Micromachined Test Patterns for Rapid Screening of Etchants

CNF Project # 641-97

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Abstract:
A new technique for the rapid quantification of orientation-dependent etch rates, which uses micromachined test patterns and optical microscopy, has been developed. Etch rates measured with this technique are in good agreement with conventionally measured rates. The etching of silicon in KOH and TMAH has been quantified. In many cases, the measured anisotropies are well described by a simple model that is based on step flow etching.

Summary:
Etching is considered more of an art than a science, as etchant development often proceeds by trial-and-error, not by rational chemistry. This is unfortunate, because etching is a technologically important process that is used in everything from the cleaning of silicon wafers to the production of MEMS to the detection of dislocations.

We have developed a new technique for the rapid quantification of etchant anisotropy that uses micromachined silicon test patterns. Our standard pattern consists of 180 1°-wide wedges arranged in an evenly spaced, circular array. Each wedge is bounded by a different set of vertical planes, so the sides of each wedge etch with a characteristic, face-dependent rate. Anisotropic etching leads to the development of a “flower” which can be analyzed to yield absolute, face-specific etch rates of 180 surfaces simultaneously.

This pattern can also be used to investigate the morphologies of etched surfaces. Using a scanning electron microscope, the sides of the wedges can be imaged. A number of interesting morphological features, including macrosteps, pyramids and hillocks, have been seen on etched silicon surfaces.

This technique has been used to measure the orientation-dependent rates of KOH/silicon etching in the Si[110] and Si[100] zones. The concentration and temperature dependence of the reaction was quantified, and a pronounced kinetic isotope effect was observed for all orientations. The deceleration of the etch rate upon deuterium substitution is attributed to the rate-limiting cleavage of an Si–H bond. The macroscopic etch rate displays markedly non-Arrhenius behavior, and the concentration dependence cannot be fit by a simple empirical rate law. Both of these observations are attributed to the multisite nature of the etching reaction. The etch rate of vicinal Si(111) surfaces is well fit by a simple step flow model; however, etching-induced step bunching is also observed.

TMAH, tetramethylammonium hydroxide, is another strong aqueous base that is often used in silicon micromachining. Interestingly, a comparison of the etch rates of KOH and TMAH towards silicon surfaces shows pronounced differences even when corrected for the total hydroxide ion concentration. In contrast to KOH, TMAH is much less susceptible to macrostep formation; however, its etch rate is more affected by finite size effects.

References:
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- Etched test pattern measures face-specific etch rates.
- Face-specific etch morphologies imaged by SEM.
- Compatible with all silicon etchants.
- Quantitative, rapid and economical.

Figure 1, opposite:
Composite optical micrographs of micromachined test patterns; (a) Before etching, (b) After etching in a 70°C, 50% w/v KOH solution. The entire pattern is 18 mm in diameter.