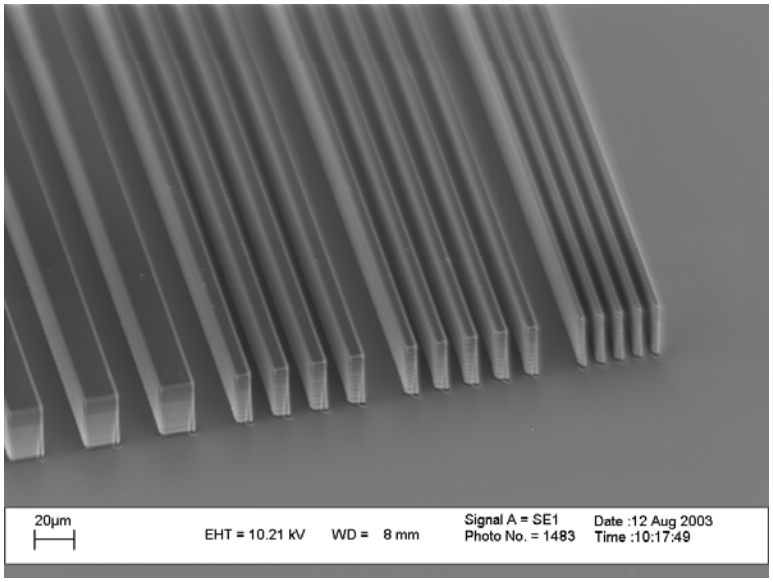
An Introduction to

Bosch processing on the ICPRIE

At the University of Alberta's NanoFab



Bosch processing on the ICPRIE

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Introduction

The Bosch process is a deep silicon etch which was developed and patented by Robert Bosch GmbH. This process uses a two step plasma process which alternates between deposition and etching. The result is an anisotropic etch that can have a vertical sidewall regardless of the orientation of the silicon crystal. Although a noticeable rippling of the surface can be found on the sidewalls. The Bosch process is currently the most popular process for deep silicon etching in the NanoFab. It provides a very consistent etch with a near 90 degree sidewall.

Background

The Bosch process is referred to as a dry silicon etch. This designation comes from its contrast to other deep silicon etches which take place in aqueous solutions. The etch mechanism is chemical and the reaction takes place in a controlled plasma chamber. The machine that we use to control this plasma is the Inductively Coupled Plasma Reactive Ion Etcher (ICPRIE). The ICPRIE has the ability to control the plasma in two ways. The first is magnetic/inductive. This takes place in a large tube shaped electromagnet. The magnetic field can control the energy of the plasma, which will in turn control the atomic species that are in the plasma. These atomic species are typically ions and free radicals. The second way of controlling the plasma is electrically. This is done using an electric field, which is applied along the axis of the tube. This provides the forward momentum to the particles to bring them down to the surface of the wafer. A typical configuration is shown is figure 1.

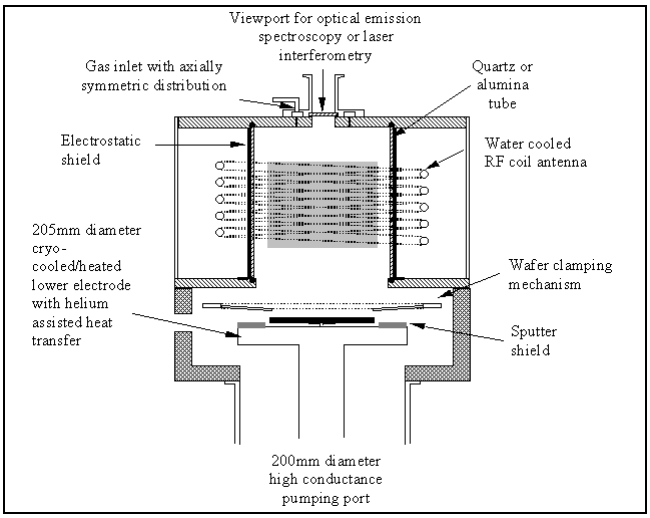

Figure 1: Typical ICPRIE configuration (courtesy of Oxford Instruments)

There are two different plasmas that are created in the chamber. An etch plasma and a deposition plasma. The anisotropic etch is formed by alternating between these two plasmas. The details are shown in figure 2

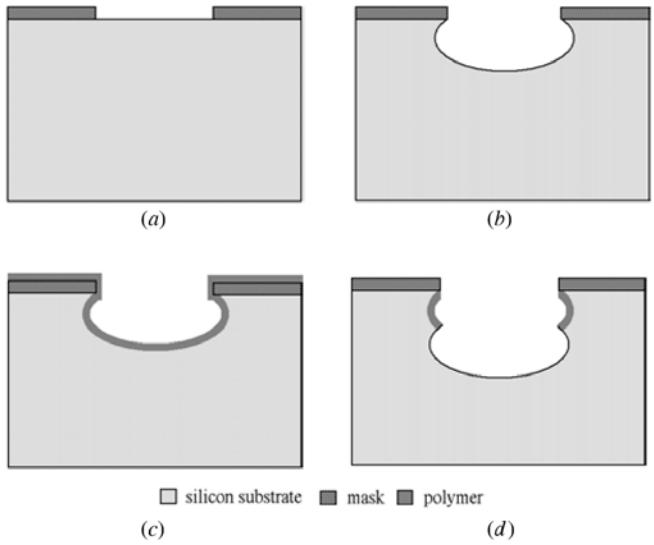

Figure 2 [3]: Bosch progression: a) Sample with mask, b) First etch step, c) Deposition Step, d) Second etch step

The first step is the etch step, it uses SF_6 to form a plasma that is rich in fluorine radicals which react with the silicon to produce SiF_4 which is gaseous and pumped out of the system by the vacuum pump. This etch is isotropic and will only be allowed to etch for a limited depth which is usually less than one micron. It is followed by the deposition step, which uses C_4F_8 to form the plasma. The C_4F_8 changes configuration in the plasma and links together to form chains of a Teflon-like polymer, which is deposited on the surface of the wafer. This Teflon-like polymer does not react with the etch plasma and provides protection to the silicon it covers from being further etched. During the second etch step the Teflon-like polymer must be removed before etching can start. This is done by using the ions in the plasma to physically sputter the polymer away from the surface. Because the ions are accelerated by the electric field they are very directional and strike the surface with near normal incidence. Hence the polymer is not removed from the sidewalls and leaves them protected when the reactive part of the etch takes place. By switching back and forth between etch and deposition plasmas the silicon is etched in an anisotropic fashion to the desired etch depth.

Advantages and Disadvantages

The most important advantage that the Bosch process has is that it etches independently of the crystal orientation; it etches straight down from the masked surface. Wet chemical deep silicon etches will etch along the crystal plane. This will produce angled walls and v-groove channels on a typical <100> silicon wafer. The Bosch process will always produce square walls and square channels. The trade off for this is that the walls are not perfectly smooth. The rippling from the alternating etch and deposition steps, although sub-micron, is inherent to the process.

Characteristics

The Bosch process has some unique characteristics that need to be considered when working with it. The first one to consider is etch rate. The etch rate of the Bosch process is dependent on the amount of exposed silicon on the wafer to be processed. The standard Bosch process that was developed at the NanoFab, and is being used for most applications, has an etch rate that can vary from 3 microns per minute to 1.33 microns per minute depending on the amount of exposed silicon.

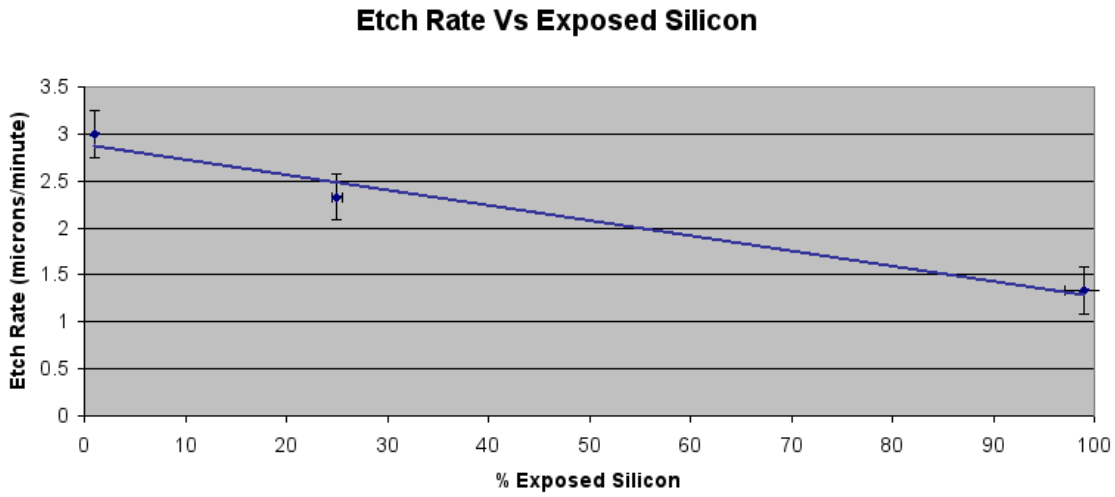

Figure 3: Etch rate curve

The second most important characteristic of the Bosch process is the uniformity of the etch. Figure 4 shows the typical etch rate change with position on the 100mm wafer in microns per minute and in percent. A 70mm diameter has been drawn in with a dashed line to show where the uniformity of etch is plus or minus 10%.

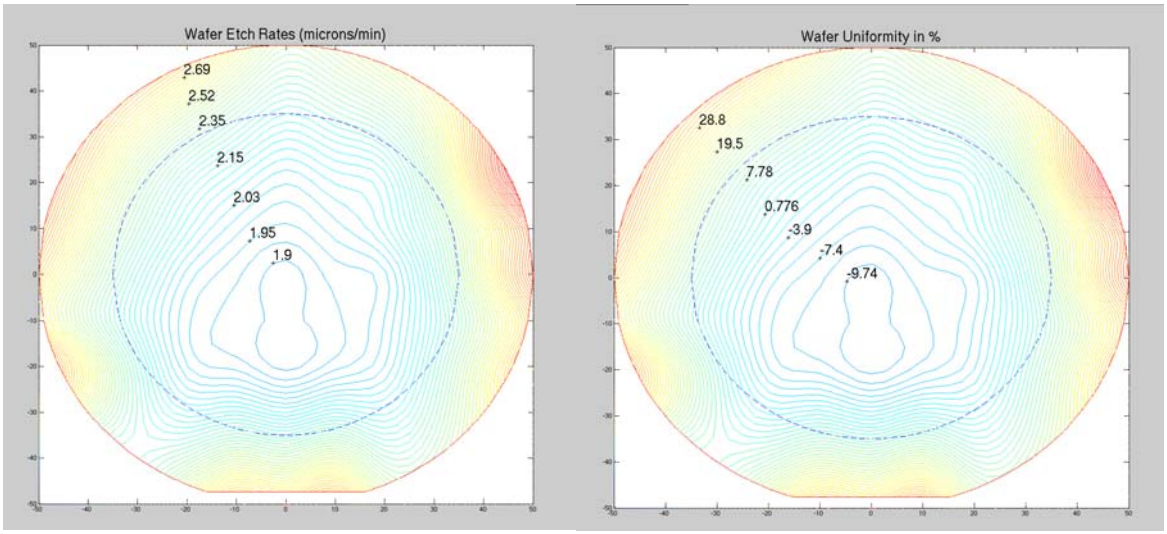

Figure 4: Etch rate maps

The third and final important characteristic that will be discussed is called the mask selectivity. The masking layer in Bosch processing can be photoresist and/or silicon dioxide. This masking layer will be etched during the process but at a much slower rate than the silicon. Mask selectivity varies from design to design but as a quick rule of thumb 1 micron of photoresist will last for 20 microns of silicon etching or a ratio of 20:1. One micron of silicon dioxide will last for 100 microns of silicon etching or a ratio of 100:1. These rules of thumb are based on a worst-case scenario and have a small safety margin in them. Actual selectivity will vary depending on the design. It is always a good idea to err on the side of too thick of a mask than too thin as there is no way to add more masking material one etching has started.

Standard Recipe

The NanoFab has developed a standard Bosch recipe to be used on the NanoFab's ICPRIE. This recipe is meant to perform well for the majority of the projects that are being done in the facility. The process is qualified using the NanoFab's standard test mask, which has ~26% of it's area as exposed silicon, and provides a near 90° sidewall at an etch rate of 2.33 microns per minute. The details of the recipe are documented below.

1) Pump Step:

Once the wafer has loaded the system will pump for 1 minute to reach base pressure before beginning processing. The details of the system parameters are below.

TEMP: 20 ºC	PRESS: 0	HE: 0 sccm
ICP: 0 Watts	RF: 0 Watts	TIME: 1 min
C4F8: 0.0 sccm	SF6: 0.0 sccm	O2: 0.0 sccm

2) Strike Plasma Step:

The plasma is lit and then held on throughout processing. The system parameters are the same as the deposition step with the exception of the gas flow where only 50 sccm's of C_4F_8 are used. This step will deposit a small layer of polymer on to the sample but should not slow etching onset by any appreciable amount. The details of the system parameters are below.

TEMP: 20 ºC	PRESS: 0	HE: 20 sccm
ICP: 750 Watts	RF: 12 Watts	TIME: 3 sec
C4F8: 50.0 sccm	SF6: 1.0 sccm	O2: 20.0 sccm

3) Repeat Step

The deposition and etch steps that follow are repeated in a cyclic fashion until the desired etch depth is achieved. The repeat step has to be modified manually each time before running the recipe to control this amount of etching. By default this value is set to 50, but will take values between 1 and 10000.

4) Deposition Step:

The deposition step is for 9 seconds and the details of the system parameters are below

TEMP: 20 ºC	PRESS: 30	HE: 20 sccm
ICP: 750 Watts	RF: 12 Watts	TIME: 9 sec
C4F8: 200.0 sccm	SF6: 1.0 sccm	O2: 0.0 sccm

5) Etch Step:

The etch step is for 9 seconds and the details of the system parameters are below

TEMP: 20 ºC	PRESS: 30	HE: 20 sccm
ICP: 750 Watts	RF: 40 Watts	TIME: 9 sec
C4F8: 1.0 sccm	SF6: 150.0 sccm	O2: 0.0 sccm

6) Loop:

This step returns to the repeat step and decrements the count.

References:

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