Generation and decay of SiCl radicals in a pulsed inductively coupled plasma with a pulsed bias voltage

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Abstract: In this contribution, we report the generation and decay of SiCl radicals in a pulsed inductively coupled microelectronics processing plasma operated with a pulsed bias voltage. The etch by-product SiCl radicals were detected using laser-induced fluorescence. SiCl radicals were found to increase in density slower than their decay in the afterglow. The decay of the SiCl radicals is dominated by the gas-phase reactions and the wall losses.

1. Introduction

It is essential to ensure that the etch profile of the smallest and largest features exhibits a similar sidewall profile. Pulsed plasmas have been shown to provide better control over the etch wall profile in the processing of microelectronics [1], with the duty cycle being an important control knob. It is currently unclear which of the etch by-products such as Si, SiCl and $SiCl_2$ get redeposited on the feature walls and result in the non-uniform loading of the etch profile. It is essential to understand how these species are produced and destroyed in a processing reactor.

In this work, we used laser-induced fluorescence (LIF) to study the generation and decay of SiCl radicals in a pulsed inductively coupled plasma.

2. Methods

An Applied Materials Inc. etch reactor was used in this work. In this reactor, the ionization and dissociation were controlled by an inductively coupled radiofrequency (RF) coil on the top electrode, whereas the ion energy towards the substrate was generated by establishing a pulsed voltage (PV) waveform at the embedded bottom electrode separated from the substrate by a thin dielectric layer. Both the RF (source) and pulsed (bias) powers were applied as synchronized trains of bursts to etch a bare silicon wafer. The plasma was produced using Ar + 50% Cl_2 gas mixture, 15 mTorr pressure, 1 kW RF power, and 800 V substrate bias voltage. The etch by-product SiCl was detected using laser-induced fluorescence (LIF) [2,3]. A ns pulsed OPO laser set to 286.5 nm excited the $B^2\Sigma^+$ state of SiCl. An iCCD camera collected fluorescence through a bandpass filter (300 nm, 10 nm FWHM). The fluorescence spectrum was measured using a 75 cm length spectrometer. Time-resolved generation and decay of SiCl radicals 2 cm above the wafer at specified time points was monitored by LIF.

3. Results and Discussion

Figure 1 shows the envelope of the applied power. Between 0-3 ms, a synchronous RF and PV was applied. Afterglow starts at 3 ms when all power was turned off. The figure shows the time evolution of plasma emission, generation, and decay of SiCl radicals. The emission builds up during the plasma-on phase and saturates towards the end of the on-phase. It drops immediately in the afterglow due to a quick drop in T_e. SiCl radicals are produced by the electron impact dissociation of etch by-products $SiCl_{2-4}$ being released from the wafer [4]. Hence, SiCl radicals are produced with a delay compared to the emission signal. SiCl radicals decay faster in the afterglow compared to their generation in the plasma-on phase. The slower generation timescale is due to competing processes of SiCl generation from $SiCl_{2-4}$ and its removal from the observation volume by particle motion and gas-phase reactions. In turn, a much faster than a few-hundred-millisecond decay timescale (from gas residence time estimation using mass flow rate) suggests a decay dominated by gas-phase reactions and wall losses as opposed to removal by the vacuum pump.

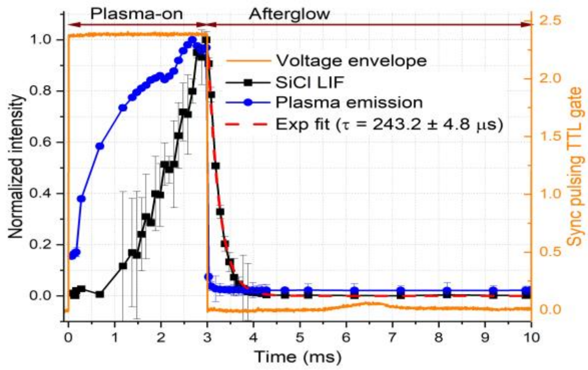

Fig. 1. Optical emission and SiCl radical evolution as a function of time during a 100 Hz, 30% duty cycle, 13.7 MHz, 800 V pulsed bias, 15 mTorr, Ar-Cl_2 ICP plasma.

4. Conclusion

The generation rate of SiCl radicals is slower than their afterglow decay. Gas-phase reaction and wall losses dominate the decay rather than vacuum pump removal. SiCl radicals decay timescale suggests that redeposition on etched walls is likely not due to deposition of SiCl radicals.

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References

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