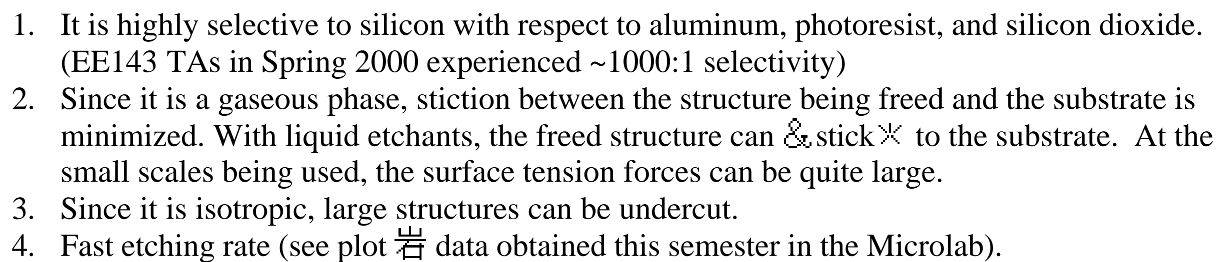
XeF_2 Etching of Silicon

Characteristics: dry, isotropic, vapor-phase etch

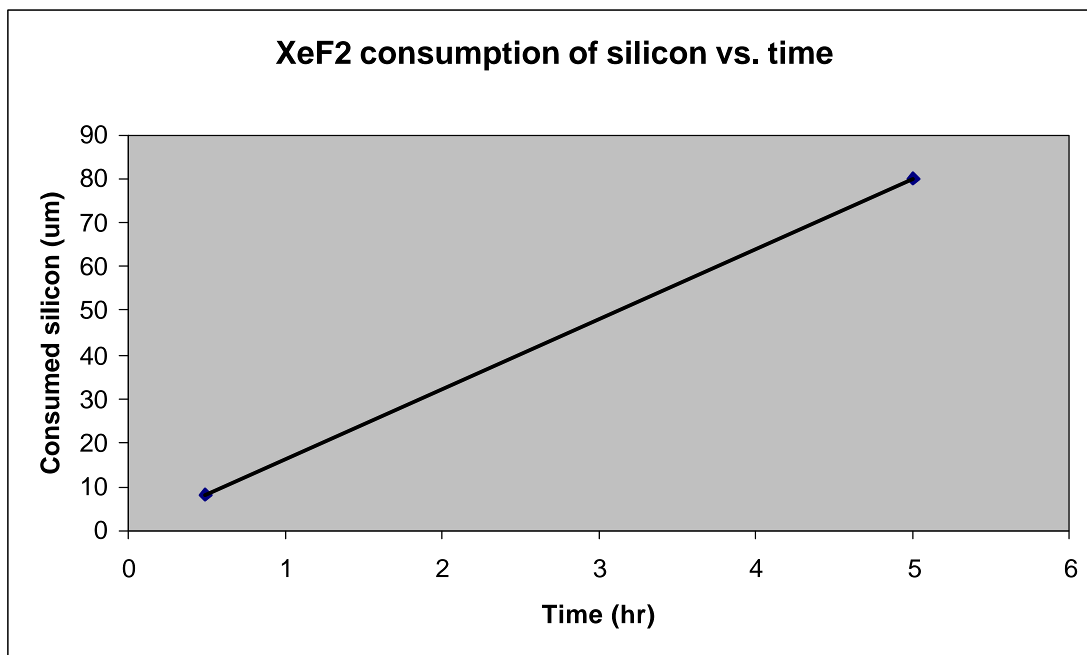
XeF_2 sublimates at its vapor pressure (~3.8 Torr at 25 °C) to etch silicon.

Important: Wafer surfaces need to be dehydrated immediately prior to etching for about 5 minutes. Otherwise a thin silicon fluoride polymer layer forms due to a reaction with the water on the silicon. This can dramatically reduce the etch rate, or even stop it completely.

Advantages of XeF_2 etching vs. other silicon etchants:



1. It is highly selective to silicon with respect to aluminum, photoresist, and silicon dioxide. (EE143 TAs in Spring 2000 experienced ~1000:1 selectivity)
2. Since it is a gaseous phase, stiction between the structure being freed and the substrate is minimized. With liquid etchants, the freed structure can “stick” to the substrate. At the small scales being used, the surface tension forces can be quite large.
3. Since it is isotropic, large structures can be undercut.
4. Fast etching rate (see plot — data obtained this semester in the Microlab).



The above data suggests an etch rate of 16 µm/hour, or about 2700Å /minute, which is in agreement with values in the literature.

Disadvantages:

1. There are no known silicon etch stops. The XeF_2 etching rate does not depend on crystal plane, or silicon dopant content. It is often beneficial to know when the silicon etch is

going to stop. KOH, for example, etches the (100) planes of silicon about 400 times faster than the (111) planes. This allows one to stop the silicon etch on the (111) planes.
2. The etching process poses a safety hazard. A fume hood is needed because SiF_4 is a byproduct. Breathing too much XeF_2 or SiF2 can result in chemical burns to the respiratory tract.

Etch Mechanism:

Primary reaction occurring between XeF_2 and silicon:

$$2\ XeF_2 + Si \rightarrow 2\ Xe\ (g) \uparrow + SiF_4\ (g) \uparrow$$

Sequence of reaction:

1. non-dissociative adsorption of XeF_2 at the silicon surface
2. dissociation of the absorbed gas, F_2
3. reaction between the adsorbed atoms and the silicon surface to form an adsorbed product molecule, SiF_4 (ads)
4. desorption of the product molecule (SiF_4) into the gas phase
5. volatilization of non-reactive residue (dissociated Xe) from the etched surface

Etch Methods:

A. The “pulse” method – specimen is alternatively exposed to XeF_2 vapor and vacuum.

(1) The etch chamber is pumped down to vacuum (~20mTorr) then all valves are closed.
(2) The XeF_2 inlet valve is opened and the timing for a pulse duration begins (e.g. 20sec).
(3) The XeF_2 inlet valve is closed when the chamber pressure reaches a desired value (e.g. 1.4 Torr).
(4) XeF_2 is consumed and silicon is etched for the selected pulse duration (e.g. 20sec).
(5) The chamber is pumped back down to vacuum, and steps 1-4 are repeated.

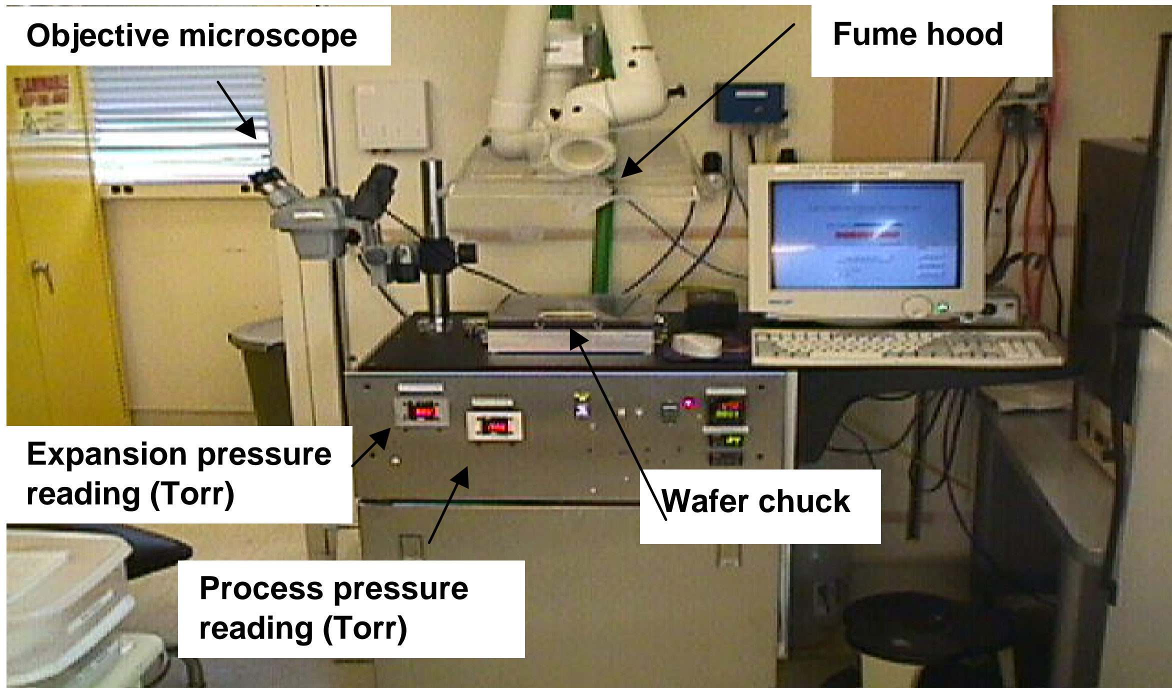
The etch rate is proportional to the expansion chamber pressure (step #3), but the chamber has to stabilize at the desired pressure. The chamber in the microlab often has trouble exceeding 1.4 Torr.

B. Constant pressure etching for a set amount of time

(1) The chamber is initially at vacuum (~20 mTorr).
(2) The XeF_2 inlet valve is opened and etching begins.
(3) The pressure is immediately adjusted to the desire etch pressure (e.g., 1.4 Torr) using the throttle valve.
(4) The XeF_2 inlet valve is closed when the desired etch time is reached.
(5) The chamber is pumped back down to vacuum.

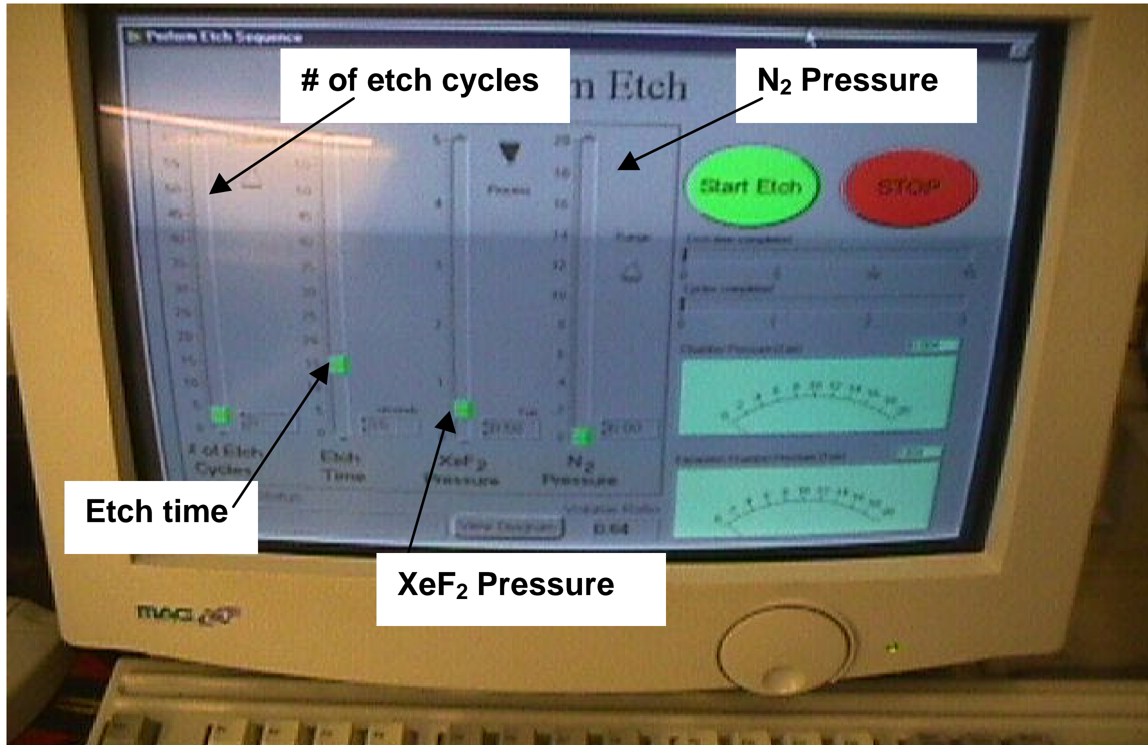
For EE143, the TAs have been using pulse etching, with pulse cycles of 20 sec. To remove about 50 μm of silicon, about 30 pulse cycles have been necessary.

Microlab XeF$_2$ etch tool

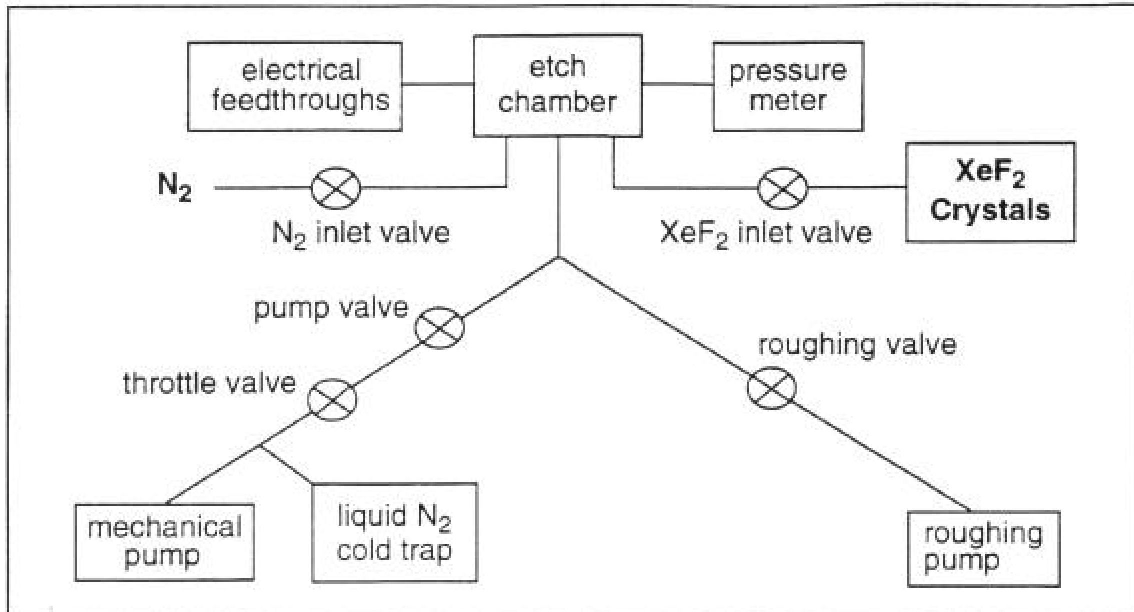


User Menu

Note control variables!



XeF_2 Etching System Schematic



Above is a diagram of the XeF_2 etching system. One can view the path of the XeF_2 gas from the source, expansion, and process chamber, and finally the vacuum pump. For one etch ※pulse§ , the
XeF_2 inlet valve is first opened, then closed when the pressure reaches a desired value.
The XeF_2 is left in the chamber for a predetermined period of time (etching), and then the gas is removed using the vacuum pump.

For more info, see the Microlab web-site:

http://www-microlab.eecs.berkeley.edu:8080/manual/chap7.15