Characterization of SiAlON for Hydrogen Diffusion Barrier Application in Nonvolatile Memory Devices

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Abstract:

In this study, silicon aluminum oxynitride alloys (SiAlON), were investigated as a candidate material for a hydrogen diffusion barrier in non-volatile memory (NVM) devices. SiAlON/SiO_2/Si samples were fabricated using combinatorial pulsed laser deposition and the electrical properties throughout the full composition spectrum of SiAlON ranging from pure Si_3N_4 to pure Al_2O_3 (x = 0-1) were determined. The capacitance-voltage and current-voltage measurements of the SiAlON films indicate good dielectric performance, making the electronic properties of SiAlON sufficient to warrant the investigation of its use as a hydrogen diffusion barrier in NVM devices.

Introduction:

Non-volatile memory (NVM) has a metal/oxide/nitride/oxide/semiconductor (MONOS) structure and it retains data by trapping charges at the lower nitride-oxide interface.

Hydrogen diffusion is believed to limit the device performance and reliability [1]. If a hydrogen diffusion barrier were incorporated in the MONOS structure, there would be an anticipated improvement in the device endurance and retention.

In a successful diffusion barrier, a high capacitance and low leakage current are desired to reduce the electron leakage from the nitride/oxide trap layer, increasing the maximum retention time of the device and the film should not trap charges, which would result in eventual device failure. Therefore, it is important to investigate the SiAlON electronic properties as well as its properties as a hydrogen diffusion barrier in order to determine its potential to improve the performance of NVM devices.

This report emphasizes the electronic properties of SiAlON.

Experimental Procedure:

SiAlON Deposition. Thin films of SiAlON were deposited on thermally oxidized SiO_2 substrates. The SiO_2 was prepared in an oxidation furnace at 800°C under an oxygen flow of 400 mL/min for five minutes and annealed for another five minutes without an additional oxygen flow. In order to deposit a single SiAlON layer with a variation in composition ranging from Si_3N_4 to Al_2O_3 (x = 0-1), a combinatorial technique was applied to a pulsed laser deposition process [2]. The procedure included moving a mask with a 7 × 7 mm square cutout across the substrate as material was deposited. This resulted in thin wedges, of approximately 2.5 nm at its thickest, deposited on the substrate with each pass.

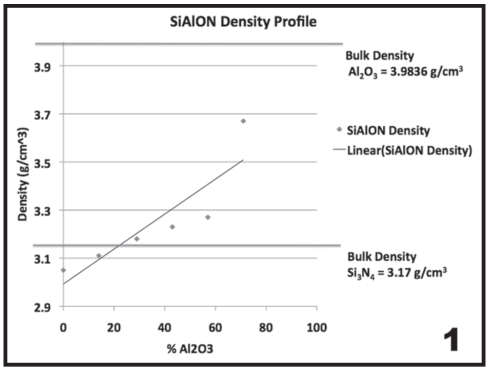
During deposition, the mask started in a central position and moved 7 mm in one direction as a layer of Al_2O_3 was deposited. The mask then moved back to the central position and moved in the other direction 7 mm as a layer of Si_3N_4 was deposited. A total of four layers of Al_2O_3 and four layers of Si_3N_4 were deposited in an alternating fashion on the substrate at a substrate temperature of 300°C, oxygen pressure of 1×10^{-5} torr, and KrF (248 nm) laser energy of 90 mJ per pulse at 5 Hz to obtain a 10 nm thick composition spread of Si_3N_4/Al_2O_3.

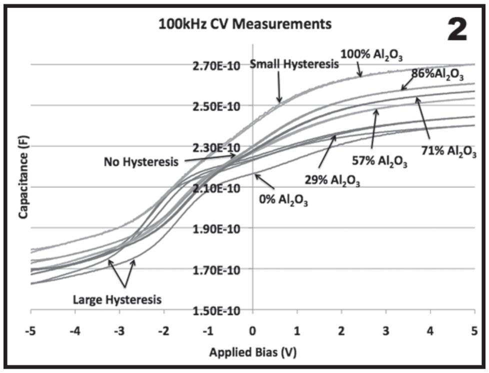
The thickness, roughness, and density of the film were characterized by x-ray reflectivity (XRR) and the electrical performance of the film was characterized with capacitance-voltage (C-V) and current-voltage (I-V) measurements.

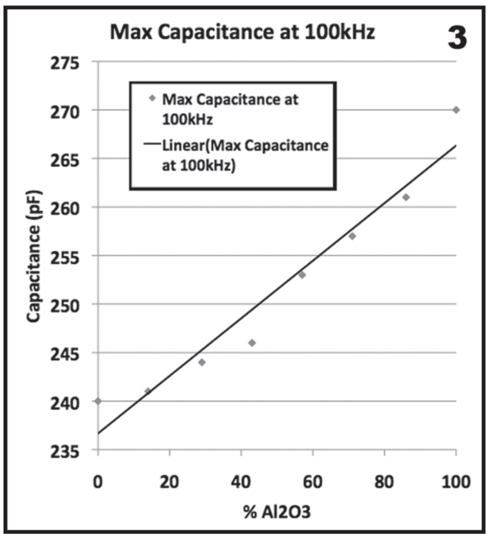
Results:

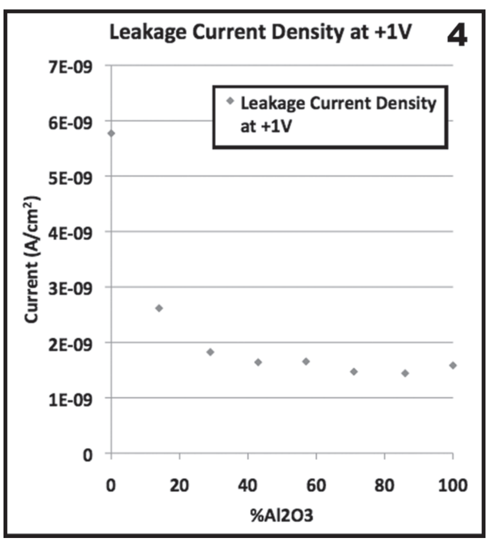
X-ray reflectivity [3] scans were taken every 1 mm on the SiAlON/SiO_2/Si sample using a 0.1 mm beam size. The x-ray reflectivity results indicated that the average SiO_2 and SiAlON layer thicknesses were 6.4 nm and 10.6 nm with an average deviation of 0.15 nm and 0.05 nm, respectively. The average layer roughness was measured to be 0.78 nm in the SiO_2 film and 0.46 nm in the SiAlON film. Figure 1 shows the measured density of SiAlON, which exhibits a linear relationship with the Al_2O_3 fraction, x.

The C-V [4] data showed large hysteresis in the pure Si_3N_4 film (which is typical for Si_3N_4), no hysteresis for Al_2O_3









compositions between 70% and 85%, and a slight hysteresis in the pure Al_2O_3 film (Figure 2). The presence of a hysteresis in C-V measurements suggested trapping of charge at the film/SiO_2 interface or in the SiAlON film itself. At +5V and 100 kHz, the maximum capacitance increased linearly from 240 pF to 270 pF as the Al_2O_3 concentration increased from 0.0% to 100% (Figure 3). These results illustrated that the SiAlON film did not trap charge and that its capacitance was within a tolerable range for hydrogen diffusion barrier application.

The current-voltage measurements [4] (Figure 4) exhibited significantly higher leakage current in the sample at +1V with low Al_2O_3 concentration, but were low and nearly constant for all measurements taken at Al_2O_3 concentrations from 29% to 100%.

The low leakage current density (~ 10^{-9} A/cm^2) shows that the SiAlON can be used not only for a hydrogen diffusion barrier but also as a top block oxide layer to reduce the leakage current to the gate contact.

Conclusions:

A binary composition spread of Si_3N_4 and Al_2O_3 was successfully fabricated using the combinatorial pulsed laser deposition technique. Based on the C-V and I-V characterization, the electronic properties indicate that the SiAlON with a composition between 70% and 85% Al_2O_3 has the best potential to be used as a hydrogen diffusion barrier in non-volatile memory devices. Future research should be done to determine the effect of annealing in hydrogen on the SiAlON film, and diffusion rate experiments should be performed at various SiAlON compositions on single composition samples.

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Figure 1: Density profile of SiAlON film vs. Al_2O_3 composition.

Figure 2: C-V measurements of SiAlON film with 100 kHz at varying Al_2O_3 compositions.

Figure 3: Maximum capacitance at 5V vs. Al_2O_3 fraction in SiAlON films.

Figure 4: Leakage current density vs. Al_2O_3 composition.