A Micromachined Sensor for In-Situ Monitoring of Plasma Etching

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Introduction

Trends in integrated circuit (IC) fabrication continue in the direction of smaller device geometries, higher levels of density and complexity, larger wafer sizes, and improved performance without accompanying increases in manufacturing cost. As a result, the production of highly complex circuits requires extremely stringent process control methods to ensure manufacturability. Based on this continuous need to process devices with shrinking features, plasma etching has emerged as a critical step in the IC fabrication process.

Existing techniques used to monitor plasma etching include interferometry and residual gas analysis [1-2]. Interferometry is only capable of monitoring one spot on the substrate, and works only for opaque surfaces. Residual gas analysis is indirect, since it only provides information on chamber conditions which may or may not fully reflect the etching conditions on the substrate surface. In this paper, we present a prototype etch rate sensor which correlates film thickness with the change in resonant frequency that occurs in a micromachined platform during etching. This approach is similar to the use of crystal oscillators to monitor deposition processes. The platform is suspended over a drive electrode on the surface of the wafer and electrically excited into resonance. As material is etched from the platform, its fundamental resonance frequency shifts, thus allowing etch rate to be inferred. The sensor has the potential to allow in-situ process monitoring of both etch rate and uniformity at a nominal cost.

Sensor Design and Fabrication

As a proof-of-concept experiment, a platform 700 μm long and 200 μm wide suspended four microns above drive and sense electrodes was fabricated (Figure 1). The etching of DuPont 2611 polyimide on top of a 4500Å layer of gold coated with 200Å of titanium was investigated (Figure 2). The sensor was driven into resonance electrostatically at a pressure of 2 mtorr by superimposing a 30V DC and 1V peak-to-peak AC signal at the drive electrode using a network analyzer. The resonant frequency of a single material platform neglecting axial load may be expressed as:

$$\omega_1 = 2\pi f_1 = \frac{\lambda_1^2}{\sqrt{12}} \frac{h}{l^2} \sqrt{\frac{E}{\rho(1-\upsilon^2)}}$$

where ρ, υ, and E, are the density, Poisson's ratio, and Young's modulus of the platform material, respectively, and λ_1, h, and l are its mode constant, thickness, and length [3]. Resonance was detected by monitoring the change in impedance between the drive electrode and platform as the drive frequency was swept (Figure 3). This technique is illustrated by considering the circuit model of the sensor (Figure 4) when the dynamic signal approaches the natural frequency of the platform. The static capacitance Co is the capacitance of the airgap. The RsLsCs branch represents the vibrational behavior of the platform associated with the fundamental mode [4]. The platform is designed such that the ratio of the plasma frequency to the fundamental mode of the sensor is approximately 400:1. This large ratio will enhance filtering of the sensor signal in the noisy plasma environment.

The prototype sensor was etched in a Plasma Therm etcher in a chloroform/oxygen plasma for 60 second intervals. After each etch, the thickness of the platform was measured using a profilometer. This procedure was repeated until approximately 5.0μm of polyimide (initial thickness: 6.5μm) remained. The etchrate of the polyimide is shown in Figure 5. Figure 6 illustrates how the resonant frequency decreases with decreasing polyimide thickness.

Future Work

Our efforts now focus on integrating the sensor into a real-time data acquisition system. In order to integrate the basic sensor into a control system, provision will have to be made for supplying power to the sensor and for getting the sensed information out of the etch chamber and into the control system. One approach we have identified for transmitting the sensor signal involves excitation and measurement of the platform resonance using wireless techniques. A longer term goal is to study methods of fabricating platform structures in parallel with whatever "standard" process is taking place without significantly increasing process complexity.

Acknowledgments

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References

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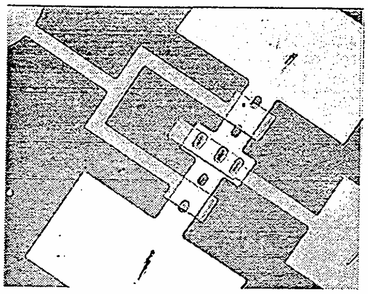

Figure 1: Micrograph of fabricated sensor

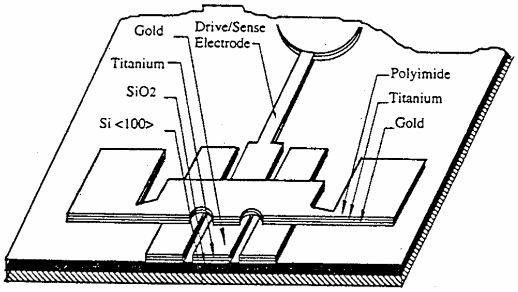

Figure 2: Schematic cross-section of etch rate sensor

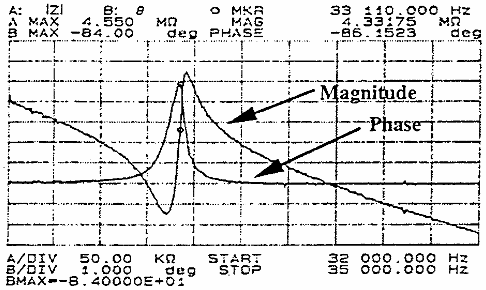

Figure 3: Impedance of airgap capacitor around fundamental resonance of platform

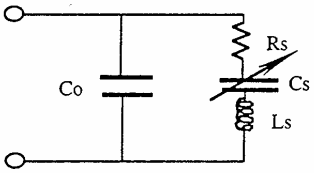

Figure 4: Equivalent electrical circuit

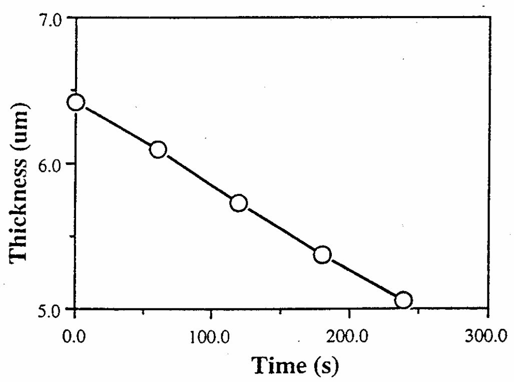

Figure 5: Etch rate of DuPont 2611 polyimide in a CHF_3/O_2 plasma

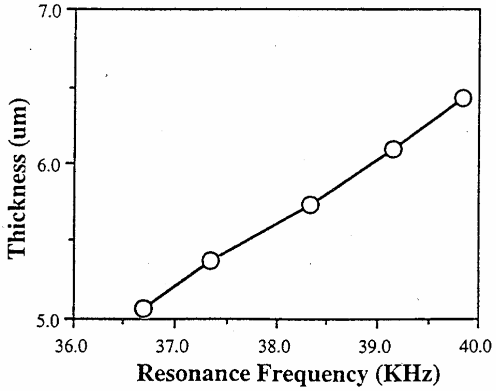

Figure 6: Change in resonance frequency with polyimide thickness during etch