant flux of ions which strike the wafer is produced in the lower plasma zone by the spiral coil. The composition of these ions can be controlled by selection of the injected gases.

The 13.56-MHz azimuthal inductively coupled electric field (color background) and power deposition (contours) are shown in Fig. 1(a). A metal support structure between the dielectric inlet tube and flat window prevents the electric field from penetrating into the chamber, thereby producing two distinct power deposition regions. The electric field and power deposition in the lower plasma zone are limited by the metal nozzle. The total ion density (negative and positive) is shown by the color background in Fig. 1(b). The maximum ion density (8.5×10^{11} cm^{-3} including 3×10^{11} cm^{-3} of Cl^-) occurs in the upper zone. The Cl^+ and Cl_2^+ ions (left panel) are largely limited to the upper plasma zone with a small leakage to the lower zone. The Cl_2 is largely dissociated in the upper plasma zone, thereby reducing the production of Cl_2^+ in the lower plasma zone. BCl_2^+ and BCl_3^+ ions (right panel) are produced in and largely restricted to the lower plasma zone. BCl_n^+ constitute the major flux of ions to the substrate. Etching is primarily by Cl atoms (Fig. 1(c), left panel) which are dominantly produced in the upper zone and flow to the lower chamber (see flux vectors). The etch product (SiCl_2) is generated from the wafer and dissociated to form SiCl (right

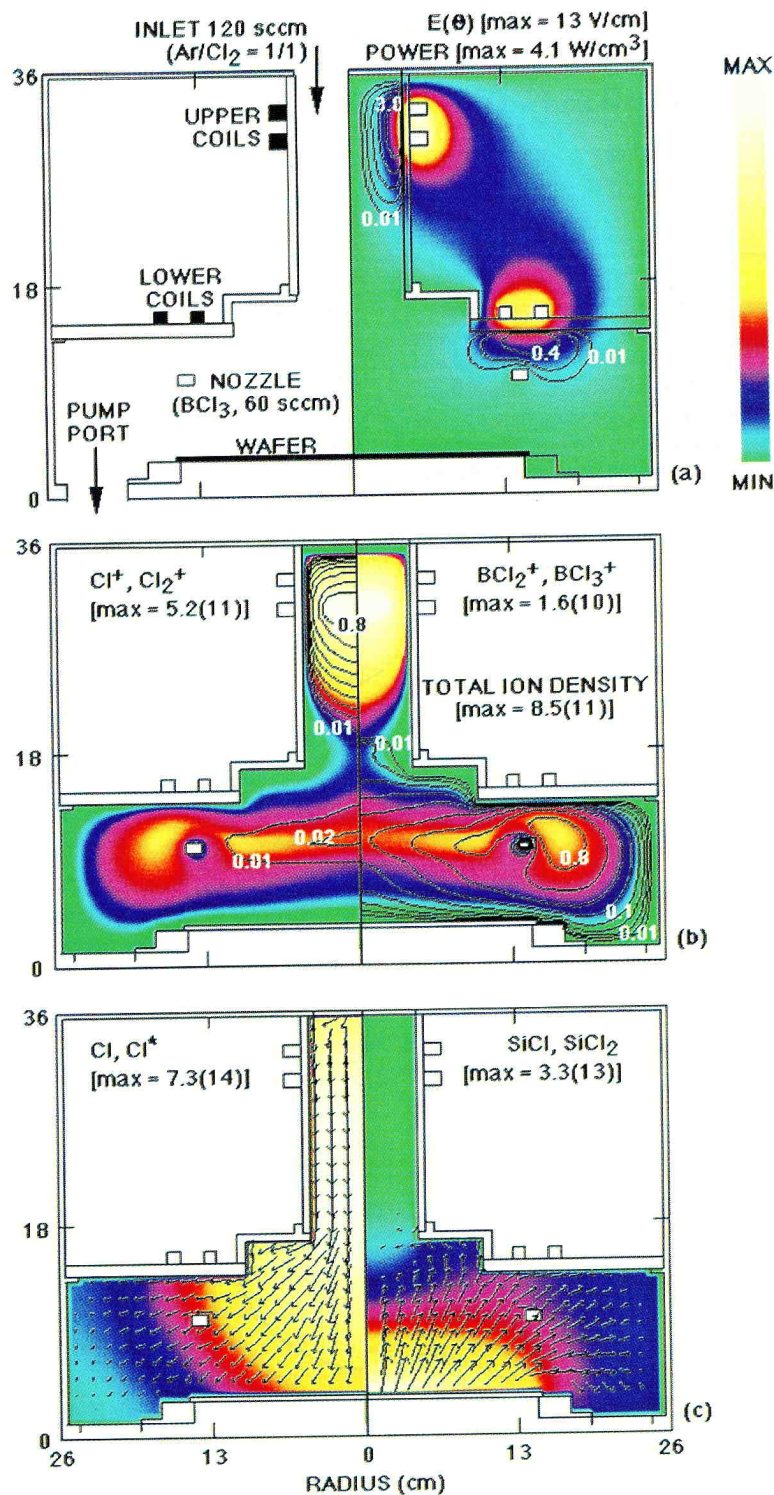


Fig. 1. Plasma characteristics for a dual plasma zone ICP etching tool. The maximum values of the variables are shown at the top of each figure (densities have units of cm^{-3}). Contours are labeled by their fraction of the maximum value. (a) Schematic of the reactor, electric field (color background), and power deposition (contours). (b) Total ion density (2.5-decade range, color background), and Cl_n^+ and BCl_n^+ densities (contours). (c) Densities (color background) and flux vectors for Cl (two-decade range) and SiCl_n .

panel). Both SiCl_n species are largely restricted to the lower plasma zone.

In conclusion, images of a conceptual design for a dual-zone ICP etching tool have been presented. This configuration provides additional control over the magnitude and composition of reactant fluxes which are incident onto the wafer.

REFERENCES

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