Microfabricated Germanium X-Ray Optics for the Cornell High Energy Synchrotron Source (CHESS)

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Primary CNF Tools Used: Plasma-Therm Versaline® Deep Si Etcher

Abstract:

With microfabrication and deep reactive ion etching, we have developed an x-ray optic called the Collimating Channel Array (CCA) for confocal x-ray fluorescence (CXRF) using germanium substrates. This builds on our previous efforts where these optics were fabricated out of silicon and demonstrated to have a depth resolution of 1.7 µm. The etch mechanisms and comparison between Si and Ge substrates are highlighted.

Summary of Research:

Confocal x-ray fluorescence (CXRF) is a depth resolved x-ray microprobe technique used to spatially resolve the elemental and chemical speciation of thin films or virtual cross sections of materials that cannot be thinned. The technique is realized by isolating a probe volume formed by the overlap of the foci of a focusing optic and a collection optic. CCAs are excellent collection optics in this regard since its depth resolution is nearly energy independent and more flexible to design [1-5].

CCAs contain a set of radially arranged, collimating channels that point to a single source position at the focus. The channel geometry, which collects the fluorescent x-ray photons from the defined probe volume to the detector, is defined with staggered pillars. The range of energy where these optics are useful is limited by attenuation losses at higher energies with silicon substrates. Optics fabricated from germanium (Ge) substrates as an alternative can operate well up to 30 keV compared to 12 keV with silicon (Si).

Since there are very few publications on plasma etching of germanium and even fewer on deep etching, a study was done to compare the etch performance of Ge with Si. The etch chemistry of Ge to SF₆ is similar and comparable to that of Si and as such, deep reactive ion etch recipes for Si also work well with germanium substrates. Using the Plasma-Therm Versaline® deep silicon etcher, a Taguchi L₉ orthogonal partial factorial Design Of Experiment (DOE) was conducted to compared the trends of the etch rates by varying the ICP power of the three processing steps; polymer deposition, polymer removal etch, isotropic Si/Ge etch, and the peak-to-peak voltage of the polymer removal etch step.

The etch comparison done for 4 µm and 40 µm features shown in Figures 1 and 2 suggests that the etch mechanisms for Ge differ from Si and that accounts for the difference in the etch rates and trends of the Ge and Si. The Ge etch rate is higher for the larger 40 µm features and smaller for the 4 µm features when compared to the Si etch rates as shown in Figure 3.

There is a strong aspect ratio dependent etching (ARDE) effect with Ge compared to Si and this suggests that the Ge etch is more chemically dependent process and as such, more susceptible to RIE-LAG. This unusual etch response actually also makes Ge a preferred substrate for fabricating CCA optics as the optic design inherently imposes a variable loading effect. The desired larger features are preferred to etch as deep as possible while maintaining the structural integrity of smaller features to survive the etch.
Figure 1: SEM profile of the etched 40 µm and 4 µm features in Si (A) and Ge (B).

Figure 2: Etch rate dependence on the Dep ICP power for the Si and Ge. The etch rate for the 40 µm features (A) is higher for Ge compared to Si but lower for the 4 µm features (B).

Figure 3: Comparison of ARDE with Ge (A) and Si (B) substrates demonstrating the differential etch rates for 4 µm and 40 µm trenches.

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