Oxygen radical density enhancement in radio-frequency plasmas via microwave-excited plasma gas activation

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Abstract: A microwave-excited plasma gas activator driven by a microwave resonant electrode effectively activates argon-oxygen gases before injection into a radio-frequency capacitively coupled plasma (RF CCP). Optical emission spectroscopy reveals a two-times increase in atomic oxygen line intensity under gas activation. Global plasma models qualitatively confirm the enhanced radical transfer and increment of excited oxygen species.

1. Introduction

Plasma-based processes play a critical role in advanced semiconductor manufacturing, where the precise control of radical species is essential for surface treatment and etching. This research aims to enhance oxygen radical density in RF plasmas using a plasma gas activator system. The motivation for this study stems from the need to improve oxygen radical generation and delivery, especially for applications in plasma-enhanced chemical vapor deposition (PECVD) and etching processes. In this study, a microwave resonant electrode-based plasma gas activator system has been developed for efficient radical generation. Simulation models have corroborated the performance of the plasma gas activator to predict radical transport and density from the microwave-excited plasma to an RF CCP chamber.

2. Methods

The microwave-excited plasma gas activator system uses a 2.45 GHz microwave resonant electrode [1] to pre-treatment the oxygen and generate excited oxygen species. The electrode structure allows optimal power transfer, achieving a reflection coefficient of -28.1 dB at 2.449 GHz. This system is connected to a low-pressure RF CCP chamber using a 4-way cross vacuum component. The optical emission spectroscopy (OES) is used to monitor intensities of the atomic oxygen lines from O $3p^5P$ to $O3s^5S^0$ and from O $3p^3P$ to $O3s^3S^0$, respectively (777.4, 884.0 nm) at the RF CCP as a measure of the effect of plasma gas activation.

3. Results and Discussion

Figure 1 compares the experimentally measured atomic oxygen emission intensities at 1% and 3% oxygen partial pressures, normalized against the initial emission signal before microwave power delivery (2–8 W). An atomic oxygen emission increment indicates that emission intensity scales with atomic oxygen density, confirming faster radical generation at higher oxygen partial pressures. Global model-based plug-flow simulation [2, 3] shows a 1.5-times increase in excited oxygen species (O^*) for 1% oxygen and a 1.3-times increase for 3% oxygen. Although these modeling results align qualitatively with experiments.

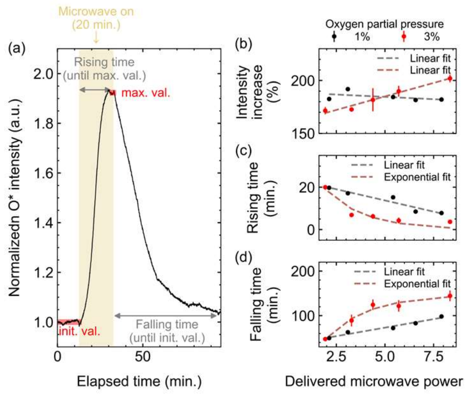

Fig. 1. Characterization of the temporal change of atomic oxygen emission lines at 777.4 and 884.0 nm, depending on the delivered microwave power and oxygen partial pressure (1% and 3%).

4. Conclusion

The study demonstrated the enhancement of oxygen radical density in an RF CCP plasma through microwave-excited plasma gas activation. Plasma global simulation results qualitatively confirmed increased atomic oxygen density by injecting activated gases. The findings contribute to understanding gas activator plasma system design, particularly optimizing radical species density for advanced semiconductor processing. Further refinement of simulation models will enhance the predictive accuracy of radical behavior under varying plasma conditions.

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