Investigating the Stress Development of Argon-Irradiated Thin-Film Silicon Over a Range of Incidence Angles

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ABSTRACT

The tendency for various nanostructures to form on solid surfaces due to broad-beam ion bombardment has important potential applications in surface cleaning, solar panel production, and nuclear reactor wall construction. In particular, broad-beam (>10^16 ions/cm^2) ion bombardments self-organize into nanostructures at a much faster rate than current narrow-beam (~10^15 ions/cm^2) in wide lithographic techniques can achieve. Unfortunately, many of the mechanisms behind the formation of these surface morphologies are not yet understood (i.e., surface diffusion and viscous flow) to explain the process, but researchers have not yet gained upon a universal model.

Our research evaluates a possible explanation for this phenomenon: one that incorporates both the plasticity and release of stress through the annealing process; we use a vacuum furnace that allows us to stress a sample for a range of different incidence angles. Using a 250nm 3-cm wide Ar beam, we bombard a silicon cantilever at various angles of incidence in ultra high vacuum while performing transverse measurements with a multi-beam optical stress sensor (MOS). We use Stoney's Equation to calculate the stress on the silicon and observe the pattern generated on the sample using atomic force microscopy. Finally, we compare our results with existing theories that predict the stress necessary to form nanostructures. We find that the stress generated during bombardment, the stress development of silicon is compressive at lower angles of incidence (~45°) and tensile at higher angles.

METHODS

To prepare our substrate, we cut a 1 x 6.5-9.5mm cantilever from a 100 ± 12.5-μm-thick silicon wafer. We coat one end of the sample with thermal paint, clump between two copper plates, and use more thermal paint to mount the copper clump onto the copper wedge inside the chamber. Inside the chamber, we use silicon shielding to coat the copper wedge (to reduce metallic backscattering). As shown in Figure 4 below, the argon ion source is free to rotate, allowing it to bombard from a range of incidence angles.

RESULTS

We bombarded silicon wafers at incidence angles of 0°, 20°, 40°, and 60° inside the chamber. Each time, we collected data for between 30 and 60 minutes, generating between 1,800 and 2,400 data points per trial. Average stress for each trial is graphed as a function of time (as the bold solid line in Figure 6), and stress measurements due to broad-beam ion bombardment were plotted (above and in orange, yellow, gray, and brown) with the approximate times at which we turned the ion source on and off. In our ATM pictures, we noticed no significant differences for 60° bombardment, where we observed well-developed ripples on the sample surface.

MEASURING STRESS

The low-energy, wide-beam ion bombardment of various surfaces to generate nanostructures has widespread potential applications despite not being understood. For example, the scalability of the process makes it very quick and cost-effective method for printing quantum dots on various surfaces, which is needed for manufacturing electronic parts and solar panels. Ion bombardment can be used for surface cleaning in laboratories, and understanding nanostructural formation can be the construction of nuclear reactor walls that are better able to withstand helium irradiation.

Below bombarding the sample, we pump the vacuum chamber down to pressures near 10^-10 torr. We flow argon into the chamber while maintaining pressures between 10^-10 and 10^-11 torr. We use a 10mA beam current setting to bombard the sample at normal incidence and 25mA at all other incidence angles. Our MOS arrangement (Figure 5) shows a 458.5-mm lens into a range window at the top of the chamber. The laser travels through an etalon (which splits into several beams) and a 651.07-mm bandwidth filter that filter out ambient light before reflecting off the sample and traveling out of another window, directly to the CCD camera. The camera reports to a k-space Associates, Inc. program. The program determines the location of the brightest pixels on each laser dot and periodically records the distances between them, returning the spacings between the laser dot every three seconds.

We use atomic force microscopy (AFM) to analyze the surface of our bombarded sample.

CONCLUSIONS

We studied how our data contains some discrepancies, the observable features in our experiments are generally consistent with stress development models proposed by Swenson and Norris. In addition, our AFM images led us to hypothesize a possible correlation between stress and pattern formation on this thin film, which could be of topical interest.

The chamber we use for our experiments has potential for further use in industry. More trials using a more continuous range of incidence angles can be performed in order to gather enough evidence for any sinusoidal or deterministic stress interference angles, which can be found by utilizing the crystallographic stress and which can be used to improve the stress and pattern formation in the final film. Our results point to a potential that could be of further investigation of the stress development of of the argon ion source.

REFERENCES

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