Low Stress Oxides for use in Microfabricated Ion Traps for Quantum Computation

Margeaux Wallace
Materials Science and Engineering, Cornell University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology, Atlanta, GA
NNIN REU Principal Investigator(s): Dr. Kenneth R. Brown, School of Chemistry and Biochemistry, Georgia Institute of Technology
NNIN REU Mentor(s): J. True Merrill, School of Chemistry and Biochemistry, Georgia Institute of Technology
Contact: mlw239@cornell.edu, ken.brown@chemistry.gatech.edu, true.merrill@gatech.edu

Abstract and Introduction:

Trapped atomic ions are a leading technology for performing quantum computation [1]. The Brown Lab, in collaboration with the Quantum Information System group at the Georgia Tech Research Institute, is fabricating surface-electrode radio frequency ion traps for trapping and controlling calcium ions. On the trapping device, a set of electrodes produce a time-dependent potential in which an ion with sufficiently low kinetic energy is trapped. To insulate these electrodes, we require thick dielectric films that will survive cooling to 4.2K without substantial deformation to the devices. Internal stresses of these oxides will be further aggravated by the extreme change in temperature when the trap is cooled. Upon cooling, the film and substrate will shrink to different sizes due to different coefficients of thermal expansion. However, they must remain the same length; this creates an uncompensated bending moment. The film will cause the substrate to bend up or down with tensile or compressive stresses, respectively. Reducing the stress in the film minimizes the possibility of the oxide buckling [2].

The focus of this project was to create a recipe for the lowest stress oxide on one specific plasma enhanced chemical vapor deposition (PECVD) tool. Baseline stress measurements of standard recipes were taken and the parameters, pressure, radio frequency (RF) power, gas ratios and gas flow rates, were changed to optimize the stress.

Process Optimization:

Oxides were deposited on <100> silicon wafers at 250ºC using PECVD. Variations of pressure, RF power and reactive gas ratios had perceptible effects on the stress of the films. These parameters were varied to find the optimal film deposition recipe for the production of low stress oxides. For every change, stresses were measured using a contact profilometer and an optical stress measurement tool. The gas flow ratios were substantially altered, thus changing the material being deposited. To verify that the film was indeed an oxide, the index of refraction was measured. In addition, since the oxide needs to be a sufficient insulator, the breakdown voltage was measured.

Results:

Figure 1 demonstrates the dependence of stress on the pressure. Increasing the pressure resulted in a decrease in stress; as the pressure was increased to the limit of the machine, the stresses dropped by about 100 MPa. RF power was varied next. Lower RF powers corresponded with lower stresses. However, as demonstrated in Figure 2, as the RF power was lowered below 25 watts, what appears to be a lower limit was observed. The last changed parameter was the ratio of the nitrous oxide (N_2O) to the 2% silane gas mixture. As the ratio of the silane gas was increased, drastic changes in the stresses were observed. It had the largest impact on the stress, turning the film from a compressive stress to a tensile one (Figure 3).

Oxides deposited with varied gas ratios were tested and ellipsometry data revealed index of refractions that were very close to each other, differing by only 2.7%. The highest index of refraction was 1.50 — higher than a typical silicon dioxide (about 1.46), but still within a reasonable range, indicating that the deposited film was an oxide.

The breakdown voltage was measured to be 8.53 MV/cm with a standard deviation of 1.823 MV/cm. The accepted literature values for the breakdown voltage of silicon dioxide falls within this range [3]. The maximum voltage used for the device was 0.35 MV/cm, so this oxide will be more than sufficient for use in the traps.

Discussion:

Possible mechanisms to explain these trends involve the density and amount of silicon in the film.

Films with a higher density exhibit lower values of stress. This is likely related to the organization of the lattice, a concept which is easily demonstrated by looking at a dislocation as seen in Figure 4. The extra half plane of atoms causes the top half to be stressed in compression and the bottom half, tension. While the stresses of the oxides are more complicated than a single dislocation, it is easy to extrapolate and see how the disorganized lattice associated with low density films would give high stresses.

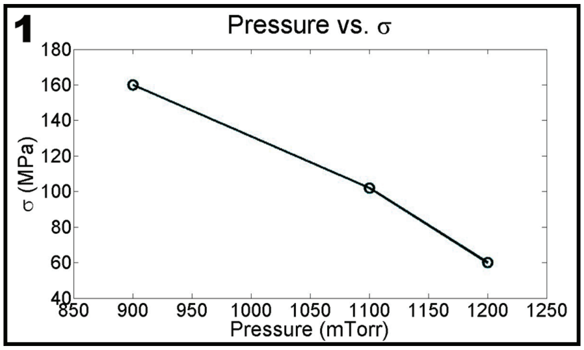

Figure 1: Pressure versus absolute value of compressive stress.

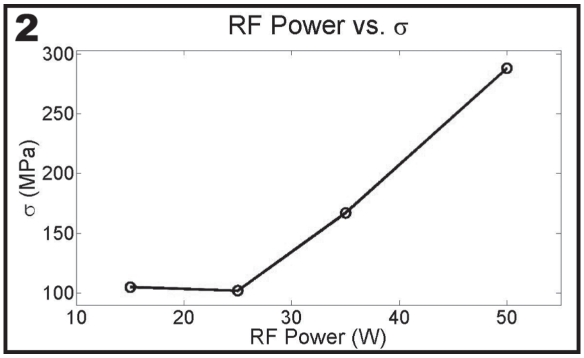

Figure 2: RF power versus absolute value of compressive stress.

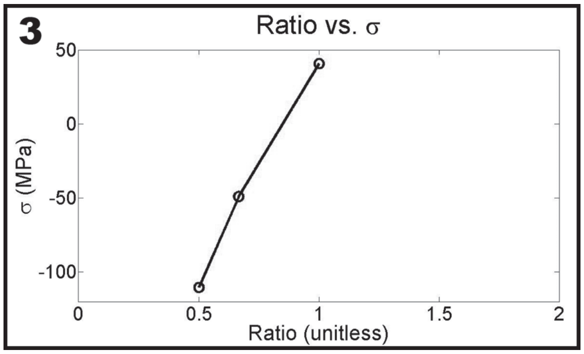

Figure 3: Gas ratio versus stress. The ratio is N_2O to silane.

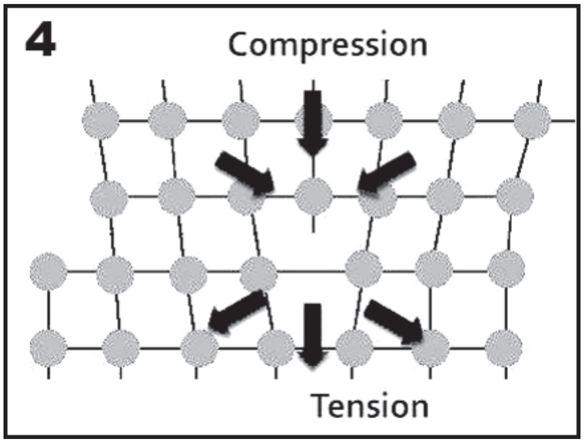

Figure 4: Edge dislocation demonstrating lattice disorganization inducing stresses.

In addition, silicon-rich oxides demonstrate significantly lower stresses than their traditional oxide counterparts. While it is possible the lattice constant may be more similar to silicon, and thus there is less stress due to lattice matching, a more likely source for the lowered values is a change in the thermal expansion coefficient of the film. It is likely the thermal expansion coefficients become more similar the more silicon rich the film. This convergence translates to a reduced bowing of the film.

Conclusion:

Based on the results of these experiments, the films with the lowest stress were found to be those with lower RF powers and gas ratios, for instance 1:1, and the higher pressures.

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