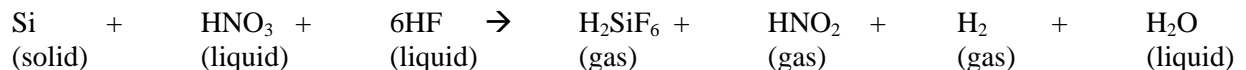


## Silicon Wet Isotropic and Anisotropic Etching

Wet etching is a process in which chemical solutions, or etchants, are used to dissolve areas of a silicon substrate that are unprotected by an etching mask. The two different types of wet etching are isotropic and anisotropic etching. Comparing these methods will give insight to their advantages, disadvantages, and applications in monolithic IC fabrication.

### Wet Isotropic Etching

In wet isotropic etching, non-directional etchants are used to remove exposed areas of a substrate, meaning that etching occurs equally in all directions [6]. Wet isotropic etching consists of three general processes: the transport of etchants to the surface of the wafer, a chemical reaction producing soluble by-products, and the movement of reaction products away from the wafer surface [7]. The etchant is transported to the wafer surface by either spraying the solution onto the substrate or submerging the wafer in the solution. Depending on the type of material being etched, along with the desired etch rate, different etchants can be used at various dilutions. For silicon dioxide, hydrofluoric acid (HF) is often used at H<sub>2</sub>O-to-HF ratio of 6:1, yielding an etch rate of roughly 1200 Å/min. For pure silicon, hydrofluoric nitric acetic (HNA) acid is often used. Also, silicon nitride is etched using H<sub>3</sub>PO<sub>4</sub> at 10:1 for nitride over oxide and 30:1 for nitride over silicon [7]. When an etchant is applied to the substrate, a chemical reaction occurs that leads to the transport of products. For example, in the chemical reaction between Si, HF, and HNO<sub>3</sub>, it is clear that the products of the reaction are only gases and liquids:



It is also important to note that for pure silicon, a strong oxidant HNO<sub>3</sub> is combined with the etchant HF, because oxidized silicon has a much higher etch rate compared to pure silicon. In addition, buffering agents such as ammonium fluoride (NH<sub>4</sub>F) and acetic acid (CH<sub>3</sub>COOH) can be included in a solution to help restore etchant being lost through the chemical reaction [7].

Iso-etch curves are useful for estimating the etch rates for a given solution. Figure 1 shows the iso-etch curve for silicon using HF, HNO<sub>3</sub>, and acetic acid. First, intersecting lines are drawn based on the ratio of HF, HNO<sub>3</sub>, and CH<sub>3</sub>OOH in the overall solution. Then, by matching the point with one of the iso-etch curves, the etch rate of the solution can be estimated in units of μm/min.

Wet isotropic etching is advantageous for several reasons. First, it is highly selective, meaning that there is a significant difference between the etch rates for what is and is not desired to be etched. For example, when using hydrofluoric acid to etch silicon dioxide, the selectivity is often better than 100:1 between SiO<sub>2</sub> and the silicon substrate [7]. Also, wet isotropic etching techniques are relatively simple and inexpensive.

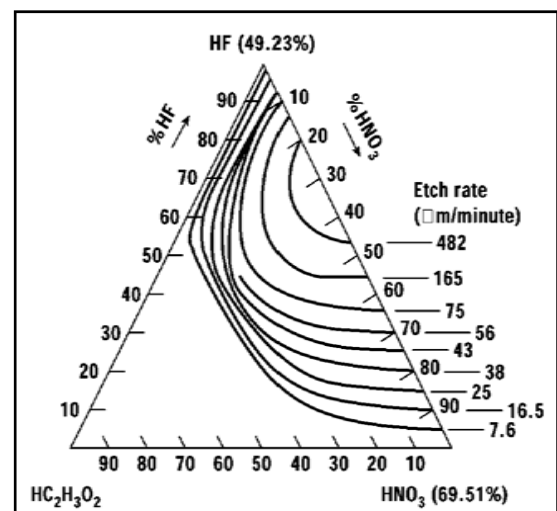


Figure 1 [8]

The biggest disadvantage of wet isotropic etching is undercutting. Undercutting is the lateral extent of etching under the photoresist mask. In order to quantify undercut, we can use the etch rate anisotropy equation  $A = 1 - R_L/R_V$ , where  $A$  is anisotropy,  $R_L$  is the lateral etch rate, and  $R_V$  is the vertical etch rate [7]. Ideally, for a completely isotropic etch,  $A = 0$ , meaning that the lateral and vertical etch rates are identical. This is depicted in Figure 2, where the lateral undercut equals the thickness of the oxide.

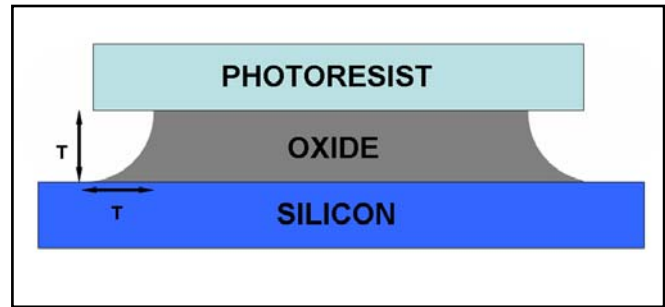


Figure 2

Other disadvantages of wet isotropic etching are the safety and sanitary hazards dealing with harmful pollutants such as hydrofluoric acid. Furthermore, wet chemical etching is prone to high defect levels due to solution particulate contamination, and generally has poor process control for repeatability [7].

### Wet Anisotropic Etching

Unlike in isotropic etching, undercutting is sharpened to well-defined corners in anisotropic etching since etchants such as KOH etch at different rates for different crystal planes. Such etchants are termed 'orientation dependant' [2]. Depending on the orientation of the silicon crystal lattice, apparent atomic density will be greater or less which effects the etch rate of a particular etchant. Higher densities will create a lower etch rate. Miller indices become very important when etching using an anisotropic process. For example, when etching silicon with a Miller index of  $\langle 100 \rangle$  with KOH, sidewalls oriented by a  $\langle 111 \rangle$  Miller index will appear making an angle of 54.74 degrees as shown in figure 1 [1].

Some examples of wet anisotropic etchants are variants of alkali metals (K, Na, Cs, Rb, etc) combined with Hydroxide (OH). One of the most common alkali metal/OH combination is KOH. As mentioned before, this group of etchants can be used to selectively attack certain crystal orientations faster than others. Other examples of common anisotropic etchants are ethylene diamine pyrochatechol (EDP) and tetramethyl ammonium hydroxide (TMAH).

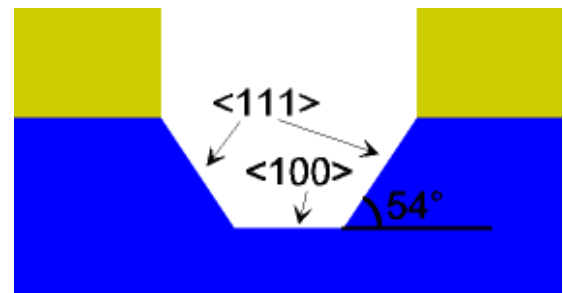


Figure 3: An anisotropic etch of a crystal with  $\langle 100 \rangle$  [3]

Wet anisotropic etching carries benefits when performing fabrication. Cost is a major factor when planning a fabrication process. Most wet etchants are quite inexpensive and very easily acquired. The level of anisotropy is also very easily controlled. As described earlier, very specific etch patterns can be implemented due to the use of directional dependent etchants. Etch rates can also be controlled by etchant type, concentration and temperature.

There are also drawbacks corresponding to the benefits of wet anisotropic etching. The fact that the process is orientation dependent can cause issues. During the fabrication process, silicon wafers must be chosen with specific Miller index orientations. If the orientation is incorrect, etch patterns in the wafer will also be incorrect, adding to the cost of the process. Wet etching is also very temperature and concentration dependent. Figures 4 and 5 show these dependencies. These variables must be carefully controlled for results to be satisfactory. Another negative aspect is that many of the etchant solutions are dangerous and also require special disposal procedures [2]. As with isotropic etching, undercutting is still prevalent since the wet chemical still etches in all directions.

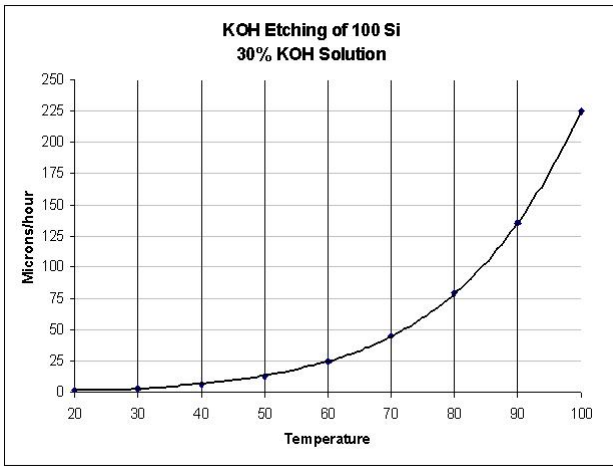


Figure 5: Etch rates for 30% KOH Solution [4]

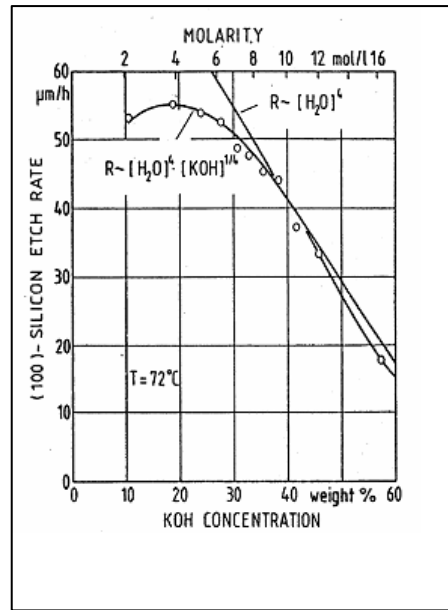


Figure 4: Etch Rate of <100> KOH Solution at 72° C

#### Applications of Wet Isotropic and Anisotropic Etching

Though both isotropic and anisotropic etchings both have relatively high etch rates, isotropic etching is faster than anisotropic etching. Typical etch rates for isotropic etching range from a few microns to several tens of microns per minute, while anisotropic etching generally has an etch rate of about 1 μm/min [8]. Furthermore, isotropic wet etching is more useful for non-critical tasks with relatively large geometries. For example, isotropic etching is used in the removal of work-damaged surfaces, rounding of sharp anisotropically etched corners, and creating structures and planar surfaces on single-crystal slices [8]. On the other hand, anisotropic etching is more useful for smaller and more specific geometries that require more vertical sidewalls in etching. Specific applications of anisotropic etching include radiation hardened circuits, J FET arrays, solar cell anti-reflecting surfaces, waveguides, infrared detectors, high value capacitors and blackbodies [1].

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