

Wet Isotropic and Anisotropic Etching of Silicon

Silicon wafer etching, a process used in the fabrication of microelectronic devices, is the removal of excess material that is not sheltered by a resistive material. The etching process occurs multiple times during the wafer creation, so it is important to maintain accuracy. The depth and shape of the cut can be monitored by the amount of time the wafer is being etched, the choice of etching and resistive chemicals and the style of etching.

Wet etching, as opposed to dry etching, is when the wafer is engulfed in a chemical solution which decays any material not covered by a resistant material on the wafer. The chemical solution, usually containing hydrofluoric acid, reacts with silicon much faster than the resistive materials in order to create the desired etch. Wet etching process is quick, cost-effective and can be done in bulk, but requires safety precautions and produces toxic waste. Wet etching is typically done isotropically, but can go through a more selective etching process called anisotropic etching.

Isotropic etching is uniform etching process that decays the material at the same rate in both vertical and horizontal directions while anisotropic etching decays the material in a more selective direction. Anisotropic etching uses chemicals that remove crystalline materials at different rates depending on their density and orientation. This can be used to prevent undercut etches, also known as a bias [1]. A bias is when the resistive material hangs over the non-resistive material because of its curved U-shape. Even an ideal isotropic etch will have these curved walls while an ideal anisotropic etch will leave vertical walls and little to no overhanging bias. Figure 1 shows an example of isotropic and anisotropic etching. Isotropic and anisotropic have different selectivity properties on different materials which lead to the different wet etching processes. Anisotropic etching tends to use more hazardous materials that are more expensive and can cause damage to some of the more sensitive materials such as CMOS materials [2].

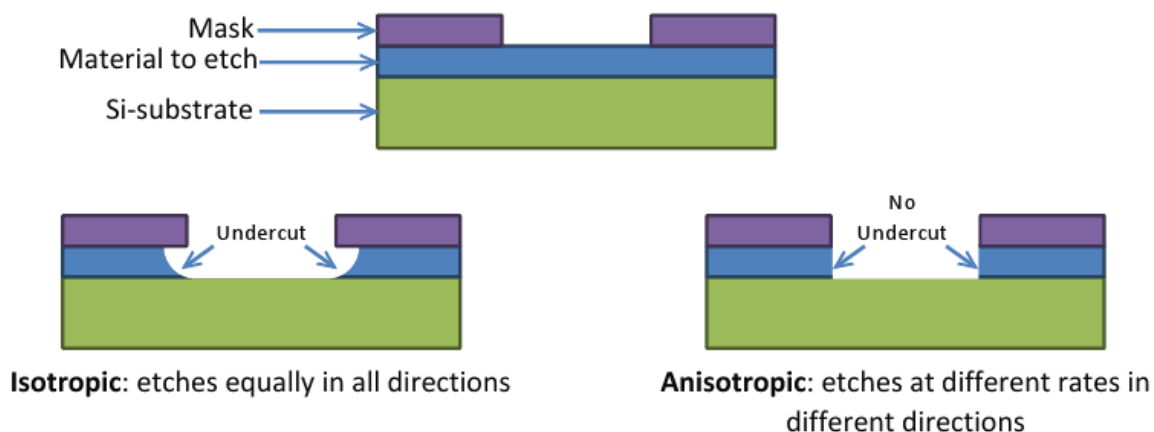


Figure 1. Example of isotropic and anisotropic etching.

Wet-etch chemistry relies essentially on redox reactions, reactions in which electrons are transferred between the surface to be etched and the etchant. These reactions represent the main process by which silicon atoms become oxidized and susceptible to dissolution. Typically, wet etchants have an oxidizer to facilitate the reaction, a solvent to dissolve the reaction products, and a diluted solution to transport the reaction products. Thus the etching process involves three key steps: (a) transport of etchant to the surface to be etched, (b) reaction of the etchant with the surface atoms, and (c) transport of reaction product away from the etched surface. A water solution of hydrofluoric acid, nitric acid, and acetic acid (called “HNA”) is typically used as an isotropic etchant for silicon. Silicon reacts with HNA in a redox reaction as follows: NO_2 in nitric acid is reduced to its ionized form, liberating holes which are used to oxidize silicon. The oxidized silicon combines with hydroxide ions in the water to form silicon dioxide molecules, which are then dissolved by hydrofluoric acid. [3]

In most wet subtractive processes, each of the transport and reaction steps is subject to a rate-limiting step: the transport steps (a and c) are subject to reactant diffusion while the reaction step (b) is subject to the temperature of the environment in which the reaction is occurring. Reactant diffusion can be facilitated by agitation of the liquid around the wafer. However, agitation can also make repeatability of the etching process very difficult. Higher-temperature solutions are able to supply more energy to the reaction, increasing the rate at which it occurs as compared to lower-temperature environments, in which the reaction rate is lower.

When considering etchant masks, we must anticipate the selectivity of the etchant we use. For example, HNA can be masked by a layer of silicon dioxide, but it is not completely unsusceptible to etching. In fact, silicon nitride is a better mask because has a lower etch rate than silicon. Masks created by photolithography are very useful in defining two-dimensional areas to be etched. We have also discussed various ways in which the depth of etching can be controlled by using anisotropic etching techniques, which are indirectly dependent on the two-dimensional mask layer. However, direct control of etch depths and widths cannot be achieved using masks.

In order to add sensitive controls to etch-depths and etch-directions, we can include “etch stops” in the wafer design. Etch stops are material modifications in silicon that have different etchant selectivities. These material modifications can be achieved in several ways. First, photolithography can provide enough energy to change the chemical structure of a layer such as photoresist. An etchant can then be selected which removes exposed or unexposed portions of material. Secondly, anisotropic etchants can be used to limit the etching process based on mask sizes and orientation selectivity. Figure 2 demonstrates etch patterns using similar masks on substrates that have different crystal orientations. In addition, etchant selectivities to doping can be utilized to fabricate etch boundaries. A common dopant etch stop is the p^+ or boron etch stop: as regions of silicon become very heavily-doped ($\sim 6 \times 10^{19} \text{ cm}^{-3}$), etch rates for common etchants drop dramatically. However, because the doping levels are very high, the material for the etch stop is rendered practically useless for electrical devices. This means that boron etch stops can only easily and effectively be used for micro-mechanical systems [4].

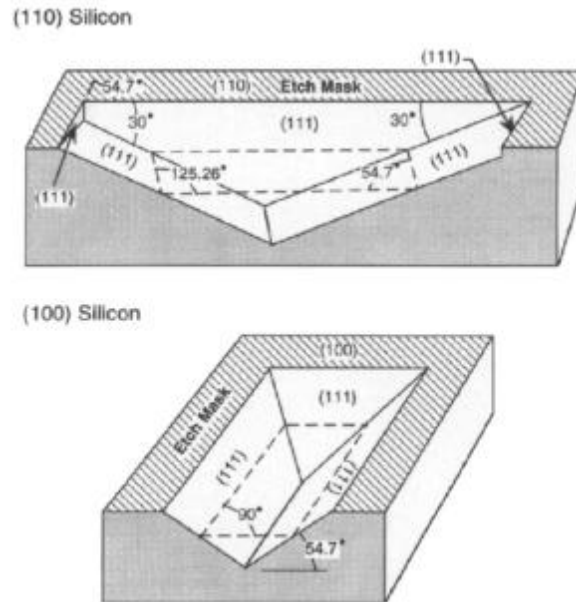


Figure 2. Examples of $\langle 111 \rangle$ plane selectivity with differently oriented silicon planes. (Image from Collins, [4].)

References

- [1] Chen, Erli. *Fabrication III – Etching*, Harvard University, Applied Physics 298R. 4-12-2004.
<http://www.mrsec.harvard.edu/education/ap298r2004/Erli%20chen%20Fabrication%20III%20%20Etching.pdf>
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