plasma process group

Simple Ion Beam Solutions

Stress Modification by Ion Assist during Ion Beam Deposition

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Single-layer thin films of SiO_2 were deposited onto fused silica substrates using the Techne dual ion beam deposition system at different assist beam conditions. The assist ion source conditions were varied to examine their effect on stress levels in the film. Some samples were post process annealed in a box furnace at various temperatures, after which the stress was measured again. Results are presented and discussed in this paper.

Introduction

Ion beam sputter deposition with an assist ion beam has been used in industry for years to produce dielectric coatings used for optical devices [1-3]. A dual ion beam system utilizes two sources as depicted in Figure 1. One ion beam source (deposition source) is directed at a target material to be sputtered. The system geometry is designed so the sputtered target material arrives at the substrates while ions from the second source (assist source) also arrive. Early investigations observed that when an assist source was used, the film stoichiometry improved for films deposited by evaporative type sources as well as films produced by ion beam sputtering [2,3]. Researchers examined the energy of the ion bombardment on the surface, referred to as the “ion energy”, in the range of 30 to 500 eV. They also examined various ion doses (beam current) and different gas combinations.

In this investigation, the effects of ion assist and annealing on film stress are examined. Excess stress in thin films can result in film adhesion problems, optical absorption, and surface distortion, as well as film and even substrate failure. Historically, film stress has been addressed by post-process annealing, which adds time to already lengthy deposition processes and can result in other undesirable film changes.

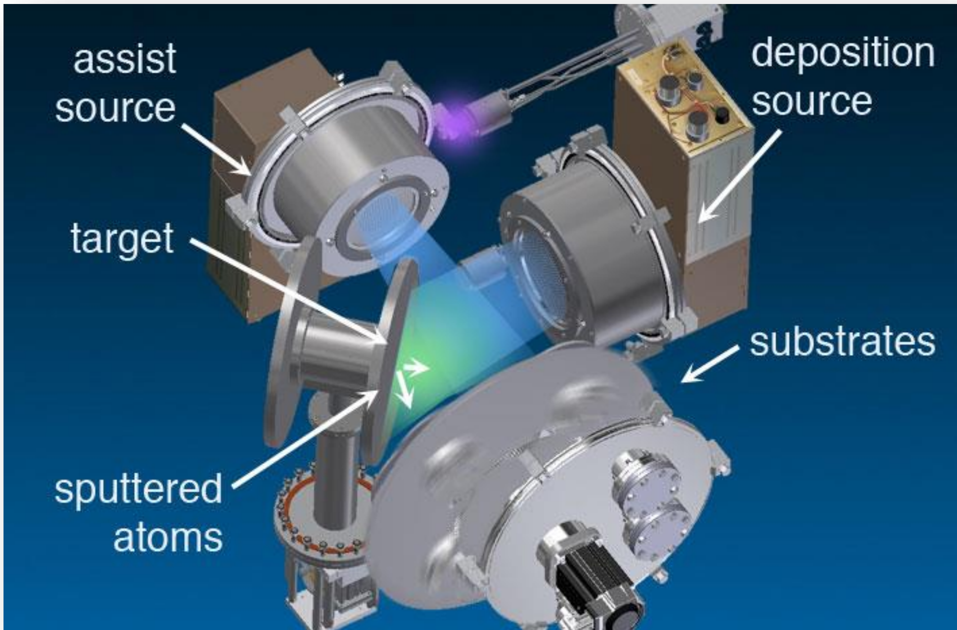

Figure 1. Dual ion beam deposition system layout.

Experimental Apparatus and Procedure

Stress magnitude was measured using a Zygo Verifire XPZ interferometer to record physical deflection of the substrate surface before and after the deposition process. These measurements were used to extract the applied stresses through Equation 1 below, known as the "Stoney Equation" [4], where E_s and v_s are the Young's Modulus and Poisson's Ratio of the substrate, t_s and t_f are the thickness of the substrate and Si thin film respectively, and R_0 and R are the radius of curvature of the wafer before and after deposition respectively:

$$\sigma = \frac{E_S {t_S}^2}{6t_f(1-\nu_S)}\left(\frac{1}{R} - \frac{1}{R_0}\right) \qquad (1)$$

The fused silica substrate discs of diameter 25mm and thickness 2mm were first annealed to eliminate any inherent stresses. Next, single-layer thin films of SiO_2 were deposited. The radius of curvature was measured before and after deposition. Stresses induced by the coating are apparent as a change in this radius, and can be calculated via Equation 1.

In this study, a metallic silicon (Si) target was bombarded by a 16cm RF ion source in a Techne Ion Beam Assisted Deposition (IBAD) system. Oxygen was injected into the system near the target at a rate of 25 sccm, determined to optimize stoichiometry of the film. The substrates were simultaneously bombarded by a 12cm RF assist ion source with ion energy varying from 0eV (off) to 200eV. As a control, deposition source conditions were held constant at 400mA beam current, 1250V beam voltage, and 250V accelerator voltage. The process run-time was held constant at 4.5 hours, corresponding to a final thickness of around 2000nm. Higher assist source ion energies resulted in thinner films due to sputtering.

Several samples were processed at each assist source condition. After processing, these samples were measured for stress, then baked in a Lindberg BF51866A-1 box furnace at temperatures ranging from 150°C to 450°C. To prevent thermal shock, the oven was set to have a one hour period to warm up, followed by one hour at the specified temperature, and ending with a one hour cooldown after which the samples were removed. Samples processed with the assist source off are then compared to those processed with the assist source on. Additionally, samples are compared between different baking temperatures.

Results and discussion

Figure 2 below shows film stress with different assist ion energies with a 0 eV pertaining to the case with the assist beam off. Of note is the decrease in compressive stress as the ion energy increases with an apparent plateau near 330MPa, corresponding to a ~10% difference. Figure 3 illustrates the effect of baking on a film deposited with the assist beam off. The stresses initially increase significantly, but ultimately decrease by ~20%.

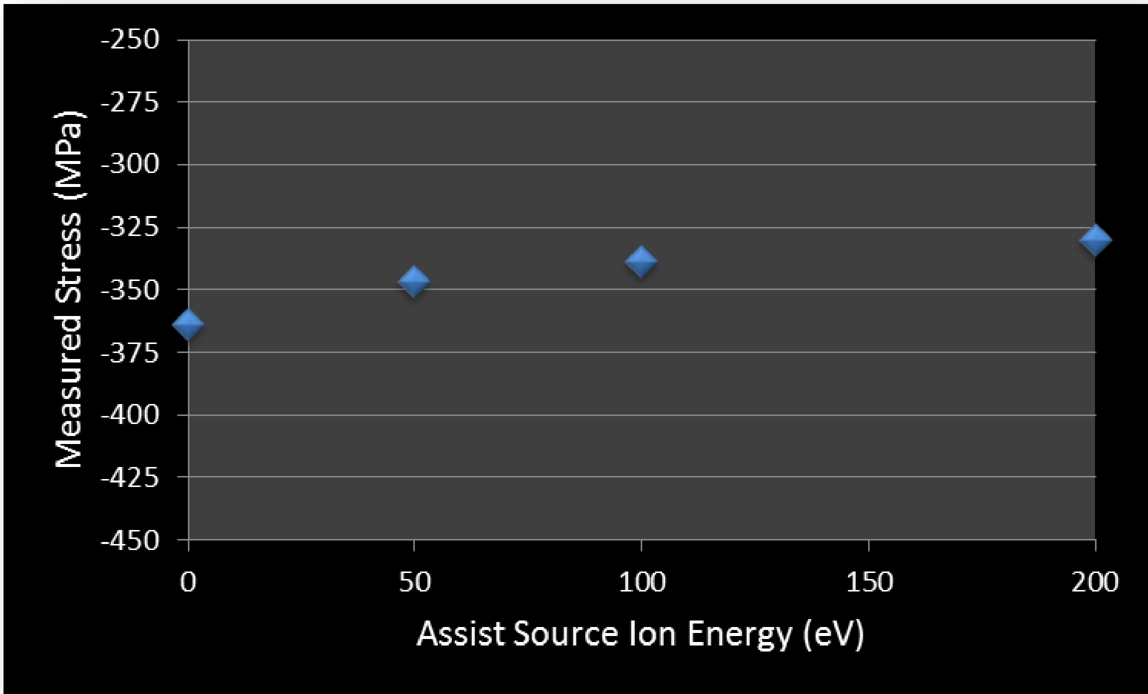

Figure 2. Substrate stress mitigation with varying assist source ion energy.

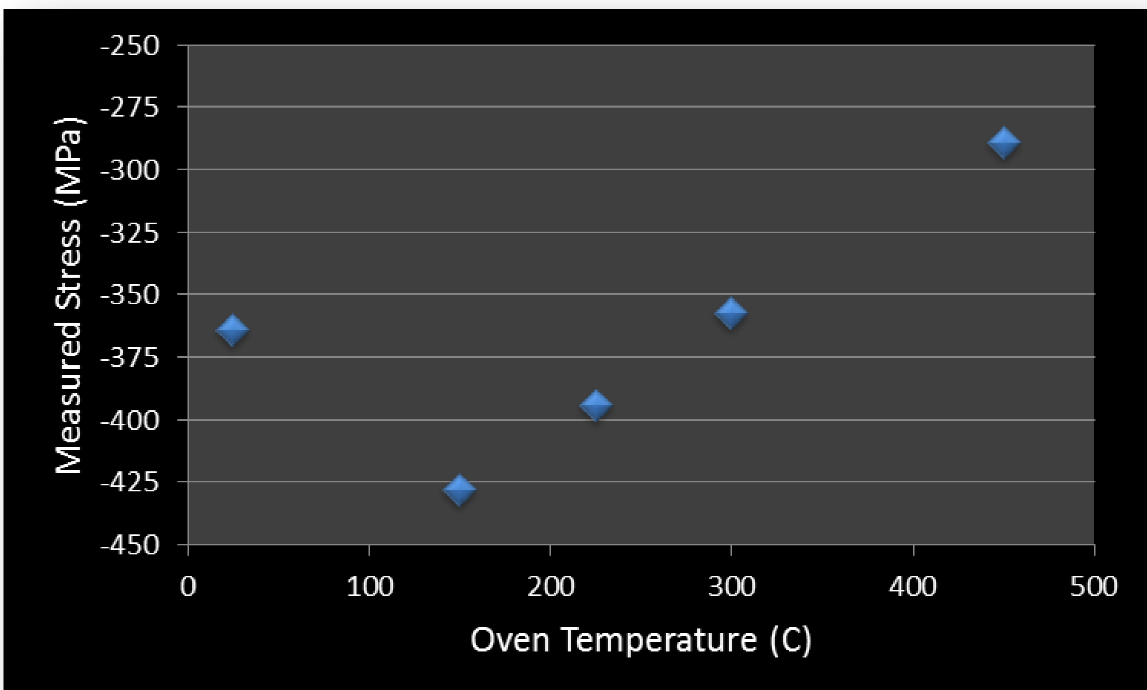

Figure 3. Stress in samples without the assist source after post-process baking.

Figure 4 compiles all the tested assist conditions and baking temperatures. It is readily apparent that the assist source provides a benefit regarding the stress conditions in the film over no assist source. Additionally, the assist source significantly improves stress conditions as compared to post-process baking at any temperature below 450°C. However, a one hour post-process bake at 450°C results in similar stress conditions when compared to having the assist source on during processing.

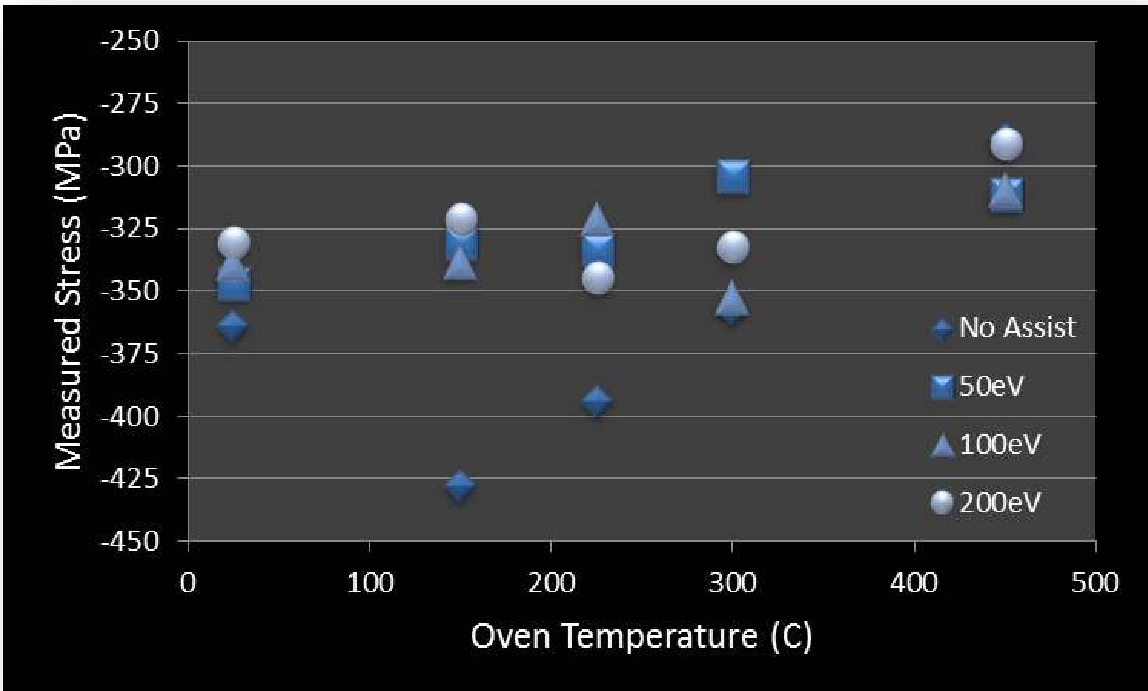

Figure 4. Measured stress at all assist and baking conditions

Conclusions

The effect of the assist source on coating stress is readily apparent as shown in Figure 4, though perhaps not as significant as one might expect. It is also not yet clear whether it is the assist ions themselves which are impacting the stress levels or the thermal energy which they impart causing an "annealing" effect similar to that from an oven. Since the assist ion source can be used during the coating process, the danger of contamination during transfer to an oven can be completely eliminated, further improving the performance of coatings, while simultaneously reducing the overall process time.

Since SiO_2 plays a major role in dielectric coatings - very often used as the low-index material - the 10% stress reduction shown above can have a significant impact on the final performance of the coating. Finally, this study indicates similar results in film stress can be achieved by either baking the sample at 450°C or using the assist ion source at 200eV. However, plastic substrates often cannot be baked at high temperature. Thus, the use of an assist ion source may allow thermally sensitive substrates and coatings to obtain the same stress-reducing effects without high-temperature baking.

While this paper by no means represents a comprehensive study, it does present justification for further review of conditions and other coating materials. The energy range tested in this paper was limited and future studies will include a larger energy range. Additionally, the results presented herein do not account for stoichiometric variation in the film which may also have an underlying effect on the film stress - further testing is necessary to isolate this variable. Finally, the stress reduction observed presents a compelling reason to use some level of ion assist in coating applications.

References

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