Time-resolved optical emission spectroscopy of an inductively coupled Ar-Cl_2 plasma at low-pressure for Atomic Layer Etching

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Abstract: Transient Ar-Cl_2 ALE discharge is studied through optical emission and absorption spectroscopy, coupled with a recently developed Bayesian collisional radiative model. Such measurements and calculations provide a good overview of the time-varying discharge properties, particularly for different substrates exposed to the reactive plasma.

1. Introduction

Atomic layer etching (ALE) is a relatively recent technique allowing an atomic-scale etching. Specifically, this fine etching is achievable via a cyclic process generally consisting of the alternating 2 gases. The first gas is used to modify the surface to etch, while the second one is used to ignite a plasma, inducing ion bombardment for ion-assisted chemical etching. By carefully controlling the ion energy bombarding the surface (i.e. the aim is to achieve the "ALE window"), a self-limiting etching mechanisms appears, enabling removal of only the top layer of the substrate [1]. This ion energy and gas control implies a fine monitoring of the fundamental plasma properties, which can be achieved by purges phases between the gases.

Recently, some works have focused on the transient aspect of those discharges and the corresponding effect on the etching rate, when the plasma remains on during one or both of the purging stages, [2]–[4]. Herein, we use different time-resolved optical spectroscopic methods (actinometry and absorption) coupled with a collisional radiative model to probe the influence of the substrate nature on the transient physical properties of a commercialized inductively-coupled Ar-Cl_2 plasma at low-pressure.

2. Experimental details and results

The reactor is a tabletop plasma etching system commercialized by Plasmionique. The cylindrical chamber is 20.3 cm wide, 16.5 cm high. The discharge is operated in the inductively coupled regime with a power of 160 W with no bias on the plasma-exposed surface. ALE-like conditions are made of 100 s cycle of continuous 0.5 SCCM of either Ar or TRG (a mixture of rare gases, 40% Ne, 20% Ar, 20% Kr, and 20% Xe) with a 50 s pulse of 9.5 SCCM of Cl_2. The rise and fall time of the Cl_2 gas in the plasma chamber are linked to the characteristics of the mass flow meter and pumping system. Over the range of operating conditions investigated, work pressure lies between 0.25 and 10 mTorr, residual pressure is 6E-5 Torr.

Broadband optical emission spectroscopy is used to acquire the intensity of the Cl_2 306 nm band, the Cl 792 nm Cl line, and the Xe 828 nm line; these emission intensities are used in an actinometry technique to calculate the Cl and Cl_2 densities [5]. Ar 1s densities are also probed via absorption spectroscopy, using a tuning laser diode. Finally, Ar 1s densities and Ar 2p-1s line emission intensities are used in a collisional radiative Bayesian model to evaluate the electron temperature, electron density and quenching frequency of Ar 1s states in the highly transient Ar-Cl_2 plasma.

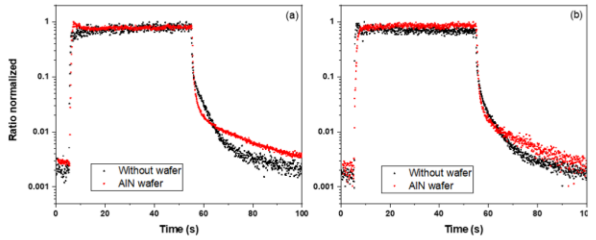

Fig. 1. Evolution of the normalized Cl density (a) and the normalized Cl_2 density in a ALE cycle with and without the presence of an AlN wafer

Figure 1 shows the evolution of Cl (a) and Cl_2 (b) normalized densities as a function of time during a typical ALE cycle, with and without the presence of a 6" AlN wafer placed on the bottom electrode in the chamber. For Cl and Cl_2 densities, the increase is sharp during injection, but the decrease is relatively slow, whether wafer is present or not. The differences between the presence or the non presence of a wafer in the chamber mainly lies in the decay of the Cl and Cl_2 densities. These different decays reveal the impact of the surface on Cl recombination kinetics and therefore on the evolution of Cl and Cl_2 densities. This effect is also visible on the Ar 1s densities and other fundamental plasma properties and will be examined in more details for different wafer materials.

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