FREQUENCY AND ION EFFECTS IN CHLORINE PLASMA ETCHING

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ABSTRACT

The effect of frequency on voltage-current characteristics, emission spectra, etching and the distribution of ions across the sheath of chlorine plasmas at 0.3 torr has been studied in several laboratories. These investigations consistently reveal a dramatic change in plasma properties and etch rates in the 1-10 mHz range.

INTRODUCTION

The effect of frequency on voltage-current characteristics, emission spectra, etching and the distribution of ions across the sheath of chlorine plasmas at 0.3 torr has been studied using a number of techniques. Most of the discharge characteristics, as well as the etch rate, display large changes as power frequency is lowered from the megahertz to kilohertz regimes. The measurements consistently revealed a large increase in the potential across the sheath region with decreasing frequency, and an increase in the energies of ions that bombard the electrodes. Although the high frequency measurements indicate plasma characteristics generally consistent with the usual assumptions, plasmas in the low frequency regime display unexpected behavior.

EXPERIMENTAL

Power from a broad-band amplifier was coupled into Cl_2 plasmas using a pi-network at high frequencies (> 1Mhz) and ferrite balun transformers below 1Mhz. Optical emission from small He and Ar additions were used to sample excitation rates as a function of energy range, in order to determine relative chlorine species concentrations from their excited state emission intensities.

Several anodized aluminum and stainless steel parallel plate reactors ranging from ≈2 cm to 20 cm i.d. were used in these experiments. In one reactor, ions could be extracted through pinholes into a differentially pumped high vacuum chamber. Retarding grids and an in-line mass spectrometer were used to detect the ions and measure their energies. A second reactor was equipped with optical ports for a spacially resolved dye laser fluorescence probe and monochromator detection optics. This apparatus was used to determine the concentration of Cl_2 as a function of frequency and distance from the electrodes. Emission spectra from a third, large reactor could be acquired and analyzed by a computer driven optical multichannel analyzer (OMA). In addition, plasma current and the dynamic (time-resolved) power actually transferred to the plasma were measured in a large number of experiments. The peak average and instantaneous voltages were routinely monitored.

RESULTS AND DISCUSSION

Emission spectra (fig. 1) and mass spectral analysis of ions extracted from the sheath region show a dramatic shift in the ratio of Cl_2^+ to Cl^+ signals as power frequency is lowered from the megahertz to kilohertz regimes. Concurrently, the effective plasma impedance increases dramatically, ion bombardment energies rise, optical emission from Cl^+ intensifies, and there is a large increase in silicon and InP etching rates (fig. 2). Although the etching of polycrystalline silicon in high frequency Cl_2 plasmas is isotropic under these conditions, anisotropic etching is obtained at low frequency. These phenomena indicate an ion enchanced etch mechanism. Spacially-resolved laser fluorescence measurements of Cl_2^+ show that the emission from excited states of this ion does not follow the ground state concentration. However, variations in the time-average Cl_2^+ emission intensity with frequency does track Cl_2^+ concentrations measured by fluorescence.

At low frequency the dynamic power is positive (real) throughout a cycle, although the plasma sheath width increases with decreasing frequency. It follows that the capacitive voltage drop across the sheaths are negligible under these conditions and, hence, ions cross the sheath impact the electrodes, and produce sufficient secondary electrons to provide a large ratio of conduction to displacement current over most of the sheath region. This is also consistent with time and spacially resolved emission spectra from Cl and Cl_2^+ as a function of frequency. These phenomena and their significance for plasma etching will be discussed in more detail.

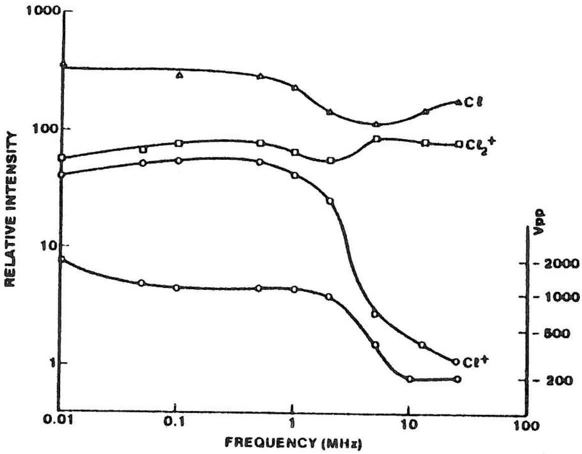

Fig. 1: Normalized emission from Cl, Cl_2^+ and Cl^+ as a function of frequency. Peak-to-peak voltage is also shown in the lower curve.

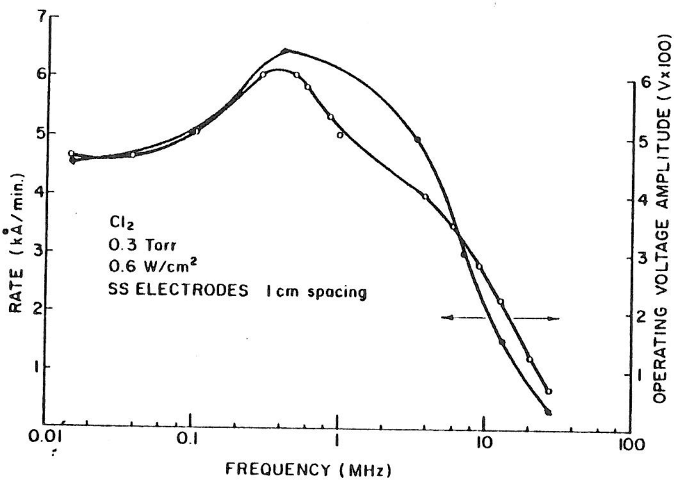

Fig. 2: Silicon etch rate and applied voltage as a function of frequency