Swift Heavy Ion Irradiation of Si/SiOx Multilayered Sculptured Thin Films

C. Patzig [a], J.W. Gerlach [a], A. Bergmaier, and W. Assmann
[a] Leibniz-Institut für Oberflächenmodifizierung, Leipzig, Germany

Various physical vapor deposition processes like evaporation or sputtering are commonly used to deposit thin films. Usually, the particle flux contributing to the growing film reaches the substrate surface parallel to the substrate normal, resulting in a compact, dense film. If, however, the particles reach the substrate under a highly oblique angle β with respect to the substrate normal, self-shadowing of the initial islands that form in the beginning of the film growth sets in. The islands act as seeds for the following particle flux, shadowing the substrate region opposite to the direction of the incoming particles on a shadowing length l that is determined by the seed height h and the deposition angle $\beta : l = h \cdot tan\beta$. Thus, a highly underdense film consisting of needle-like structures, slanted into the direction of the incoming particles, results.

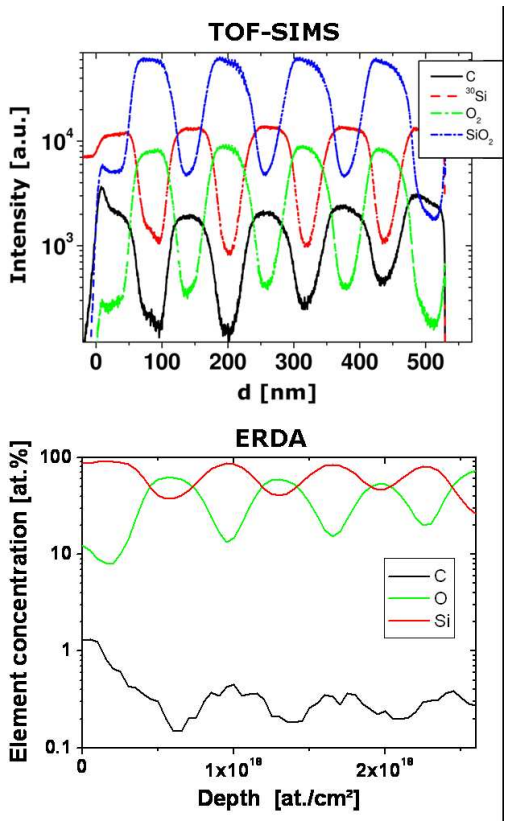

Fig. 1: Comparison of TOF-SIMS and ERDA concentration depth profiles of a Si/SiOx multilayered sculptured thin film.

By applying a constant or alternating substrate rotation, the needles can be sculptured to more complex structures like spirals, columns or chevrons. The resulting films are referred to as sculptured thin films (STF). This glancing angle deposition (GLAD) technique offers the possibility to deposit separated, complex nanostructures that can be implemented in many possible applications, e.g. polarization filters, Bragg filters or anti-reflective coatings, as well as pressure, gas or humidity sensors.

In the present study, GLAD at room temperature by means of argon ion beam sputter deposition of a Si target was performed. The deposition angle $\beta \approx 85$ deg combined with constant substrate rotation resulted in separated, helical structures [1]. A heterostructure design, i.e. a Si/SiO_x multilayer stack (5 x Si, 4 x SiO_x, single layer thickness $\sim$ 75 nm) on a Si substrate was achieved by alternately applying oxygen gas during deposition. To check the chemical composition of the heterostructure and to quantify time-of-flight secondary ion mass spectrometry (TOF-SIMS) measurements already made of it, elastic recoil detection analysis (ERDA) with a 200 MeV $^{197}Au^{15+}$ ion beam was done at the Garching Tandem accelerator. The comparison of the results (Fig. 1) demonstrates the high depth resolution of SIMS and the excellent quantifiability of elemental distributions with ERDA. Both methods combined prove that the oxygen depth profile in the helical multilayered STF was almost as intended with an x-value of $\sim$ 1.8 in the SiO_x layers. As the optical appearance of the samples changed distinctly within the ion irradiation spots, cross-section scanning electron microscopy (SEM) was performed in pristine and irradiated parts of the sample (Fig. 2) revealing a severely increased porosity of the Si layers accompanied by layer swelling. Contrary, the SiO_x layers showed lateral spreading and exhibited clearly visible ion tracks. Further investigations using new samples revealed significant changes in STF morphology and density as a function of the ion incidence angle and of the ion fluence. The observed effects increased with decreasing ion incidence angle and increasing ion fluence.

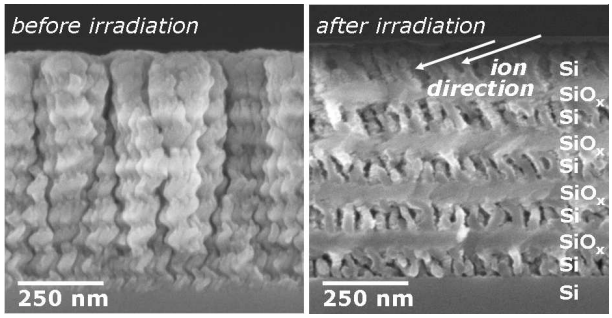

Fig. 2: SEM micrographs of a helical multilayered sculptured thin film before and after 200 MeV Au ion irradiation at 19 deg.

The origin of the observed effects seems to be a combination of the ion hammering effect [2], here accounting for the SiO_x layers, and an up to now not fully understood ion irradiation induced porosity enhancement effect that was already observed in medium energy ion implanted Si [3] and Ge irradiated by swift heavy ions. Further experiments are inevitable to explain the present combined mechanisms in the multilayered STFs.

References

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