Characterization of 2-300 nm Alumina Thin Films Deposited via ALD

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Abstract:

Thin films are used widely across the engineering field, as electrical semiconductors, optical coatings, in drug delivery systems and in solar cells. Alumina (Al_2O_3) thin films are the most ideal type of films due to their properties. They are hard and stiff, have good chemical and thermal stability, firm adhesion to many surfaces, a high dielectric constant as well as excellent insulating properties. However, even though these thin films are used frequently, the properties of the thinnest films are assumed to behave the same way as thicker films. The objective of this research is to characterize alumina thin films to give accurate measurements of the electrical properties at the nano-scale. Al_2O_3 thin films were deposited on silicon wafers via atomic layer deposition at thicknesses ranging from 2-300 nm and ellipsometry was used to determine the films thickness. Then, electrodes of various diameters were deposited on the films and impedance measurements were carried out at different frequencies. From these measurements, resistance and capacitance values were derived as a function of film thickness and electrode size and compared to expected properties. Results are found to depend heavily on the geometric parameters.

Introduction:

Thin films are made from layers of materials, ranging from fractions of a nanometer to several micrometers in thickness. There are many ways to deposit thin films. The most efficient method is atomic layer deposition (ALD). ALD is a chemical gas phase thin film deposition method based on alternating surface reactions. As the steps are repeated, one layer is deposited one at a time. This self-limiting growth nature is one of the most unique features of ALD, making it an exclusive thin film growth method differing from other deposition techniques. Compared to other deposition techniques, ALD offers ideal film characteristics like thickness uniformity, film density and high interface quality [1]. In addition, it is a low temperature deposition method that has industrial applicability.

Alumina (Al_2O_3) thin films are ideal films used due to their excellent properties. They are sturdy, have good chemical and thermal stability, firm adhesion to many surfaces, a high dielectric constant and excellent insulating properties [2]. These properties are excellent in microelectromechanical systems (MEMS) devices to decrease surface wear. However, even though these thin films are used frequently, the properties of the thinnest films are assumed to behave the same way as the thicker films. In this context, our goal was to investigate the electrical properties of Al_2O_3 thin films ranging from 2-300 nm in thickness deposited via ALD.

Experimental Procedure:

Silicon (Si) wafers were cleaned and then Al_2O_3 was deposited on them using a Cambridge NanoTech Fiji 200 ALD at 250°C. Trimethyl aluminum (TMA) and water were used as the precursors with pulse times of 0.06 seconds. The process was repeated for 20, 50, 100, 200, 500, 1000 and 3000 cycles to calculate deposition rate per cycle; first on wafer pieces and then on 4-inch wafers. Film thickness was then measured using the Woollam M-2000 ellipsometer. Silver (Ag) electrodes were deposited on the wafer pieces using the DESK II TSC sputter coater at a pressure of 50 mTorr and 30% power for 999 seconds. Electrical properties were measured using a Solartron 1260 impedance analyzer at frequencies ranging from 10^7-10 Hz and then compared to expected properties.

Results and Discussion:

Figure 1 shows the relationship between the measured impedance to the log of frequency for various film thicknesses measured with 3 mm electrodes. It is clear that the thicker films had lower resistances while the thinner films had higher resistances. It is noteworthy that for the thinner films, some frequencies were un-measurable.

Figure 2 summarizes the measured response with the calculated resistance response at a frequency of 0.1 Hz. It is clear that large discrepancies occurred in all cases.

Figure 3 displays the frequency dependence for the capacitance of films with different thicknesses, which were measured with 1 mm size electrodes. It can be seen that the thinner the film is, the higher the capacitance as would be expected based on the C % 1/t response. In Figure 4, it can be seen that the capacitance of films thicker than 50 nm followed the expected values, but for the films with thinner thicknesses, the capacitance values were much smaller than expected.

Conclusions:

Al_2O_3 thin films were successfully deposited onto silicon wafers and wafer pieces, and film thicknesses were accurately determined. Ag electrodes were deposited on the Al_2O_3 thin films using shadow masks, and impedance measurements were taken. Results suggested discrepancies between the expected and the measured properties, especially for the thinnest films. Discrepancies could be due to possible film defects such as voids in the thinnest films or the electrodes not being good enough or small enough.

Future Work:

A more extensive evaluation will be done in the future by acquiring more data on films of various thicknesses and depositing more electrodes of different sizes. Also, it is important to characterize the microstructure of the films using atomic force microscopy to find out if they have any voids or if the trends observed are related to possible quantum effects.

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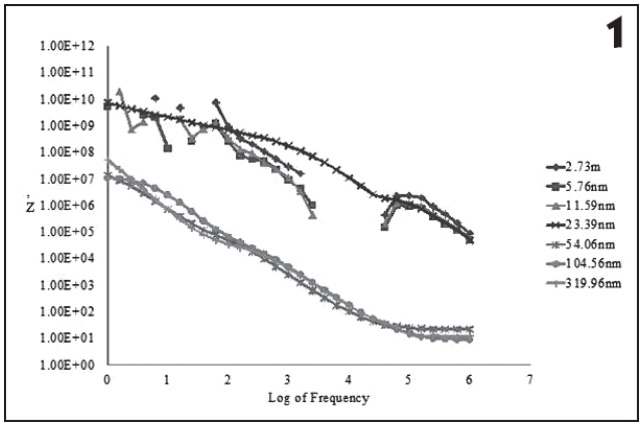

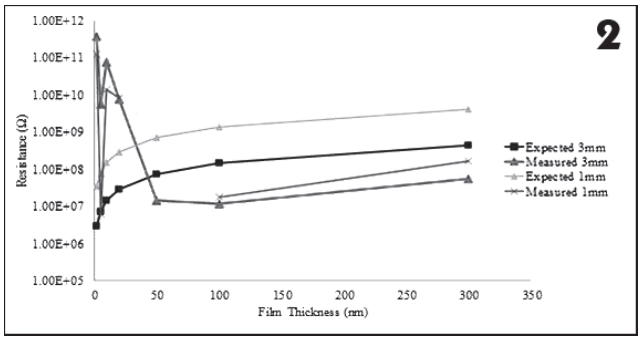

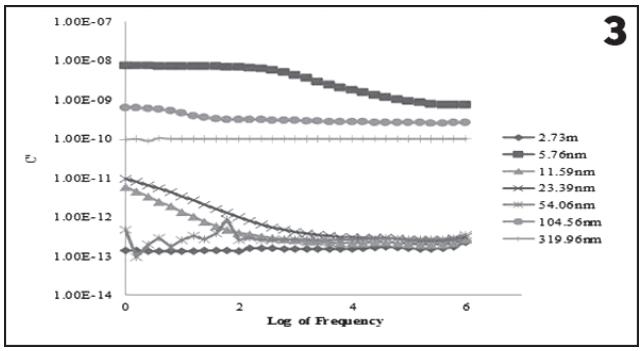

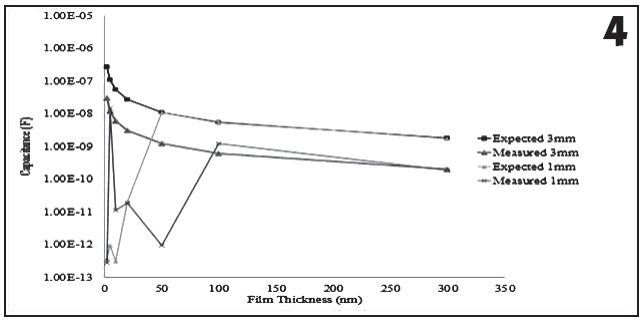

Figure 1: Impedance measurements of films with 3 mm electrodes.

Figure 2: Comparison of experimental with expected resistance.

Figure 3: Real Capacitance vs. Log of Frequency with 1 mm electrodes.

Figure 4: Comparison of measured capacitance with expected value.