

Measuring Ion Energy Distributions by Retarding Field Energy Analyzer and Using Low-Energy Ions for Si-ALE by Cl₂

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Reference

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Introduction

Atomic layer etching (ALE) is an important process for creating nano scale patterns as ALE can remove layers with atomic-scale precision, excellent uniformity, and atomic level surface roughness. However, maintaining a damage free surface is always a concern due to ion induced damage in plasma assisted processes. To address this, Impedans developed a Retarding Field Energy Analyzer (RFEA) to measure ion energy distribution functions. This was employed during the plasma-assisted etching of silicon utilizing chlorine (Cl_2). This device offers valuable insights into the impact of low-energy ions, aiming to approach the goal of maintaining an undamaged surface.

Experimental setup

The experiments' samples were silicon wafers with a diameter of 150 mm and a patterned 100 nm thin SiO_2 mask. An inductively coupled plasma (ICP) reactor for reactive ion etching (RIE) built by SENTECH Instruments was used for etching. The etching consists of two steps. The adsorption step using Cl_2 (50 sccm) for 20 s at 1.5 Pa and 600 W source power. The desorption step using Ar (50 sccm) for 20 s at 0.5 Pa, 600 W source power, and a bias power between 8 to 22 W. The process sequence and parameters are depicted in figure 1.

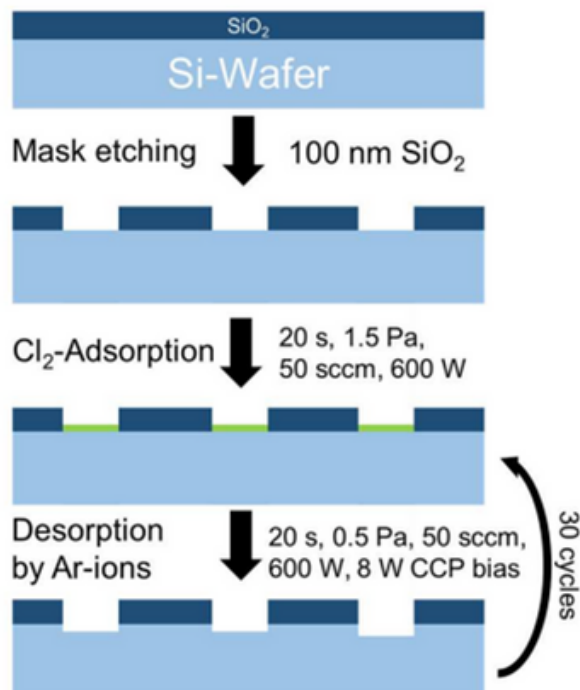


Figure 1 Etching process sequence and parameters for Si wafer masked by 100 nm SiO_2 .

Results

Figure 2 illustrates the ion energy distributions at bias power levels of 0 W, 10 W, 20 W, and 40 W (with 0 W measured twice), while Figure 3 showcases data for bias powers of 60 W, 80 W, 100 W, 120 W, and 140 W. At lower bias powers, up to 40 W, a distinct single peak is evident in the ion energy distributions, except notably at 20 W. However, as the bias power increases, a shift is observed toward two peaks in the distributions as seen in Figure 3.

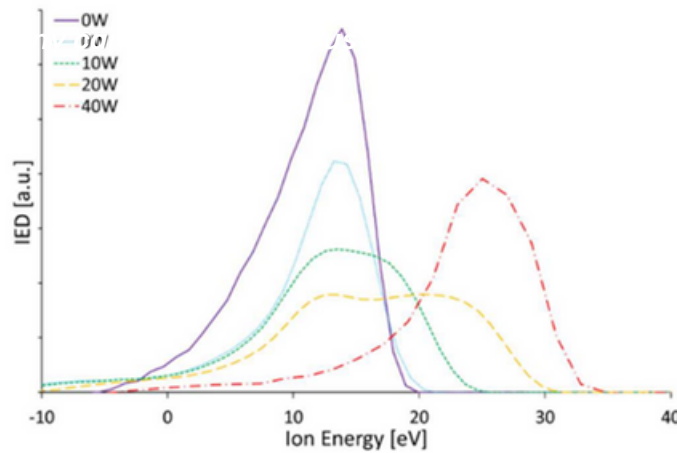


Figure 2 Measured ion energy distribution over ion energy in eV for 0 W (violet, blue), 10 W (green), 20 W (yellow), and 40 W (red) bias power.

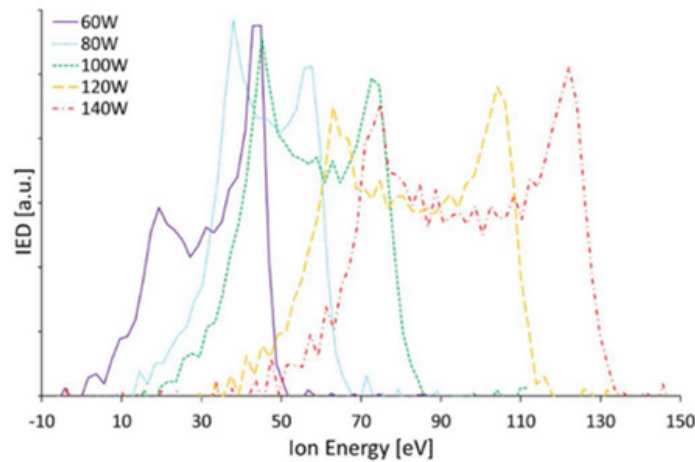


Figure 3 Measured ion energy distribution over ion energy in eV for 60 W (violet), 80 W (blue), 100 W (green), 120 W (yellow), and 140 W (red) bias power.

The ideal ALE window falls between 40 eV and 90 eV, aligning with a bias power range of approximately 80 W to 100 W as determined from these measurements. The presence of double peaks and a wide spectrum of ion energies led to ions both below and above the desired range. Low-energy ions were expected to have minimal impact, while higher-energy ions posed a risk of ongoing damage to the underlying material. To conduct the ALE experiment with predominantly low-energy ions, the bias power was deliberately maintained below 22 W, resulting in a total ion energy of approximately 35 eV or lower.

In the sense of ideal ALE, an EPC of one atomic layer of Si (0.136 nm to 0.157 nm) was not achieved. As shown in figure 4, at lowest an EPC of 0.27 nm at 8 W bias power was etched and at highest almost 14 nm per cycle at 19 W bias power. While there are a few outliers, especially at 13 W and 20 W bias power, the EPC tends to increase with rising bias power.

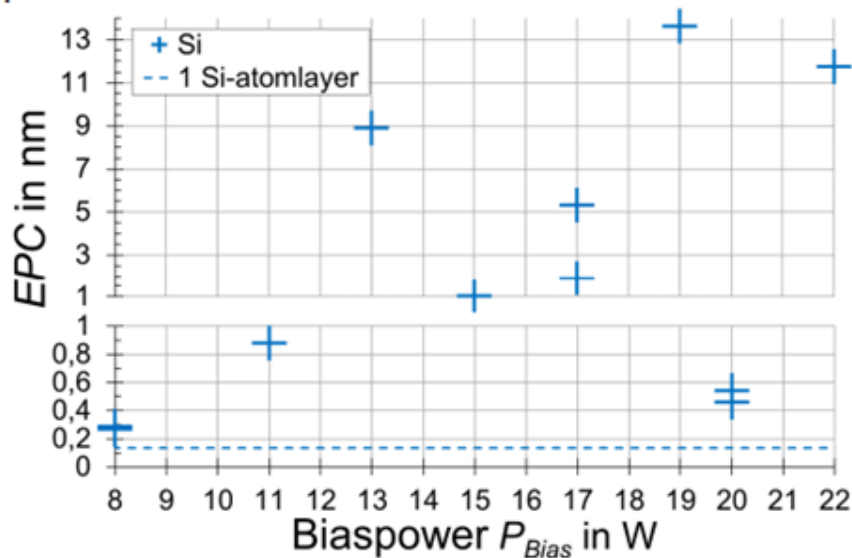


Figure 4 Etch per cycle over bias power in the desorption step following the sequence from figure 1. The height of one Si layer is marked by a dashed line.

Summary

The measurement of ion energy distributions showed, there is a minimal level of ion energy without bias power. The ion energy is distinctively distributed at lower bias powers, but broader in range with more peaks at higher bias powers. This makes it challenging to meet the ideal ALE window in the range of 40 eV to 90 eV. The measurements from RFEA provide a clear indication of the optimal bias power range required for an etching process using low-energy ions while steering clear of high-energy ions. To safeguard underlying layers from ion-induced damage, process parameters were carefully selected, ensuring ion energy distributions peaked at lower energies to minimize potential harm.