Stoichiometric Dependence of Physical and Electrical Properties of Silicon Nitride

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Primary CNF Tools Used: LPCVD Furnace, CVC SC4500 Thermal Evaporation System, FleXus, Woollam Spectroscopic Ellipsometer

Abstract:

In recent years, nitride transistors have received much attention in the semiconductor device research community due to their wide bandgap, high thermal conductivity, and polarization properties. Two important performance metrics of these devices are the suppression of leakage current through the gate dielectric and its resilience under repeated use. Previous studies [1] have shown that these properties can be improved in SiNx (a common gate dielectric for nitride transistors) by changing the stoichiometry of the dielectric deposition.

This investigation entails the physical and electrical characterization of silicon nitride (SiNx) thin films deposited on silicon substrates by low-pressure chemical vapor deposition (LPCVD). Films were deposited at temperatures of 775°C, 750°C, and 725°C, and dichlorosilane to ammonia gas flow ratios of 5:1, 5:2, and 1:4, yielding a total of nine samples. Physical characterization measurements, including stress and index of refraction, were conducted on each film. The films with the lowest Si content showed the most stress and lowest index of refraction. Aluminum contacts were deposited on the silicon nitride using CNF's CVC SC4500 Thermal Evaporation System and patterned by contact lithography in a metal-first process to form MOS capacitors.

Capacitance-voltage behavior of the fabricated capacitors was measured at a DC probe station to determine the dielectric properties of the SiNx. The leakage current through the capacitors under applied bias was also measured as a function of time to determine the time-dependent dielectric breakdown of each film.

Summary of Research:

The goal of this research was to check the impact of low pressure chemical vapor deposition conditions on the characteristics of physical and electrical properties of silicon nitride. This was done using a parallel plate capacitor that consisted of silicon and aluminum as its plates, and silicon nitride as the dielectric. The physical properties tested included the stress imposed by the dielectric and the index of refraction of the dielectric. The electrical properties consisted of the dielectric breakdown of the dielectric, and capacitance measurements of some of the capacitors that included the dielectric.

The process began with a plain 100 mm n-type silicon wafer, on which silicon nitride was deposited using low pressure chemical vapor deposition (LPCVD). This deposition was done at three different ammonia to dichlorosilane ratios and at three different temperatures. The goal of these varying conditions being to vary the concentration of silicon in the dielectric. The three dichlorosilane to ammonia ratios were regulated using the LPCVD furnace, and these three ratios were 5:1, 5:2, and 1:4. The three different temperatures chosen were 775°C, 750°C, and 725°C. This process resulted in nine wafers that had distinct deposition conditions. The physical properties, such as stress and index of refraction, were measured using the FleXus and the Woollam Spectroscopic Ellipsometer respectively. The silicon nitride index of refraction increased with the concentration of silicon during deposition. The stress imposed by the silicon nitride decreased with an increasing silicon concentration, as well as with higher temperatures during deposition (Figure 2).

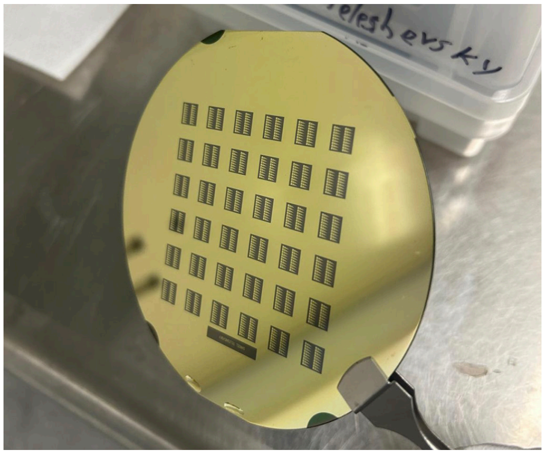

Figure 1: Photograph of the wafer with the individual capacitors visible on the black squares.

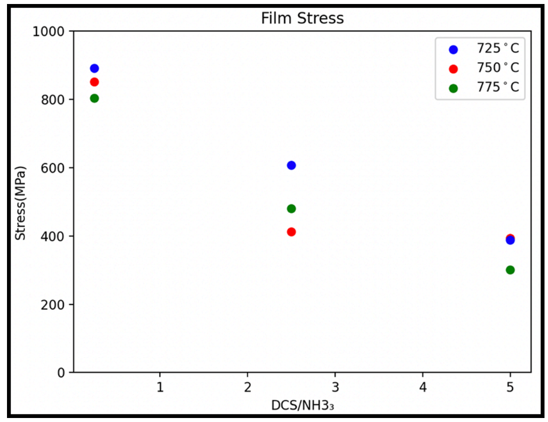

Figure 2: Graph of the stress of the wafer, which is one of the physical properties measured. A potential downward trend of increased stress with decreased silicon concentration is depicted.

Then, the wafer was coated with aluminum using thermal evaporation, which was patterned by liftoff using photolithography. This resulted in six clear square capacitors whose width was 50 μm, 100 μm, 200 μm, 300 μm, 400 μm, and 500 μm (Figure 1).

As part of the electrical characterization, the dielectric breakdown of these capacitors, as well as the capacitances of the 500 μm capacitors were measured using the Everbeing EB-6 DC Probe Station. This study included two variables, which were the flow rate of dichlorosilane to ammonia ratios, and the deposition temperature. The dielectric breakdown of silicon nitride was tested in all nine different wafers. It was found that films with a higher concentration of silicon broke down at lower voltages (Figure 3). Different deposition temperatures also showed to impact dielectric breakdown, with higher deposition temperatures causing a dielectric breakdown at lower voltages (Figure 4).

Conclusions and Future Steps:

Both deposition temperatures and silicon content had an effect on the physical and electrical properties of the dielectric. Higher silicon content resulted in lower stress and a higher index of refraction, as well as a faster dielectric breakdown. Additionally, a higher deposition temperature resulted in lower stress and a faster dielectric breakdown. While both conditions did impact the properties of the film, silicon content had a greater effect than deposition temperature.

In the future, time-dependent measurements should be taken of the dielectric breakdown at each of the conditions, and this data should be collected in much larger quantities in order to conduct statistical analysis and determine the statistical significance of the data.

Acknowledgements:

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References:

[1] W. M. Waller, et al., in Proc. CS-MANTECH, Indian Wells, CA, USA, May 2017.

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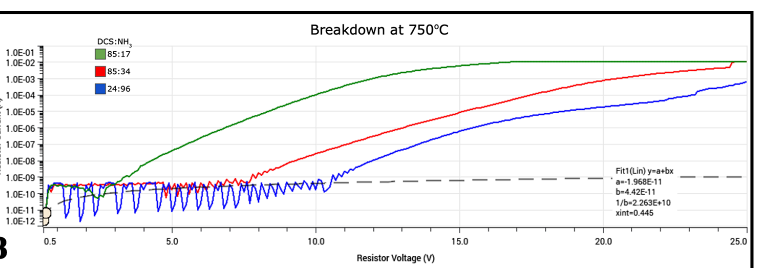

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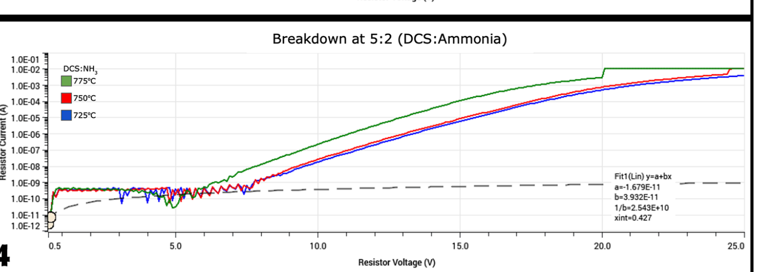

Figure 3, above: Graph of the dielectric breakdown of the silicon nitride at 750°C. A trend of a faster breakdown at higher concentrations of silicon is demonstrated. Figure 4, below: Graph of the dielectric breakdown of the silicon nitride at a 5:2 dichlorosilane to ammonia deposition ratio. A trend of faster breakdown at higher deposition temperatures is demonstrated.