Wet and Dry Etching

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Isotropy and anisotropy:

When a material is attacked by a liquid or vapor etchant, it is removed isotropically (uniformly in all directions) or anisotropic etching (uniformity in vertical direction). The difference between isotropic etching and anisotropic etching is shown in Figure 1. Material removal rate for wet-etching is usually faster than the rates for many dry etching processes and can easily be changed by varying temperature or the concentration of active species.

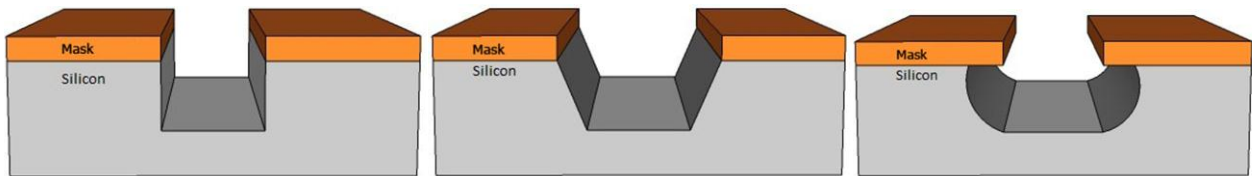


Figure 1. (a) Completely anisotropic (b) Partially anisotropic and (c) Isotropic etching of silicon

Wet Etch

Synonyms: chemical etching, liquid etching

Definition:

Wet etching is a material removal process that uses liquid chemicals or etchants to remove materials from a wafer. The specific patters are defined by masks on the wafer. Materials that are not protected by the masks are etched away by liquid chemicals. These masks are deposited and patterned on the wafers in a prior fabrication step using lithography. [2]

A wet etching process involves multiple chemical reactions that consume the original reactants and produce new reactants. The wet etch process can be described by three basic steps. (1) Diffusion of the liquid etchant to the structure that is to be removed. (2) The reaction between the liquid etchant and the material being etched away. A reduction-oxidation (redox) reaction usually occurs. This reaction entails the oxidation of the material then dissolving the oxidized material. (3) Diffusion of the byproducts in the reaction from the reacted surface.

Anisotropic wet etching:

Liquid etchants etch crystalline materials at different rates depending upon which crystal face is exposed to the etchant. There is a large difference in the etch rate depending on the silicon

crystalline plane. In materials such as silicon, this effect can allow for very high anisotropy. Some of the anisotropic wet etching agents for silicon are potassium hydroxide (KOH), ethylenediamine pyrocatechol (EDP), or tetramethylammonium hydroxide (TMAH). Etching a (100) silicon wafer would result in a pyramid shaped etch pit as shown in Figure 2a. The etched wall will be flat and angled. The angle to the surface of the wafer is 54.7°. Figure 2c-d depicts scanning electron micrographs of (110)-oriented two-dimensional silicon walls with micro and nanoscale dimensions generated based on KOH based wet etching.

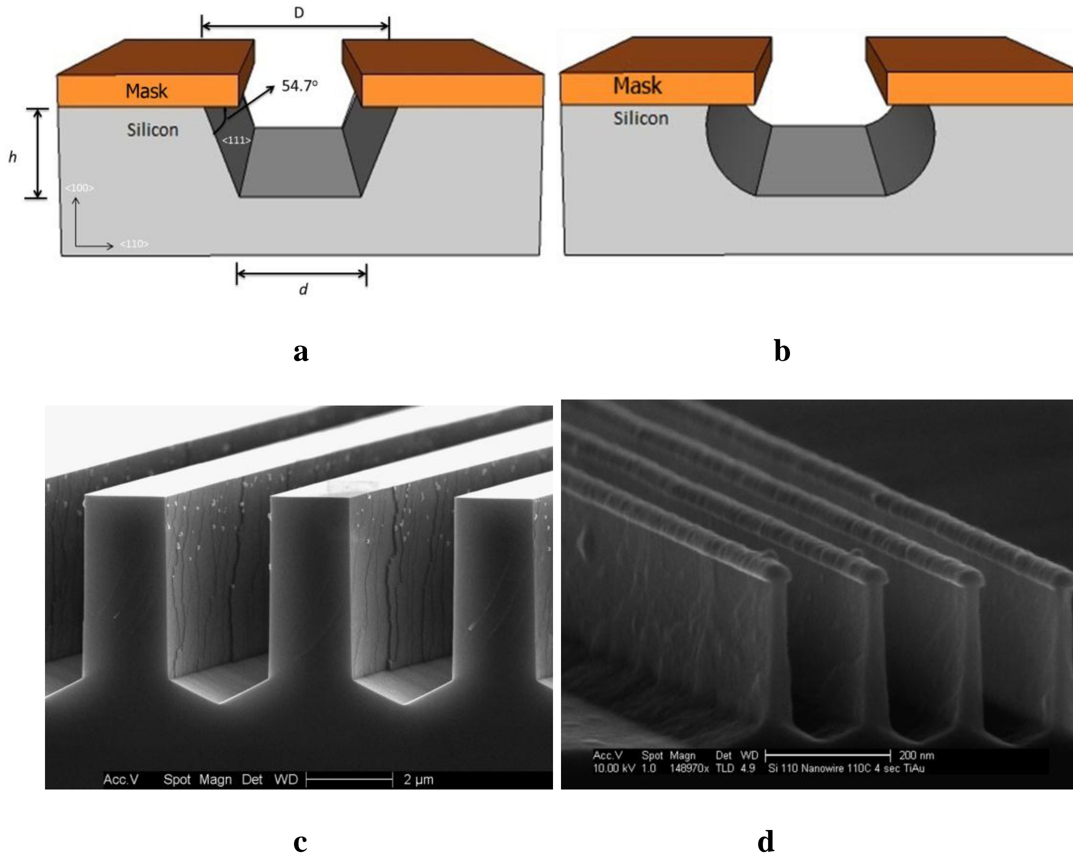


Figure 2. Schematics of an etch profile in (a) an anisotropic and (b) an isotropic etch of a (100) oriented silicon surface. (c-d) KOH based wet etching of (110)-oriented Si surfaces with micro and nanoscale two-dimensional walls.

The relationship between mask dimensions, etch depth and the floor width is given in equation 1.

$$d = D - \left(\frac{2h}{\tan(54.7^{o})}\right) \; [equation\ 1]$$

Isotropic wet etching:
For isotropic wet etching, a mixture of hydrofluoric acid, nitric acid, and acetic acid (HNA) is the most common etchant solvent for silicon. The concentrations of each etchant determines the etch rate. Silicon dioxide or silicon nitride is usually used as a masking material against HNA. As the reaction takes place, the material is removed laterally at a rate similar to the speed of etching downward. This lateral and downward etching process takes places even with isotropic dry etching which is described in the dry etch section.

Wet chemical etching is generally isotropic even though a mask is present since the liquid etchant can penetrate underneath the mask (Figure 2b). If directionality is very important for high-resolution pattern transfer, wet chemical etching is normally not used.

Dry Etch:
Synonyms: plasma etching, gas etching, physical dry etching, chemical dry etching, physical-chemical etching

Definition:
In dry etching, plasmas or etchant gasses remove the substrate material. The reaction that takes place can be done utilizing high kinetic energy of particle beams, chemical reaction or a combination of both.

Physical dry etching:
Physical dry etching requires high energy kinetic energy (ion, electron, or photon) beams to etch off the substrate atoms. When the high energy particles knock out the atoms from the substrate surface, the material evaporates after leaving the substrate. There is no chemical reaction taking place and therefore only the material that is unmasked will be removed. The physical reaction taking place is illustrated in Figure 3.

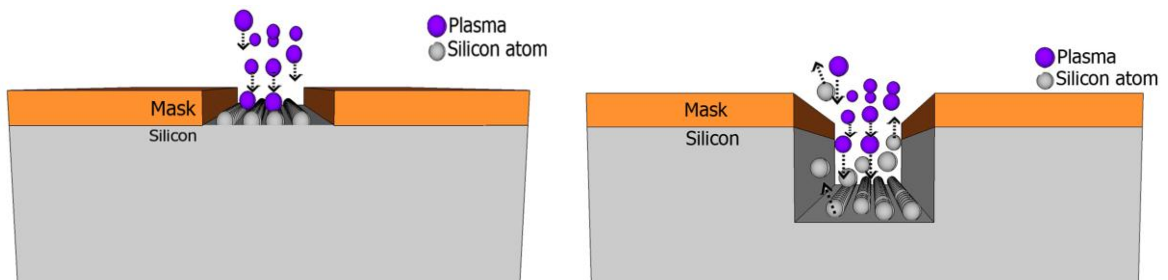


Figure 3. The plasma hits the silicon wafer with high energy to knock-off the Si atoms on the surface. (a) The plasma atoms hitting the surface. (b) The silicon atoms being evaporated off from the surface.

Chemical dry etching:

Chemical dry etching (also called vapor phase etching) does not use liquid chemicals or etchants. This process involves a chemical reaction between etchant gases to attack the silicon surface. The chemical dry etching process is usually isotropic and exhibits high selectively. Anisotropic dry etching has the ability to etch with finer resolution and higher aspect ratio than isotropic etching. Due to the directional nature of dry etching, undercutting can be avoided. Figure 4 shows a rendition of the reaction that takes place in chemical dry etching. Some of the ions that are used in chemical dry etching is tetrafluoromethane (CH_4), sulfur hexafluoride (SF_6), nitrogen trifluoride (NF_3), chlorine gas (Cl_2), or fluorine (F_2).[3]

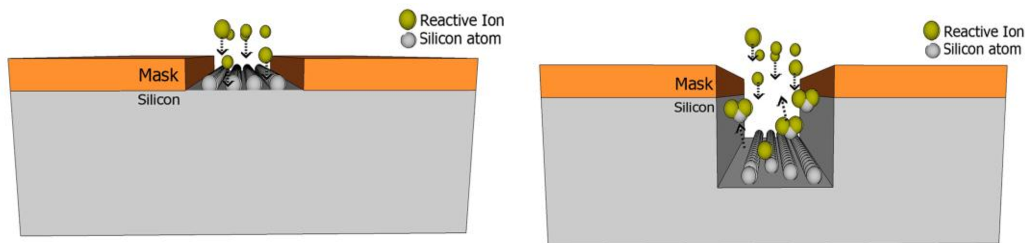


Figure 4. Process of a reactive ion interacting with the silicon surface. (a) The interaction between the reactive ion and the silicon atom. (b) A bond between the reactive ion and the silicon atom then chemically remove the silicon atoms from the surface.

Reactive Ion Etching:

Reactive ion etching (RIE) uses both physical and chemical mechanisms to achieve high levels of resolution. The process is one of the most diverse and most widely used processes in industry and research. Since the process combines both physical and chemical interactions, the process is much faster. The high energy collision from the ionization helps to dissociate the etchant molecules into more reactive species.

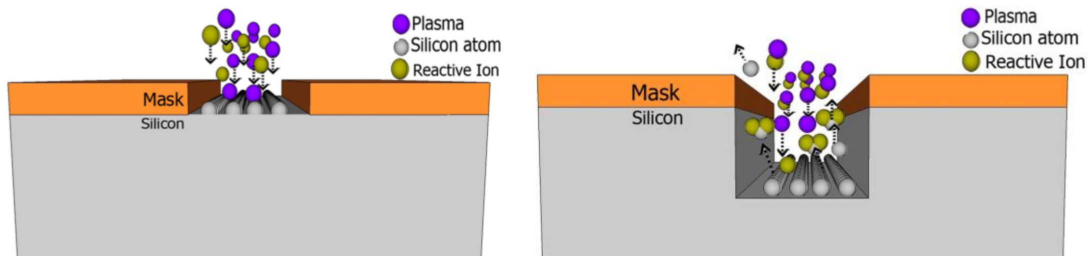
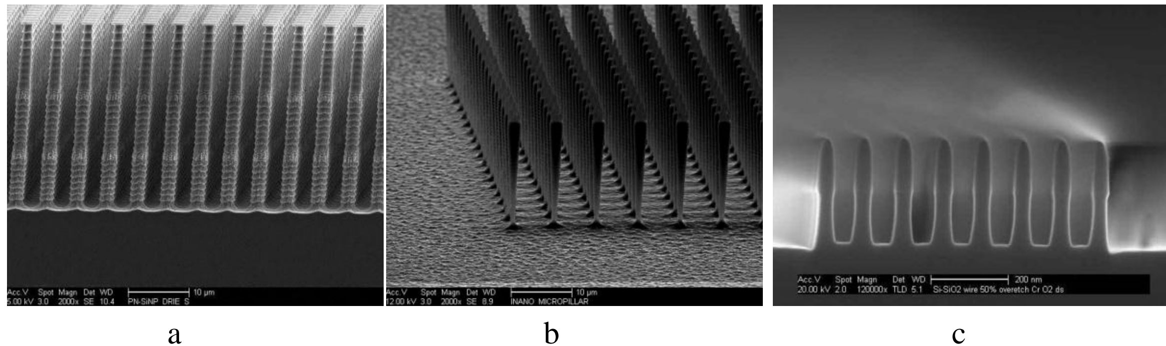


Figure 5. The RIE process. This process involves both physical and chemical reactions to etch off the silicon.

In the RIE-process, cations are produced from reactive gases which are accelerated with high energy to the substrate and chemically react with the silicon. The typical RIE gasses for Si are CF_4, SF_6 and $BCl_2 + Cl_2$. As seen in Figure 5, both physical and chemical reaction is taking

place. Figure 6 depicts some micro/nano structures with high aspect ration etched using RIE process.



a b c

Figure 6. (a-b) Silicon micro-pillars fabricated using deep reactive ion etching (DRIE). These pillars were made using a Bosch process. The Bosch process is a pulsed-multiplexed etching technique which alternates between two modes to achieve extremely long and vertical micron-scaled nanowires.[1] (c) SiO_2 and Si nanowalls etched via RIE process.

An extensive study was done to determine the dependence of the etching performance by Chen et al.[4] Factors such as applied coil or electrode power, reactant gas flow rates, duty cycles, and chamber pressures were considered. These process parameters were modeled and experimentally determined to see the effect on the surface morphology and the mechanical performance of the silicon structures.

References:

[1] V. J. Logeeswaran*, et al.*, "Harvesting and Transferring Vertical Pillar Arrays of Single-Crystal Semiconductor Devices to Arbitrary Substrates," *Electron Devices, IEEE Transactions on,* vol. 57, pp. 1856-1864, 2010.

[2] R. C. Jaeger, *Introduction To Microelectronic Fabrication*, 2 ed. Auburn, Upper Saddle River - Prentice Hall, 2002.

[3] M. J. Madou, *Fundamentals of Microfabrication: The Science of Miniaturization*, 2 ed.: CRC Press, 2002.

[4] Chen*, et al.*, *Effect of process parameters on the surface morphology and mechanical performance of silicon structures after deep reactive ion etching (DRIE)* vol. 11. New York, NY, ETATS-UNIS: Institute of Electrical and Electronics Engineers, 2002.