In Situ Monitoring of Ion Bombardment Energies in Plasma Etchers for Improved Wafer Yield and Throughput

During plasma etching processes used by the semiconductor industry, silicon wafers are bombarded by reactive chemical species and energetic ions, resulting in selective removal of material from exposed areas of the wafer. The energy of ions striking the wafer surface plays an important role in determining the etching rate, the profile of etched features, and the extent of plasma-induced damage. To obtain the best results, the kinetic energy of ions must be controlled and optimized. Unfortunately, control of ion energy in industrial reactors is difficult because of the lack of reliable methods for in situ monitoring. Traditional methods for measuring ion energy are incompatible with industrial reactors because they require that an ion energy analyzer be inserted into the plasma. A typical analyzer will not survive very long when exposed to industrial plasmas, and it may cause contamination of the wafers being processed. The goal of this work is to develop non-intrusive monitoring techniques for ion energy distributions in semiconductor manufacturing tools.

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A method for *noninvasive* monitoring of ion kinetic energy has been developed and demonstrated at NIST. Instead of inserting an analyzer into the reactor, it relies on measurements of the applied radio-frequency current and voltage, which are easily measured outside the reactor without perturbing the plasma or the process. These measurements are analyzed using electrical models of the plasma to determine the ion flux and ion energy distribution at the wafer surface.

Recently, this monitoring technique has been validated with a silicon wafer loaded in the reactor, under realistic plasma etching conditions. Under certain conditions, the wafer (or the contact between the wafer and its chuck) contributes significant electrical impedance. The effects of this impedance on the electrical signals and on the ion energy distributions have been characterized by measurements and models. The uncertainty in the noninvasive monitoring technique caused by wafer impedance has been quantified and shown to be small, over the range of conditions that are typically used in etching. The technique has been used to monitor ion energies during plasma etching of silicon dioxide films and during reactor malfunctions or "faults" in rf power, gas flow, and pressure control.

The noninvasive monitoring technique shows promise for use in automatic process control, allowing constant ion energies to be maintained during processing, despite reactor drifts or faults.

It could also help to increase the speed and decrease the cost of developing new plasma processes. The technique has attracted the attention of the major semiconductor processing equipment makers, both in the US and abroad. A CRADA has been initiated with Advanced Energy Industries, Inc. to demonstrate and evaluate the noninvasive monitoring technique in an industrial plasma reactor.

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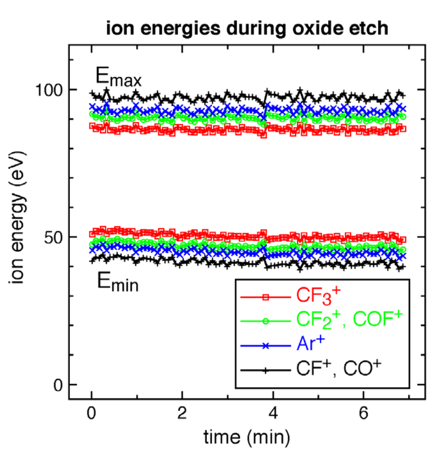

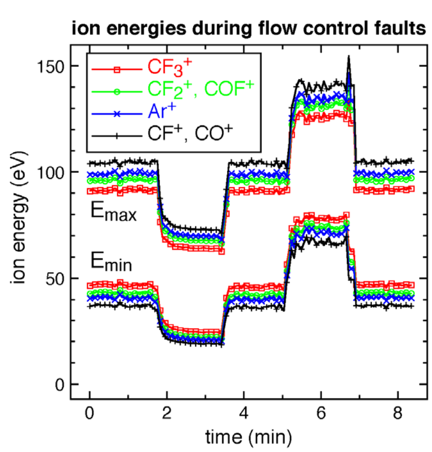

Energies of the most energetic (E_{max}) and least energetic (E_{min}) ions striking the surface of a silicon wafer, as determined by the noninvasive monitoring technique, during a normal oxide etch (left) and during mass flow controller malfunctions (right).