Microwave ECR Plasma Electron Flood for Low Pressure Wafer Charge Neutralization

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Abstract. Modern ion implanters typically use dc arc discharge Plasma Electron Floods (PEFs) to neutralize wafer charge. The arc discharge requires using at least some refractory metal hardware, e.g. a thermionically emitting filament, which can be undesirable in applications where no metallic contamination is critical. rf discharge PEFs have been proposed to mitigate contamination risks but the gas flows required can result in high process chamber pressures. Axcelis has developed a microwave electron cyclotron resonance (ECR) PEF to provide refractory metals contamination-free wafer neutralization with low gas flow requirement. Our PEF uses a custom, reentrant cusp magnet field providing ECR and superior electron confinement. Stable PEF operation with extraction slits sized for 300 mm wafers can be attained at Xe gas flows lower than 0.2 sccm. Electron extraction currents can be as high as 20 mA at absorbed microwave powers < 70 W. On Axcelis' new medium current implanter, plasma generation has proven robust against pressure transients caused by, for example, photoresist outgassing by high power ion beams. Charge monitor and floating potential measurements along the wafer surface corroborate adequate wafer charge neutralization for low energy, high current ion beams.

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INTRODUCTION

During the ion implantation process charge neutralization is employed to prevent insulating structures on grounded wafers from floating to uncontrolled voltages. This charge neutralization is brought about by ensuring that any point on the wafer sees net zero current, comprised of positive and negative charges. A good charge neutralization device thus supplies an electron current that cancels the positive ion current of the ion beam.

While earlier ion implanters relied on various types of electron sources for charge neutralization [1] most modern implanters use Plasma Electron Floods (PEFs). PEFs are usually dc discharge plasma sources, where a relatively high density discharge is initiated by electron emission from a heated filament. Using refractory metal filaments prolongs the PEF lifetime; in applications where no metallic contamination is critical, however, the use of a metal at thermionic emission temperature in close proximity to the wafer can be risky. Radio frequency (rf) discharge PEFs have been proposed to mitigate these contamination risks and to provide charge neutralization for ribbon and scanned spot beam implanters [2,3]. While rf PEFs appear promising the gas flows required, typically in the multiple sccm range, can result in high process chamber pressures, undesirable since they promote charge-exchange processes and can cause dosimetry challenges.

Microwave discharges do not use filaments or electrodes and electron cyclotron resonance (ECR) microwave sources in particular can generate high density plasmas at very low pressure. These characteristics make them excellent candidates for PEFs with superior charge neutralization performance for ion implanters.

ECR MICROWAVE SOURCES

Plasma generation by ECR is well established. In ECR electron energy absorption of microwave radiation is resonant with the electron gyromotion in a magnetic field [4]. Early ECR plasma generation was performed using a magnetic mirror geometry, where the magnetic field was produced by a pair of current carrying coils (electromagnets), or using substantially uniform magnetic field geometries such as solenoids and magnetic mirrors, realized by either conventional or superconducting electromagnets. These techniques were later adapted for use in materials processing such as deposition and semiconductor wafer etching; for a review, see, for example, [5].

Alternatively, ECR plasma development used for ion beam space propulsion application generated ECR plasmas in magnetic fields generated by permanent magnets. From its inception, such ECR systems utilized multicusp magnetic field configurations, wherein an array of alternating polarity permanent magnets line the walls of the ion source except for the region where the ion beam is extracted. This multicusp geometry has the desirable characteristics of producing a relatively large (>2 kG) magnetic field at the walls for plasma confinement and a relatively small (<100 G) magnetic field in the extraction area. For ion implanters such geometry is favorable since it permits unimpeded flow of electrons from the PEF to the ion beam and wafer.

Our PEF

In Axcelis' microwave PEF we employ a novel magnetic field geometry suited to the special requirements for charge neutralization in an ion implanter. We use a resonant chamber with exterior permanent magnets lining the length of the chamber creating ECR zones within the cavity of the chamber; details of the cusp field geometry are described in [6]. This configuration results in a static magnetic field having a high magnetic field strength, typically 2 - 4 kG, near the bottom of the cavity and a low magnetic field strength near the top of the PEF comprising an extraction aperture facing the ion beam.
Standing waves within the resonant chamber generate high electric fields, electrons are energized by the resonant fields, and collisions with neutral atoms from a PEF feed gas create a discharge. The trapping of electrons within ECR zones prolongs their residence time in the discharge with enables high densities are very low chamber pressures. With the location of the plasma chamber exit aperture directly below a wide ribbon or scanned spot ion beam, low-energy electrons from the plasma are extracted by the ribbon-beam potential.

Figure 2 shows an illustration of the microwave generator and delivery system. It consists of a magnetron head, WR-284 waveguide components such as an isolator, a microwave-tuned vacuum window, an electrically isolated flange, E and H-bends, and an RF matching aperture to the water-cooled resonant cavity. An easily ionizable, inert gas such as ^{132}Xe is delivered via an opening on the far side of the resonant cavity while microwave energy is delivered on the near side of the same cavity. The internal assembly is electrically isolated from the implanter's process chamber to permit measurement of extracted current as well as an optional variable bias for enhanced electron extraction into the beam.

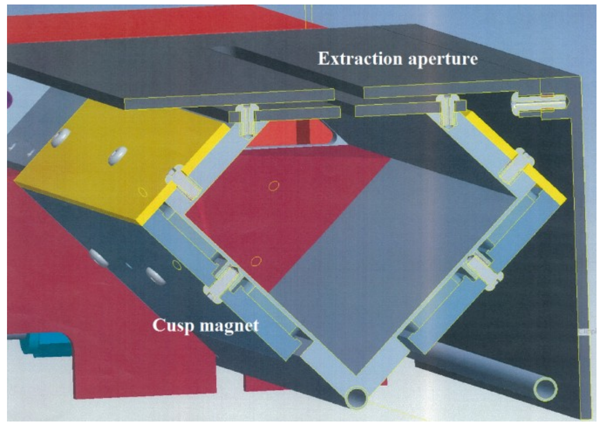

FIGURE 1. Cross-section of main PEF chamber housing the ECR discharge. Cusp magnet arrays line the lower walls of the chamber, and the whole assembly is water-cooled. PEF plasma is extracted through an extraction slit the width of the scanned beam.

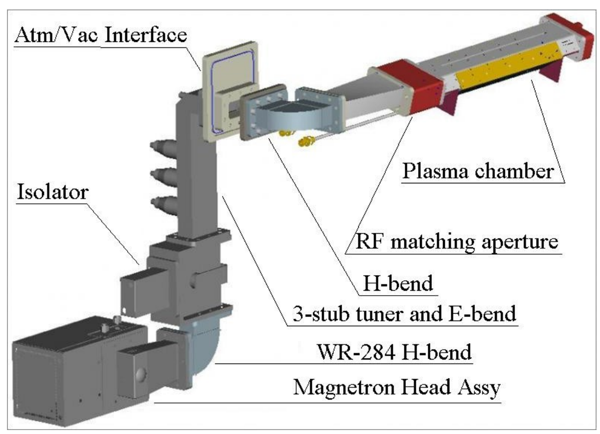

FIGURE 2. Components of the microwave plasma system

Gas flows as low as 0.15 sccm of Xe have been found to be sufficient to maintain a plasma within the resonant chamber, and 100 Watts to 200 Watts of microwave power out of the magnetron are sufficient for ignition. On our new medium current implanter, the Purion M, a flow rate of 1 sccm raises the measured chamber pressure from a base pressure of $3 \cdot 10^{-7}$ Torr to $4 \cdot 10^{-6}$ Torr; since the sensitivity of cold cathode ion gauges is calibrated with N_2, the partial pressure of Xe should be ~$1.2 \cdot 10^{-6}$ Torr per sccm of flow. A combination of power settings and gas flow are individually determined based on the implant recipe parameters. During operation a transient increase of gas pressure, such as caused by photoresist outgassing during an implant, does not perturb the discharge, presumably because it is mainly driven by the partial pressure of the Xe PEF gas.

CHARACTERIZATION DATA

PEF Extraction Data

To quantify PEF performance we measure the current leaving the extraction slit for varying PEF chamber bias with respect to the process chamber. This measurement is not directly indicative of the PEF's capability of delivering charge neutralization by providing electron current to a wafer in process, but rather a measure of plasma density achieved within the PEF as well as the efficiency of the extraction geometry.

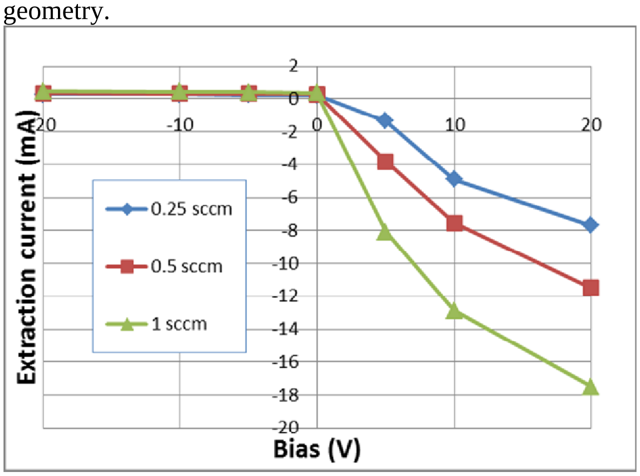

FIGURE 3. Current extracted from the PEF extraction slit by biasing the chamber. PEF power ~ 30 W.

For positive bias the extracted current is mostly ion current, low due to the high ion mass. For low negative biases the extracted current is space-charge limited electron current and approaches a density limited electron current at higher voltages. Assuming an electron temperature T_e of a few eV in the magnetic field-free extraction region, typically observed in PEFs [7], the plasma potential in the extraction region should be of the order of $5T_e$ ~ 20 V [5], and the density limited current indicates a chamber plasma density of ~$5 \times 10^{10}/cm^3$ at 0.25 sccm.

Biased Wafer Measurements

By isolating the grounding pins of the chuck in the process chamber of the Purion M we are able to bias an Aluminum plate in place of the wafer and measure the current drawn from the PEF to the plate. This measurement is performed with and without ion beam.

Without ion beam the transmission from PEF extraction to biased plate is excellent, indicating the low magnetic fields at the extraction region and adequate placement of the PEF within the process chamber.

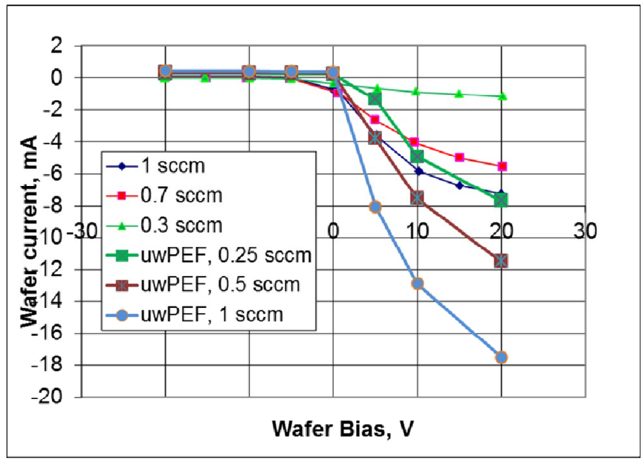

FIGURE 4. Net current to a biased wafer, no ion beam. For comparison, current drawn from a standard dc PEF (Xe-PEF, standard offering on Axcelis' Optima MD implanters, labeled std) is shown. Current delivered by our microwave PEF is labeled uwPEF.

When mimicking implant conditions by sending a low energy, relatively high current ion beam (5 keV, 2 mA ^{11}B) to the plate and biasing the plate we can also estimate the potential a truly floating structure on a wafer could attain. For varying gas flow, fixed power the "floating potentials" are of the order of a few Volts. It should be noted that under real implant conditions our ion beam would be scanned across a wafer, lowering the average beam current and shortening the dwell time on each point on the wafer, such that the floating potentials would be even lower. But even under these severe conditions, low energy beam "parked" on a wafer, the floating potential at 0.5 sccm is <2.5 V.

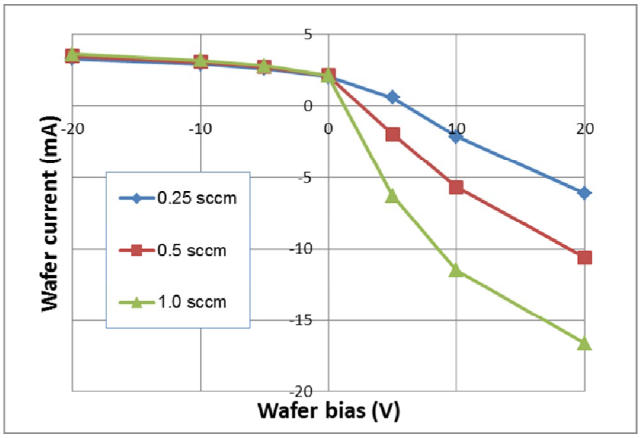

FIGURE 5. Net current to a biased wafer with unscanned ion beam, B 5 kV 2 mA, on the wafer . At a few Volts bias the net current to the wafer is zero. PEF power 30 W.

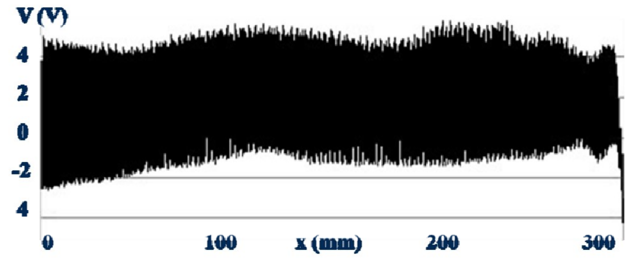

FIGURE 6. Charge monitor profile for a 10 keV, 2 mA Argon beam scanned at 100 Hz. PEF flow 0.3 sccm, power 50 W.

Charge Monitor Data

Rather than biasing a whole wafer we can also measure the potential of a floating probe in the wafer plane. One advantage of this measurement is the availability of spatial distribution of potentials in the wafer plane, rather than the integral measurement a biased plate provides. The probe is an electrically isolated graphite cylinder with 5 mm diameter mounted on our beam profiling mechanism, and can be swept across the scanned spot beam width. This method provides a "floating potential profile" and can be used to evaluate the uniformity as well as highest and lowest floating potentials during beam scan.

Figure 6 shows a typical charge monitor profile for a 10 keV Ar, 2 mA beam scanned at 100 Hz cross the wafer plane. The profile consists of a train of fast floating voltage pulses, where the probe voltage is low when the beam is not impacting the probe (Figure 4) and higher when the beam hits the probe (Figure 5). Charge monitor data is collected during a single profiling pass for ~ 4 s, so the number of ion beam passes across the probe is ~800. In this exemplary case the floating potentials swing from an absolute maximum of ~+3 V to a minimum of ~ -1 V, with good uniformity across the profile, demonstrating uniformity of PEF extraction.

SUMMARY

We have presented a novel ECR microwave plasma electron source suited for the needs of modern ion implanters: no contamination by refractory metals, uniform charge neutralization across the width of a wafer and low floating potentials at Xe gas flows as low as 0.25 sccm for low energy, high current beams.

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