

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

John J. Smith and Anita J. Jones

**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 ( $< 10\text{-}20$  mTorr) and high plasma densities ( $10^{11}\text{-}10^{12}$   $\text{cm}^{-3}$ ). 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 be easily 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 for 300 mm wafers which has two separately powered plasma zones. 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 Ref. 2. The HPEM is 2-dimensional (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: a) electromagnetics (propagation and power absorption), b) electron kinetics (Monte Carlo simulation which generates electron transport and source functions), and c) 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  $\text{Ar}$ ,  $\text{Ar}^*$ ,  $\text{Ar}^+$ ,  $\text{Cl}_2$ ,  $\text{Cl}_2^+$ ,  $\text{Cl}$ ,  $\text{Cl}^*$ ,  $\text{Cl}^+$ ,  $\text{Cl}^-$ ,  $\text{BCl}_3$ ,  $\text{BCl}_2$ ,  $\text{BCl}_3^+$ ,  $\text{BCl}_2^+$ ,  $\text{SiCl}_2$ ,  $\text{SiCl}$ ,  $\text{SiCl}_2^+$ , and  $\text{SiCl}^+$ . The raw data for the images was generated by the HPEM and post-processed using the Visual Numerics DI3000 library of graphics primitives. The final images were composed using Spyglass Transform.

The ICP etching reactor, shown schematically in Fig. 1a, 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.  $\text{Ar}/\text{Cl}_2$  (120 sccm) flows through the top inlet port.  $\text{BCl}_3$  (60 sccm) is injected through circular metal nozzles in the lower plasma zone. Ions which are produce 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 are produced in the lower plasma zone by the spiral coil. The composition of these ions can be controlled selection of the injected gases. The 13.56 MHz azimuthal inductively coupled electric field (color background) and power deposition (contours) are shown in Fig. 1a. 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.

## REFERENCES

- [1] J. Hopwood, "Review of inductively coupled plasmas for plasma processing", *Plasma Sources Sci. Technol.* 1, 109-116 (1992)
- [2] P. L. G. Ventzek, M. Grapperhaus and M. J. Kushner, "Investigation of Electron Source and Ion Flux Uniformity", *J. Vac. Science Tech. B* 12, 3118-3137 (1994).

Manuscript received 1 December 2013; revised 1 February 2014.

J. Smith and A. Jones with the University of Illinois, Department of Electrical and Computer Engineering, 1406 W. Green St., Urbana, IL 61801  
Work was supported by the Semiconductor Research Corporation.

Publisher Identifier S XXXX-XXXXXXX-X



FIGURE

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  $\text{cm}^{-3}$ ). Contours are labeled by their fraction of the maximum value.