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Anisotropic Etching in Silicon and Other Materials Using a Reactive Ion Etcher:

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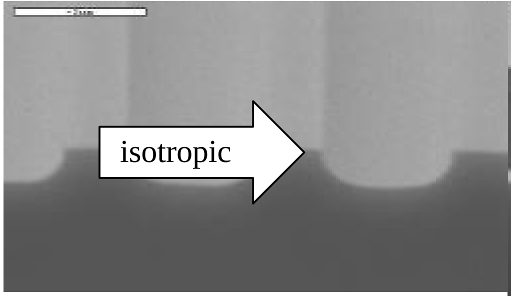
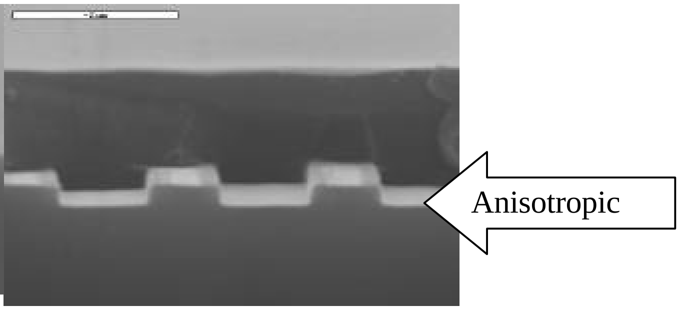
Microfabrication technology has been one of the major areas of advancement of technology from the latter half of the twentieth century until today. Initially, microfabrication wasn't a new concept—it started as a way to make large, complex electronic circuits smaller, and therefore more durable and less power-consuming. With advances in microfabrication techniques, we are starting to be able to not only manufacture solid-state electronic devices on a microscopic scale, but also mechanical devices with moving parts that operate at incredible speeds.

Etching is one of the most fundamental processes of microfabrication. Etching, which is the process of using chemicals to cut into a surface, is the "knife" of the microfabrication world. The blade, chisel, flame, arc, etc. used to cut or shape material in normal-scale fabrication or manufacturing techniques is substituted by a chemical etching process. It is necessary to use etching in microfabrication because of the *resolution*, or accuracy, that itching affords us. For example, the resolution of a knife is determined by the thickness of its blade's cutting edge. The resolution of an etching chemical is determined by the size of the molecules of the chemical—millions of times smaller than a knife edge at the least!

Etching processes, therefore, are an essential part of microfabrication. These processes, however, by their very nature involve challenges not normally encountered with the use of more conventional cutting tools. One of the classic etching difficulties is the *isotropic*, or omni-directional, nature of etching. For example, when acid is used to etch a channel into a silicon wafer, the acid does not merely etch straight down into the surface. The acid etches in all directions, creating a rounded bottom to the channel, and undercutting the edges of the channel as it does so. For more advanced microfabrication goals, such as making waveguides for communication using light on a computer chip, or makes tiny mechanical switches or machines out of silicon, this type of "cutting" is simply unacceptable. For these more difficult microfabrication projects, we need to make etching *anisotropic,* or one-directional. We want the etching chemicals to etch straight into the material surface only, producing straight sidewalls and a flat trench floor. The reactive ion etcher (RIE) is a system that is designed to do this type of etching.





The purpose of my research was to correctly set up and characterize BYU's new RIE etching system, and to achieve the anisotropic etching that was desired with the purchase of the new machine. To do this, I first had to learn a lot about how these systems work.

A RIE is a *plasma* etcher. Objects to be etched are placed in a chamber which is then vacuum-pumped down to extremely low pressure. Etching gases such as CF_4 and oxygen are streamed through the chamber, and an electronic power generator excites a glowing plasma with these gases, in much the same way that the plasma in fluorescent lighting fixtures is made. These plasma gases form highly reactive ions, which etch silicon and other materials they come in contact with. Most plasma etchers etch isotropically- the ionized gases in the chamber act just as an acid would in a wet etch. The RIE's advantage in this case comes from the special geometry of its etching chamber. Because of the architecture of the etching chamber, a strong negative charge builds up on the plate the objects to be etched rest on, and the positively charged etching ions are accelerated directly normal to the surface of this plate, causing an anisotropic, or "straight-down" etch.

My research centered mainly on using the RIE, which was not set up yet when I was ready to begin. Because my research, if successful, was intended to be used as characterization data for the machine, I was also given the job of installing the RIE in the clean room and bringing it into operation. Once this was done, I began to study the characteristics of the machine when being used to etch commonly etched substances- elemental silicon, silicon dioxide, and silicon nitride.

In seeking to achieve anisotropic etching with the RIE, I encountered several hurdles. Etching, whether for microfabrication purposes or not, always requires that some that the desired etch pattern or "mask" be laid onto the surface to be etched. In silicon processing, it is common to use a polymer called photoresist as this mask. A disadvantage of the type of etches I was running is that they generally eat away at the masking material at close to the same rate as the material to be etched, in the best possible case. An unoptimized etch would generally etch the masking material much faster that the material to be etched. The photoresist mask I used was at most 2 microns thick, so it was necessary to optimize the ratio of the mask etch rate to material etch rate before even considering optimizing the anisotropy of the machine. This ratio is referred to as *selectivity*.

After lots of work, I arrived at optimal parameters for selectivity, and we were able to start on the actual anisotropy work. After a short period of time, however, found that the degree of anisotropy that the machine produced depends simply on the power setting of the power source that excites the plasma in the first place—the higher the power setting, the stronger the positively charged etching ions are attracted to the material to be etched, and the more isotropic the etch turns out. Happily, it was easy to establish maximum power ratings for different materials, based on the selectivity data that I had already gathered. The RIE is now up and running, with a good array of characterization data that allow it to assist in other teaching and research processes with a degree of ease and accuracy that hasn't before existed at BYU.