Selective Reactive Ion Etching of P-Doped Polysilicon Using a Cl_2/HBr Mixture

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A novel reactive ion etching process for p-doped polysilicon using a Cl_2/HBr mixture with multiple process steps is presented. The smoothness and the anisotropy of the etched wall appear to be very good. The etching characteristics of the polysilicon and mask materials are also reported.

There are many chemistries available to etch polysilicon. Most of these chemistries involve Freons and are capable of non-selective, isotropic etching ideal for delayering processes. However, there are many applications that require etching to completely stop on a thin layer (usually around 20 nm thick) of silicon oxide. These applications also require an anisotropic etch with nearly vertical sidewalls. In this letter, a technique for carrying out smooth, selective, and anisotropic etching of p-doped polysilicon will be presented.

A standard 13.56 MHz driven parallel plate reactive ion etcher (Trion Technology Minilock II) with internal anodisation for use with chlorine was used for this experiment. The biased electrode has a diameter of 200 millimeters and can be heated or cooled with a liquid heat exchange system. The ground electrode has a diameter of 400 millimeters. The temperature of the bottom electrode was maintained below 75°C for the use of a photoresist mask. Many different combinations of Cl_2 and HBr have been examined with RIE power varying from 100 Watts to 400 Watts and process pressures varying from 10 millitorr to 500 millitorr.

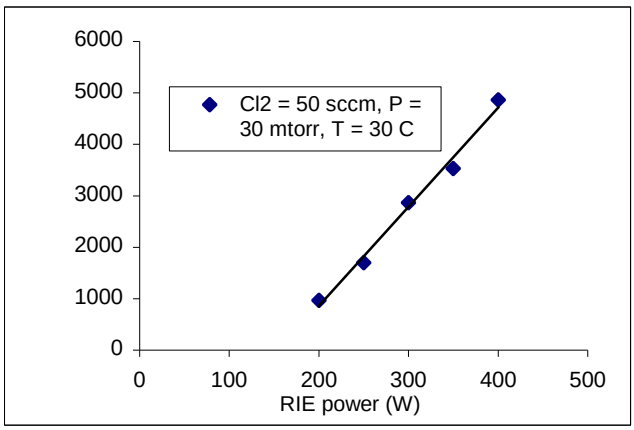


Fig. 1 *Etch rate of p-doped polysilicon against RIE power*

Initial etching experiments were performed in absence of HBr in order to dial in the process pressure and RIE power. These two parameters have the greatest effect on the etch rate and anisotropy. Higher etch rates are seen at higher pressure and higher bias power. At higher pressures, undercutting of the mask is observed.

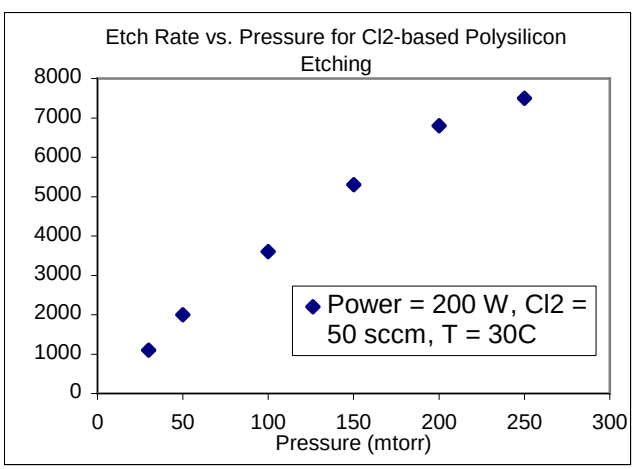


Fig. 2 *Etch rate of p-doped polysilicon against RIE power*

Anisotropic etching was observed when the pressure dropped below 50 millitorr. The photoresist selectivity of the chlorine-based process was an unimpressive 1.5:1 at lower pressures. The selectivity to the underlying silicon dioxide layer was measured to be 6:1. The chlorine-based process broke through the native surface oxide layer with relative ease, which made it seem appropriate for the first step of a multistep process. The etched surface had a smooth finish, but the sidewalls were sloped due to the etch-back of the photoresist mask.

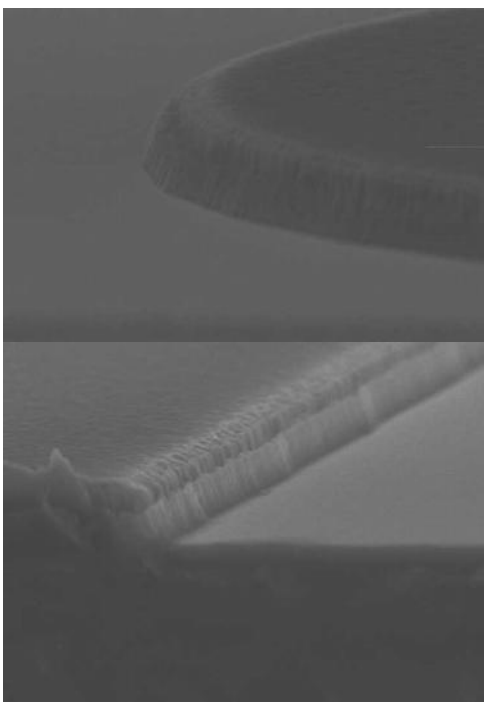


Fig. 3 *SEM photographs of RIE-etched p-doped polysilicon structures (2 μm etch depth)*

Bias powers above 400 Watts were shown to cause the photoresist to carbonize after approximately one minute of processing and are therefore, not recommended for this application. It was believed that the addition of an ICP (inductively coupled plasma) head would increase the etch rate and improve the anisotropy. Interestingly, etch rate was significantly lower when the bias power was set to 400 Watts then without the ICP. The ICP power had to be increased up to 600 Watts before the etch rate with the ICP caught up to the etch rate without the ICP. It is likely that the increased volume of the ICP played a large part in the decrease of the etch rate by diluting the concentration of chlorine in the chamber. The ICP did not improve the selectivity of the polysilicon to either photoresist or silicon dioxide. Clearly, the addition of the ICP did not help the process.

The process pressure was set at 30 millitorr. At lower pressures, the etch rate was too slow to be practical, and the mask would start to show signs of heavy erosion. A gas flow of 50 sccm of chlorine was found to give the highest etch rate at 30 millitorr and 400 Watts of power. Gas flow did not have a pronounced effect on the rate until the flow was dropped below 25 sccm. Below that point, the etch rate began to drop dramatically.

It was decided that hydrogen bromide should be added to improve the selectivity of the process to silicon dioxide. A two-step process would be required because HBr would not be able to punch through the native oxide layer on the polysilicon. The first step would be a 15-second oxide punch-through process followed by a pure HBr process that would attempt to improve on the selectivity to the PR and SiO_2. The etching speed of hydrogen bromide is approximately one-half that of chlorine. With a gas flow of 80 sccm at the same bias power level and pressure increased the selectivity to the photoresist five-fold to a respectable 7.5:1. The HBr process was allowed to overetch on to the silicon

dioxide layer that was underneath the polysilicon for two minutes. An etch step between 20 and 50 angstroms was measured for the silicon oxide. More precise measurement of the very small etch steps were not possible. This produces a selectivity between 100:1 and 250:1. The anisotropy of the etch was greatly improved and the photoresist showed no signs of erosion.

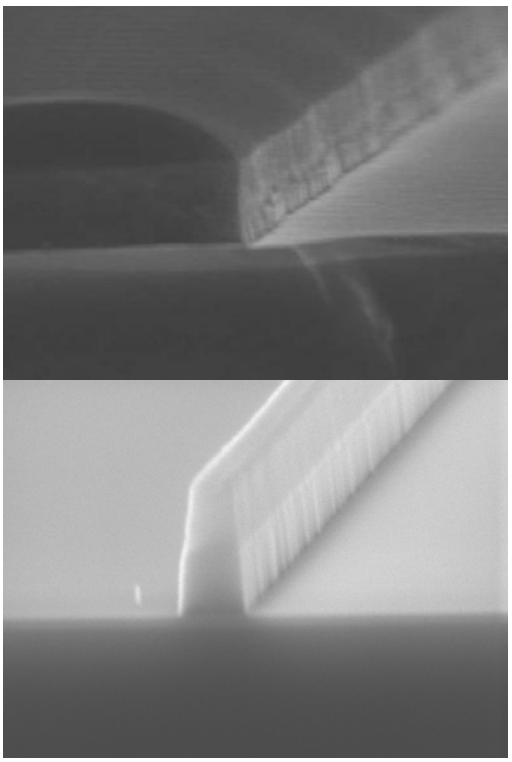
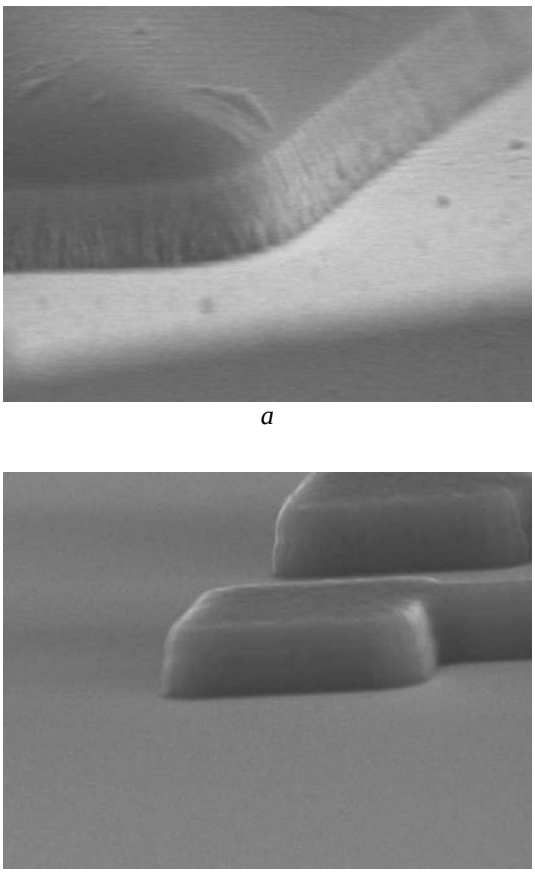


Fig. 4 *SEM photographs of RIE-etched p-doped polysilicon structures (2 μm etch depth) using HBr.*

HBr is best suited for processes that do not require high etch rates, but do require extreme precision and high selectivity. However, if a higher etch rate is desired, adding chlorine to hydrogen bromide combines the best of the two processes to obtain a moderately quicker etch rate. A 50-50 mixture of HBr and Cl_2 with a total gas flow of 100 sccm at the same pressure and bias power of the previous processes will generate a modest etch rate of approximately 3500 angstroms per minute. The selectivity to photoresist is reduced to a modest 4:1 and the selectivity to the silicon dioxide can still be maintained by using a pure HBr overetch process to clean the surface of the underlying silicon oxide.



a

b

Fig. 5 *SEM photographs of RIE-etched p-doped polysilicon structures (2 μm etch depth) using HBr/Cl_2 mixture.*

a Overetch for two minutes
b Overetch for six minutes

If the sample is left to overetch an additional four minutes (for a total of six

minutes), the surface of the silicon dioxide becomes extremely clean with minimal undercut of the mask.

In conclusion, a three step reactive ion etching process for selectively etching p-doped polysilicon over silicon dioxide has been demonstrated using a mixture of Cl_2 and HBr. The etching speed of the etch process is 3500 angstroms per minute with a selectivity to photoresist of approximately 4:1. The overetch process developed uses pure HBr to selectively etch polysilicon over 100 times faster than silicon oxide. Further optimization may be possible with a high power ICP.