The Effects of Nitrogen Annealing on Stress of HDPECVD and PECVD Silicon Dioxide Films

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Primary CNF Tools Used: Plasma-Therm Takachi HDP-CVD System, Oxford Plasmalab System 100 PECVD, Woollam RC2 Spectroscopic Ellipsometer, Flexus 2320-S Stress Measurement System, Anneal LPCVD Furnace Tube

Abstract:

While thermal oxidation is the most common method for batch processing silicon dioxide (SiO_2), the high thermal energy required (800°C -1200°C) and low deposition rates limits its use in modern semiconductor fabrication. In the late 1960's, the emergence of plasma enhanced chemical vapor deposition (PECVD) revolutionized the semiconductor industry. An inert plasma can dissociate precursor gases and provide the activation energy necessary to deposit thin films at temperatures between 200°C -450°C. Along with higher deposition rates, PECVD became a reliable method for depositing many dielectrics, but this process does not produce the same SiO_2 film quality as thermal oxidation. Typically, SiO_2 films have a moderate compressive stress which is beneficial for integrated circuit processing [1], but over time, humidity and ambient moisture will cause the stress to drift and become more compressive [2]. Controlling film stress and wafer flatness directly impacts the long-term quality of devices and excessive stress can lead to buckling or delamination. To stabilize stress, PECVD SiO_2 films are often thermally annealed after deposition to collapse micropores and breaks down bonded hydrogen (H) and hydroxyl groups (OH) [3].

Optimizing PECVD deposition parameters seems to be an alternative path for improving film quality, so in early 2022, the CNF installed a Plasma-Therm Takachi High Density Plasma Chemical Vapor Deposition (HDPECVD) system for depositing silicon oxide. This HDPECVD system uses an inductively coupled plasma (ICP) source to create a denser plasma than other conventional parallel plate PECVD systems such as our Oxford Plasmalab System 100. The higher density plasma translates into more free electrons to interact with reactive gas species, eliminating the need for high process gas flows. Combined with the capability of biasing the wafer, HDPECVD can deposit high quality films at significantly lower temperatures. While there is an abundance of information on PECVD films, little has been published about films deposited/annealed by HDPECVD. This work will compare the effects nitrogen annealing has on HDPECVD and PECVD SiO_2 film stress and wafer flatness.

Summary of Research:

For this work, approximately 1.0 μm of SiO_2 was deposited on single side polished (SSP) N-type, 100 mm diameter, 525 μm thick, prime, <100> silicon wafers. For HDPECVD, all ten depositions were completed on a Plasma-Therm Takachi HDP-CVD System at the as-deposited temperature of 100°C with silane (SiH_4) and oxygen (O_2) precursor gases. For PECVD, an Oxford Plasmalab System 100 PECVD tool was used to deposit SiO_2 on nine wafers at an as-deposited temperature of 350°C with SiH4 and nitrous oxide (N_2O). All wafers were MOS cleaned and nitrogen annealed from 300-1100°C for one hour. The anneal temperatures were calibrated from the combination of three separate heating elements in a low temperature chemical vapor deposition (LPCVD) furnace tube. A Woollam RC2 Spectroscopic Ellipsometer was used for all thickness measurements before and after annealing. Stress measurement calculations were based on these thicknesses. All the oxide films decreased in thickness when annealed, but the percentage change in thickness after annealing was significantly higher for HDPECVD films. Film stress and wafer bow were measured on a Flexus 2320-S Stress Measurement System. Measurements were at room temperature using a 670 nm laser light source and at the zero- and ninety-degree (0° and 90°) orientation.

Results:

The average as-deposited compressive stress at both orientations for HDPECVD SiO_2 was -235 MPa which is almost one-hundred MPa higher than the as-deposited PECVD oxide (-136 MPa). Both oxide films became less compressive (more tensile) as annealing temperatures were increased to 600° C, and more compressive at higher annealing temperatures (Figure 1). While the PECVD stress curve peaked at -32 MPa before becoming more compressive, the HDPECVD oxide annealed at 350° C had almost zero stress (-0.74 MPa) and films became tensile when annealed between 400°C - 700°C. At 1100°C, both films had a similar compressive stress (HDPECVD @ -244MPa and PECVD @ -246 MPa).

Wafer bow is an indicator of the flatness of a wafer in semiconductor processing. A compressive film will have a positive wafer bow and a tensile film will have a negative. New SSP wafers had an average wafer bow of -1.3 μm at the 0° orientation and -1.76 at 90° orientation. The average as-deposited wafer bow was higher for the HDPECVD films (+21.3 μm at 0° and +20.9 μm at 90°) which correlates with the higher compressive stress than the PECVD oxide (+12.3 μm at 0° and +12.1 μm at 90°). As with the stress, wafer bow changed significantly more negative (tensile) for the HDPECVD SiO_2 than the PECVD (Figure 2). Wafer bow was between +/- 3μm for SiO_2 annealed at 300°C, 350°C and 800°C for the HPCVD and from 500°C -700°C for PECVD SiO_2.

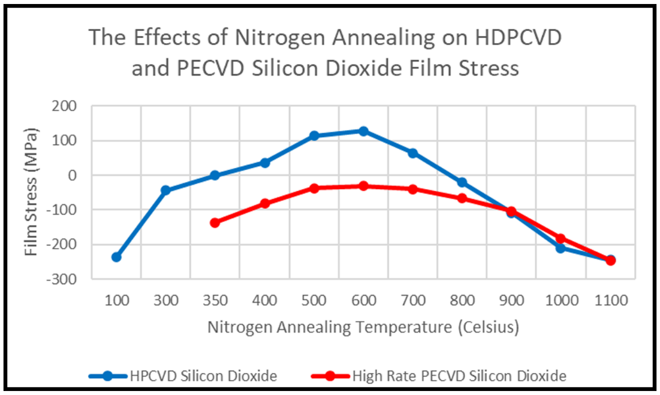

Figure 1: Changes in SiO_2 stress as nitrogen annealing temperatures increase for PECVD and HDPECVD films.

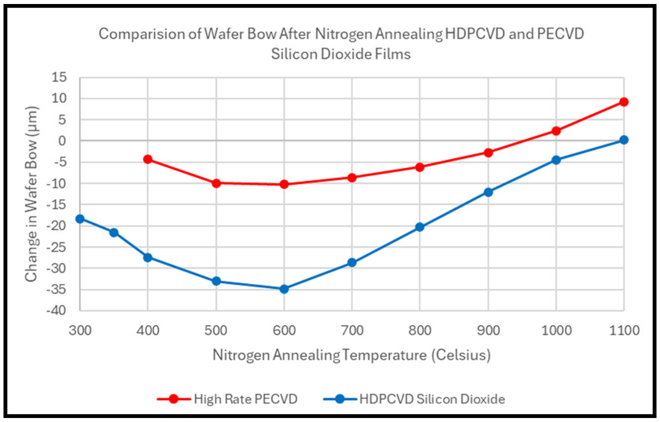

Figure 2: Changes in SiO_2 wafer bow as nitrogen annealing temperatures increase for PECVD and HDPECVD films.

References:

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