Low Temperature (LT) Thermal ALD Silicon Dioxide
Using Ozone Process
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Low Temperature ALD Overview

Atomic Layer Deposition (ALD) is a powerful nanofabrication technique capable of depositing highly-conformal coatings for a variety of applications. ALD is based on a modified chemical vapor deposition (CVD) process, in which the overall chemical reaction is split into two sequential, self-limiting, half reactions. This allows for sub-monolayer precision in material thickness, which can be controlled with a resolution of ~1 Ångstrom. Due to the self-limiting nature of the surface chemical reactions, ALD processes enable excellent uniformity when coating high aspect ratios (above 2000:1), allowing for 3-dimensional engineering of complex nanostructured architectures. The atomically-precise tuning of surfaces and interfaces afforded by this process create numerous opportunities in the fields of semiconductor devices and memory, energy conversion and storage, MEMS/NEMS, catalysis, and other emerging areas.

ALD SiO₂ is a very important material in microelectronics. The increasing interest in three-dimensional 3D transistor structures e.g., nanowire or FinFETs requires ultrathin SiO₂ as gate insulator, diffusion barrier, or sacrificial layer covering 3D nanostructures homogeneously during processing. The coating of thermally fragile substrates such as double patterning over photore sist surface by ALD SiO₂ require low process temperatures. In recent years, various Si precursors have been tested in combination with O₂ or H₂O as the oxidants. These processes include the use of pyridine and TMAl (Gordon et al) as catalysts. And because of the nature of these precursors, ALD processes are hard to practice at lower temperature (<100 °C). In addition, a thermal ALD process for low-temperature SiO₂ was reported which was free of catalysts or corrosive by-products (D. Hiller et al). In this respect, the use of precursors with amino ligands has also shown promising results, in particular when combined with H₂O, O₂, or H₂O₂ as the oxidant and the process based on these precursors can go down to really low temperature. Here Arradiance demonstrates an efficient low temperature ALD SiO₂ process based on ozone and aminosilane precursor with GEMStar ALD tool. Data presented here is for process temperatures ranging from 80°C to 200°C. Our low temperature SiO₂ process has also been successfully used in photore sist double patterning as shown here.

Characterization of LT ALD SiO₂ Films

The linear growth shows the typical ALD behavior of SiO₂ process at 80°C. And the growth rate saturates at 0.27 Å/cycle.

The growth rate increases with temperature which is consistent with the previous report. This is due to the increased reactivity of aminosilane towards ozone at higher temperature.

Uniformity of LT SiO₂ film by ozone over 8°: 0.76% (1σ)
Reagents: SAM24 and O₃

Experimental Method: GEMStar and Ozone system

GEMStar-8 system is designed for extreme surface area, high aspect ratio structures: Multi-channel precursor delivery system isolates & distributes precursors combined with a tapered exhaust to provide exceptional nanofilm uniformity.

Metrology Interface for QCM, ellipsometry, FTIR, OES and room for up to six high capacity precursors to be heated, or unheated, and can be served into the GEMStar gas ports. The hot wall design allows stacks of multi-wafer samples to improve the throughput and reduce the cost per device.

Arradiance specifies a durable ozone system (~10% ozone concentration) as an option for LT ALD. The ozone system is engineered into one of the gas ports of GEMStar with the majority of the output of ozone going to the ozone destruct. We use N₂ buffered O₂ to generate high concentration of ozone. This system shows advantage of reducing ALD oxide cycle time at low temperature.

Most of the organometallic precursors can be obtained through pre-loaded Arradiance bottles by Stem.

LT SiO₂ ALD process temperature typically range between 80 to 200°C.

Characterization of LT ALD SiO₂ Films

Saturation studies show that the growth saturates at 1200 ms dosing of aminosilane precursor. In subsequent runs a 1200 ms dose of Si precursor was used.

Double Patterning Application Using LT ALD SiO₂ Process

Typical LT ALD SiO₂ conditions on photore sist include deposition temperature of 80°C, ozone (0.2e) and aminosilane (1.2s) as reactant gas and source temperature at 50°C. In conclusion: the LT ALD SiO₂ process developed on GEMStar successfully provided a very conformal (±95%) and uniform SiO₂ patterning layer with controllable thickness (13 nm) on photore sist material. The post etching films showed conformal coatings as well (not shown here).

Summary

Arradiance has developed a LT ALD SiO₂ process on GEMStar which showed:
1. Conformal and uniform coating over photore sist substrate;
2. Excellent uniformity (± 1%) demonstrated for SiO₂ films;
3. Low temperature SiO₂ deposition, using ozone as oxidant, exhibited linear growth at 80°C;
4. Full integration of ozone source with GEMStar user interface software allows for fully automated processing.

References
