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

**Axel Palmstrom**
**Chemical Engineering, University of California Santa Barbara**

*NNIN iREU Site: National Institute for Materials Science (NIMS), Tsukuba, Ibaraki, Japan*
*NNIN iREU Principal Investigator(s): Dr. Toyohiro Chikyow, Advanced Electronic Materials Center, NIMS, Tsukuba, Ibaraki, Japan*
*NNIN iREU Mentor(s): Dr. Nam Nguyen, Advanced Electronic Materials Center, NIMS, Tsukuba, Ibaraki, Japan*
*Contact: apalmstrom@umail.ucsb.com, chikyo.toyohiro@nims.go.jp, nguyen.nam@nims.go.jp*

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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.

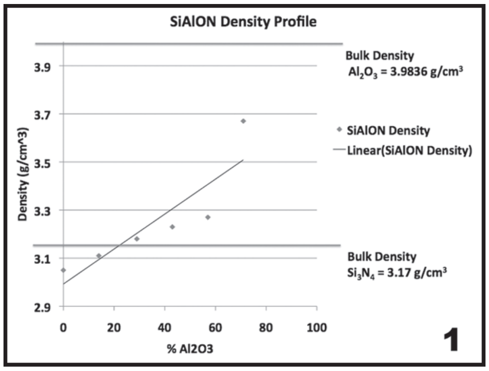
During deposition, the mask started in a central position and moved 7 mm in one direction as a layer of $Al_2O_3$ was deposited. The mask then moved back to the central position and moved in the other direction 7 mm as a layer of $Si_3N_4$ was deposited. A total of four layers of $Al_2O_3$ and four layers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

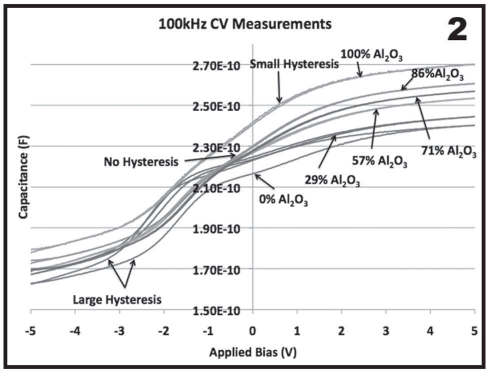
The thickness, roughness, and density of the film were characterized by x-ray reflectivity (XRR) and the electrical performance of the film was characterized with capacitance-voltage (C-V) and current-voltage (I-V) measurements.

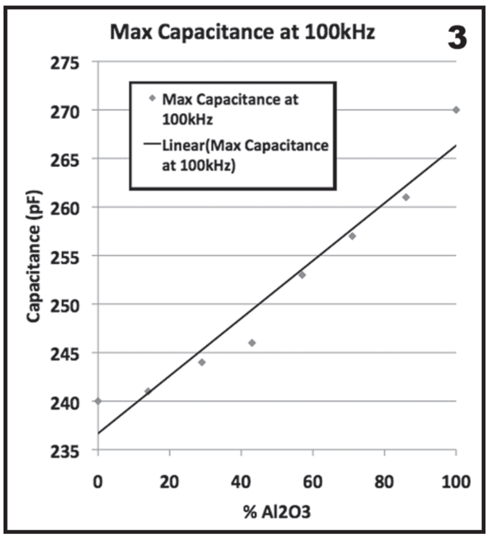
## Results:

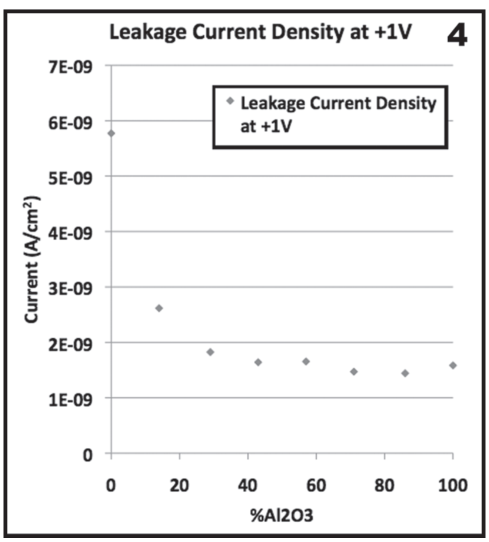
X-ray reflectivity [3] scans were taken every 1 mm on the SiAlON/$SiO_2$/Si sample using a 0.1 mm beam size. The x-ray reflectivity results indicated that the average $SiO_2$ and SiAlON layer thicknesses were 6.4 nm and 10.6 nm with an average deviation of 0.15 nm and 0.05 nm, respectively. The average 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.

## Acknowledgements:

I would like to thank Dr. Nam Nguyen and Dr. Toyohiro Chikyow for all of their advice and assistance throughout the project. I would also like to thank the National Nanotechnology Infrastructure Network International Research Experience for Undergraduates (NNIN iREU) Program and the National Science Foundation for this research opportunity.

This project was supported by the National Nanotechnology Infrastructure Network, the National Science Foundation, and the National Institute for Materials Science.

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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.*