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Ion Erosion and Elemental Purity of Deposited Si Films on Al.

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Abstract:
Direct sputter erosion depths in Si films deposited on Al substrates by PVD, CVD and plasma spay methods were measured after exposure to As^+ ions in a DC implanter beam and Ga^+ ions with a scanned FIB. Erosion depths are measured by optical methods. Metallic contamination and Si surface density in the deposited Si films were measured with RBS. SI surface textures were examined by SEM. Guidance for the operational lifetimes of Si coatings for other ions and energies is developed by scaling erosion rates by appropriate nuclear stopping powers.

1. Introduction

Deposited Si films are often used to reduce metal contamination for beam line and wafer fixturing components exposed to ion beams in implantation equipment. The erosion-limited lifetime of these Si films depends on the density, adhesion and thickness the deposited Si films.

Earlier studies of erosion of deposited Si films were part of general studies of metallic contamination reduction [1,2]. In this study, direct measurements of the erosion rates, surface texture, density and metal contamination levels were made for plasma spay, CVD and PVD-deposited Si-on-Al strips and crystalline Si reference materials.

2. Experimental details

Si films were deposited on Al test strips by a variety of means; Si from sputtered (PVD) Si targets, Si deposited in PECVD systems and by plasma spray Si methods. The Si film thicknesses ranged from 15 to over 300 um.

2.1. Ion beam exposure methods

Ion beam erosion was measured with a combination of direct 40 keV As^+ ion beams in a vintage NV-10-160 beamline and by scanned 30 keV Ga^+ ion beams in the focused ion beam (FIB) system.

Samples for the beamline tests were mounted in a modified graphite holder design used in other studies of ion erosion [3], placed in the flag Faraday location of a vintage EastonNV-10 beam line and exposed to 40 keV As^+ beams, accumulating doses between 7e17 to 4e19 As/cm^2. An auxiliary AC current was added to the analyzing electromagnet to scan the beam across the samples in a horizontal direction. With a scanned As^+ beam of ≈6 mA, 2 hours of scanned beam exposure resulted in a dose of 5e18 As/cm^2.

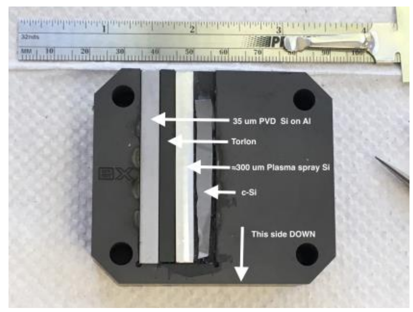

Figure 1. Photo of the samples in a graphite holder machined into the graphite beam stop of the Eaton NV-10 flag Faraday. Thermal and electrical contact between the sample base and graphite holder was assisted by a light coating of Aquadag.

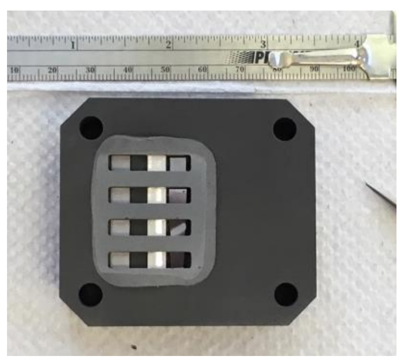

Figure 2. Photo of a 3 mm thick graphite mask plate in place over the samples and graphite holder. The lighter area on the mask plate is a beam burn from a previous exposure. The beam burn area is ≈9 cm^2.

Additional Si-on-Al and Si(100) samples were exposed to scanned 30 keV Ga^{+} beams in a ThermoFisher Scios DualBeam FIB system. Scanned Ga^{+} beams eroded a set of four 10x10 um regions separated by 20 um from each other to a typical depth of ≈1 um under constant beam current and erosion times. With a scanned Ga^{+} beam of ≈1 nA, each 10x10 um erosion pit was formed with a depth of ≈1 um in ≈6 min.

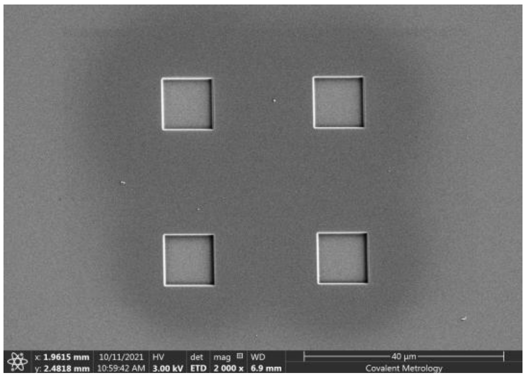

Figure 3. Micrograph of ion erosion areas in Si (100) after exposure to scanned 30 keV Ga^{+} beams. Each erosion pit was 10x10 um on a side and separated by 20 um from adjacent pits.

Since the FIM erosion runs had a flat Si surface, with no containment of secondary electrons, corrections for the total ion dose were made with secondary electron emission data for 30 keV Ga^{+} ions on Si [4, 5].

The erosion pits were imaged and depth profiles collected by repeated scans with a Keyance VK-X1100 laser confocal microscope. Data was taken with a lateral magnification of 150x and a depth resolution of 5 nm.

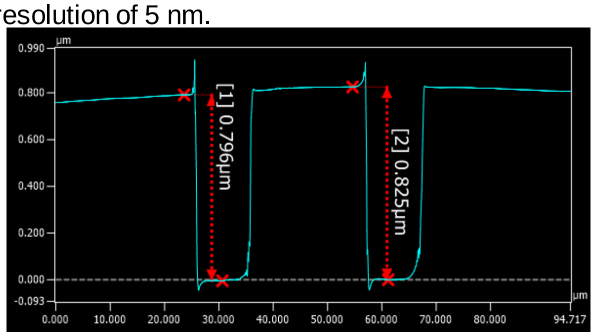

Figure 4. Optical depth profile scans Si(100) after exposure to scanned 30 keV Ga^{+} beams.

Since the FIM erosion runs had a flat Si surface, with no containment of secondary electrons, corrections for the total ion dose were made with secondary electron emission data for 30 keV Ga^{+} ions on Si [4, 5].

2.2. Surface texture measurements

The surface textures of the deposited Si films were inspected by SEM imaging before and after ion irradiation. The surface of the plasma spray-deposited Si showed the effects of the accumulation of small molten Si drops during deposition and contained many open areas.

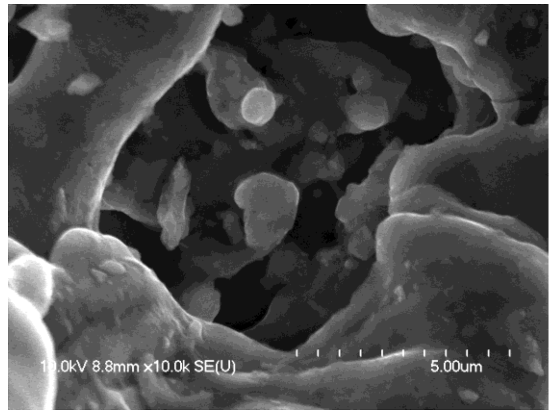

Figure 5. SEM image at 10,000x magnification of a spray-Si deposited film. Note the smooth micro-surface with no visual indications of Si crystallinity. Also note the "open" stricture of the surface.

Si films deposited by PVD and CVD methods had much denser surface textures, compared to the plasma spray deposited Si and showed indications of micro-crystallinity.

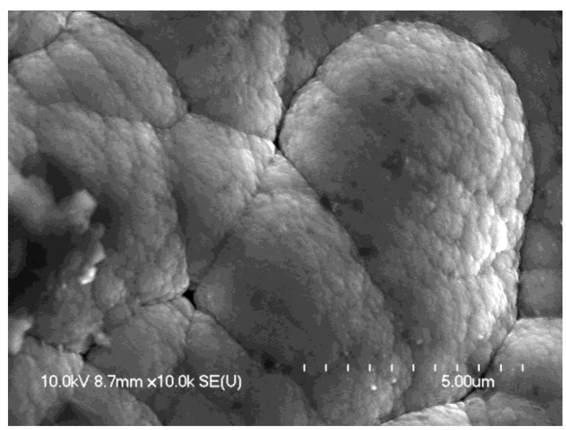

Figure 6. SEM image at 10,000x magnification of a PVD deposited Si film. Note the indications of micro-crystallinity and grain boundaries.

2.3. Erosion depth measurements.

Erosion depths from the As+ exposures were measured by optical imaging of masked and exposed surface heights and by scanned profiles along the mask edge boundaries.

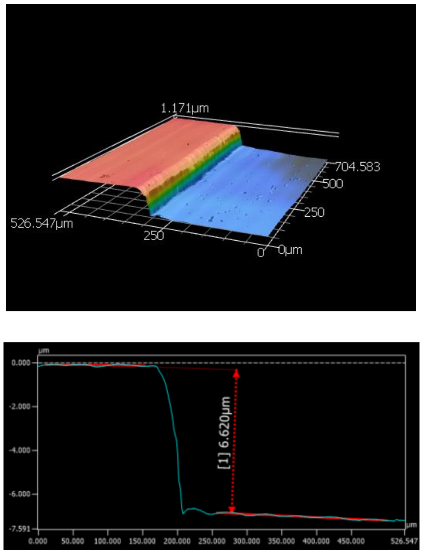

Figure 7. Optical (VK-X1100) imaging and profile scans for 40 keV As^+ exposed Si(100) wafer.

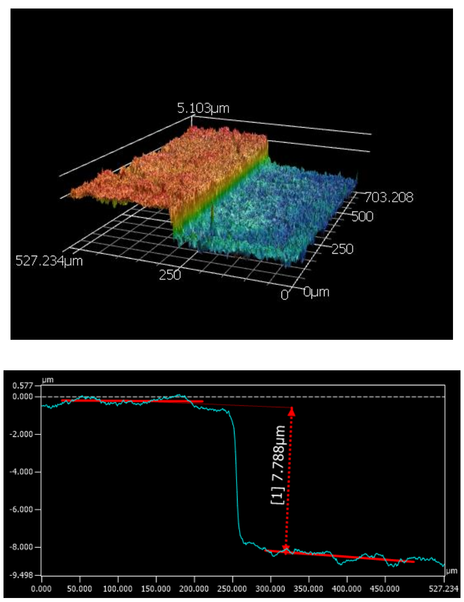

Figure 8. Optical (VK-X1100) imaging and profile scans for 40 keV As^+ exposed CVD deposited Si.

The rough surfaces of the various types of deposited Si led to the use of the step heights at the edges of the erosion pits for FIB samples as a more repeatable measure of the erosion depth than the pit bottom depth.

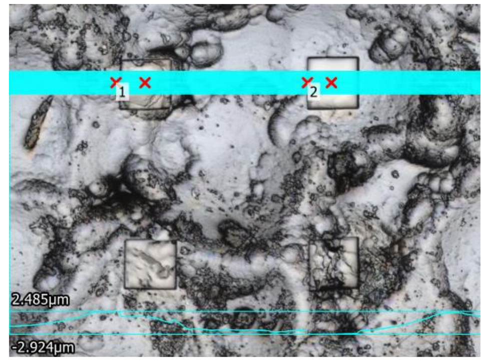

Figure 9. Laser optical image of 30 keV Ga+ erosion pits in a PVD deposited Si film. The highlighted depth measurement locations are indicated by [x] marks.

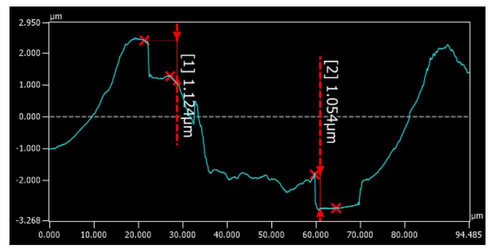

Figure 10. Optical profiles of 30 keV Ga^+ erosion pits in a PVD deposited Si film. In many cases the clear depth measurements were better obtained from the pit sidewall depths rather than the pit centers due to rough deposited Si surface.

2.4. Surface density and metallic contamination

The low density of the Si surface was evident in the lower RBS Si edge counts for the plasma spay deposited film compared to the PVD deposited and Si(100) surfaces. A high Fe concentration at ≈0.3% atomic at channel number ≈400 was also evident for the plasma spray deposited Si film. The Fe counts for the PVD Si film and Si(100) were lower than 0.08%.

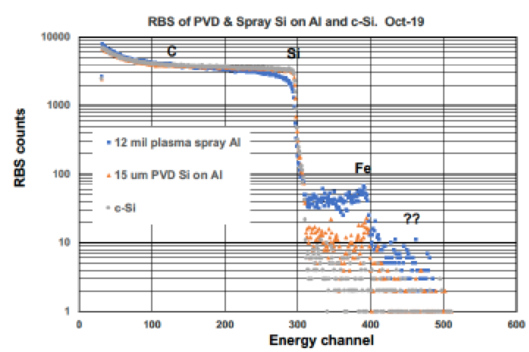

Figure 11. RBS data for plasma spray and PVD-deposited and c-Si, showing lower surface density and higher Fe contamination in the plasma spray-Si film.

3. Results

The erosion depth for all Si films followed a systematic dependence on ion dose (with the FIB results for 30 keV Ge^+ adjusted for the 10% lower relative nuclear stopping powers and sputter rates compared to 40 keV As^+ ions).

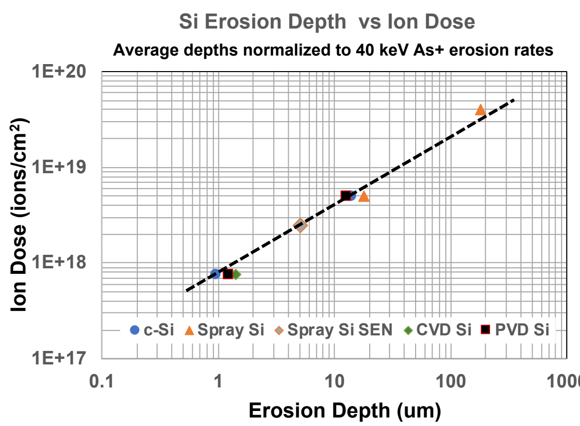

Figure 12. Si erosion depths for all ions normalized to 40 keV As^+ nuclear stopping powers.

Less dense plasma spray-Si films ion eroded up to ≈25% deeper depths than Si(100), with PVD and CVD deposited Si films eroding at ≈7 % and ≈15% relative depths respectively.

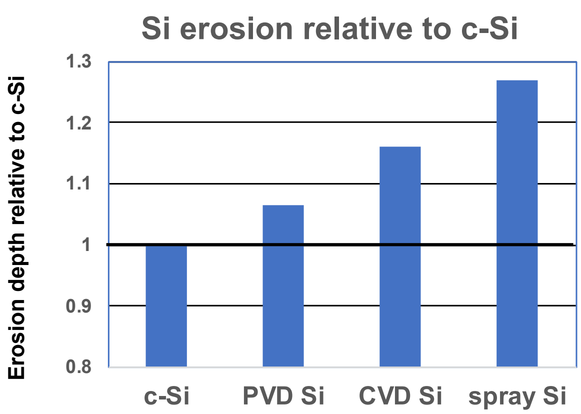

Figure 13. Average Si erosion depths for deposited Si films compared to Si(100) for all ions (normalized to 40 keV As^+ results).

4. Guidance for Si film erosion with other ions and energies.

Erosion data and nuclear stopping powers were used to estimate the sputter-limited lifetimes of deposited Si films exposed to high doses with common dopant ion beams at various energies by taking advantage of the direct dependence of ion sputter rates on the nuclear stopping powers for the ion-target combinations [6]. Nuclear stopping powers for various dopant ions on Si were calculated by SRIM/PRAL routines [7].

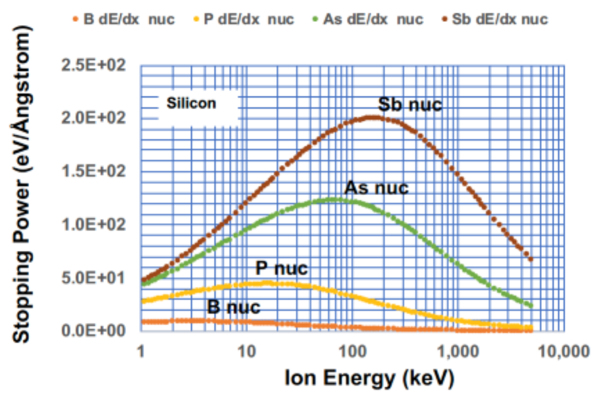

Figure 14. Nuclear stopping powers for common dopant ions on Si (calculated by SRIM).

The ion erosion depths vs. ion dose for other dopant ions was obtained by shifting the data for 40 keV As^+ (Fig. 12) by the relative nuclear stopping power (and sputter rate) for that ion (see Fig. 14).

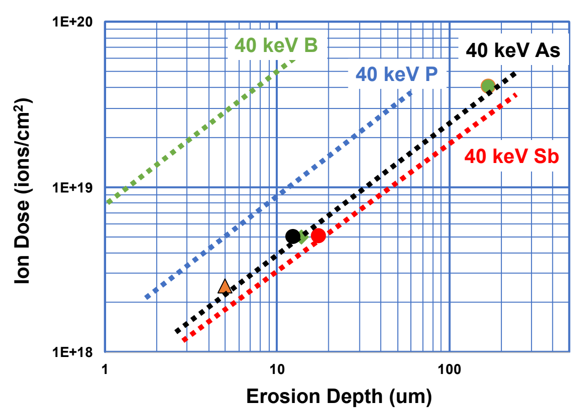

Figure 15. Ion erosion depth dependence on ion dose for 40 keV dopant ions based on relative nuclear stopping powers and data for 40 keV As^+.

The results shown in Fig. 15 can be used to estimate the lifetimes of deposited Si films with various accumulated ion doses for 40 keV ions. Estimates for ion exposures with other ion energies can be obtained with similar methods and the use of information in Fig. 14.

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