

Significant enhancement of selectivity and anisotropy for high rate plasma etching of GaAs over AlGaAs for heterojunction bipolar transistor structure

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Development of a dry etching recipe with extremely high selectivity of GaAs over AlGaAs is critically important for fabrication of heterojunction bipolar transistor (HBT). Fabrication of an HBT structures requires a process for selective etching of a few micron deep GaAs and stop on very thin AlGaAs ($< 200 \text{ \AA}$) layer. Inductively coupled plasma (ICP) etching with $\text{BCl}_3/\text{SF}_6/\text{N}_2/\text{He}$ chemistries showed extremely high selectivity ($> 200 :1$) of GaAs over AlGaAs. This process also produced very clean etched surface of AlGaAs and excellent sidewall passivation on GaAs with reasonably high rate ($\geq 1500 \text{ \AA}/\text{min.}$). It is noticed that addition of N_2 into BCl_3/SF_6 plasma helped formation of passivation on the sidewall and maintain high anisotropy. We also found that He played a key role in order to enhance selectivity and keep the surface clean after etching. An optimized condition in $\text{BCl}_3/\text{SF}_6/\text{N}_2/\text{He}$ ICP plasma showed a promising pattern transfer of GaAs with high rate, high anisotropy, very high selectivity, and residue-free clean surface for fabrication of the HBT structure.

Fabrication of an HBT device requires selective etching steps of GaAs over AlGaAs layer for contact on emitter and base.⁽¹⁾ High selectivity is a fundamental condition for the GaAs removal over very thin ($\leq 200 \text{ \AA}$) AlGaAs layer. Reactive ion etching (RIE) with mixture of Cl- and F- based chemistries has been popular for selective dry etching of GaAs/AlGaAs structures.⁽²⁻⁸⁾ A slow etch rate of less than 500 $\text{\AA}/\text{min}$ is common in RIE processing. When etching of a few micron thick GaAs feature is an issue, attention is paid to new types of plasma source for relatively fast etch rate.⁽⁹⁻¹⁴⁾ Meanwhile, it is understood that there have been potentially many challenges for processing of deep selective etching of GaAs with high density plasma sources. A typical problem of high density plasma source like electron cyclotron resonance (ECR), transformer coupled plasma (TCP) and some other ICP systems may include low selectivity due to large amount of ion bombardment on a thin AlGaAs layer during short over-etching time, which may cause severe over-etching of the layer. Those systems may require an end-point detector to monitor the process. Anisotropy is another problem in high density plasma selective etching. Significant amount of chemically reactive fluorine species will attack the sidewall and cause severe undercutting if there is not enough passivation during etching.⁽⁹⁾ New plasma recipes for extremely high selectivity and anisotropy are quite demanding for fast rate etching. We report on a breakthrough for high density selective etching of GaAs over AlGaAs.

A Plasma-Therm SLR 770 inductively coupled plasma etcher was utilized for selective etching of GaAs over AlGaAs layer. The etcher has He back-side cooling configuration and a mechanical ceramic clamp on the wafer. Bulk GaAs and 3000 \AA of AlGaAs epi-layer with 20 % Al composition were prepared on GaAs wafers. One

micron thick photoresist on top of 400 Å SiN_x was patterned as a mask for etching of GaAs and AlGaAs. Each of the 4" GaAs and AlGaAs wafers was cleaved into a quarter and attached next to each other on a 4" bare GaAs carrier with a thermally conductive paste. A short breakthrough etching step was done before selective etching started in order to remove any native oxide on the materials. Gas flow of BCl₃, SF₆, He and N₂ was controlled by electronic mass flow controllers. Total gas flow rate was kept at 20 standard cubic centimeter per minute (sccm) and pressure was at 5 mTorr. A 2 MHz ICP source power and 13.56 MHz rf chuck power was maintained at 300 W and 10 W, respectively. Self-induced dc bias on the electrode was measured to be about ~ - 45 V. Etch depth, sidewall and surface morphology was measured by a profilometer and a scanning electron microscope (SEM), respectively. In order to have accurate calculation for selectivity with a simulation of extremely long over-etching time for AlGaAs layer, all the characterization data was obtained after 15 min. etching, which made a few micron of etched GaAs feature. It is common to have short over-etching time (less than 10 %) in order to ensure complete removal of GaAs and full exposure of AlGaAs surface.

Figure 1 shows etch rate of GaAs and AlGaAs and selectivity of GaAs over AlGaAs in terms of % N₂ in total flow of N₂ and He at fixed BCl₃ and SF₆ flow rate. The result of 10 sccm of BCl₃/SF₆ ICP plasma without any addition of N₂ and He gave a rate of about 1700 Å/min of GaAs and selectivity of 70. In order to study effect on etch rate, each of He and N₂ gas was introduced separately at a fixed total flow. It is worthwhile to mention that large amounts of He may cause high reflectivity of ICP source power at low ICP power and make plasma unstable due to high ionization potential of He.⁽¹⁵⁾ However,

we found that a small amount of He addition to BCl_3/SF_6 ICP plasma astonishingly increased the etch rate of GaAs and selectivity of GaAs over AlGaAs without affecting the plasma stability. Etch rate of GaAs was raised to 3,700 Å/min in $\text{BCl}_3/\text{SF}_6/\text{He}$ plasma with 10 sccm He flow, while that of AlGaAs was very hard to measure after 15 min etching. It was not difficult to have greater than 200 selectivity of GaAs in $\text{BCl}_3/\text{SF}_6/\text{He}$ plasma, which was almost more than 3 times higher compared to the rate without He addition. Accuracy of the selectivity data was actually limited by etching time and measurement, and selectivity could be virtually infinite.

Addition of N_2 into BCl_3/SF_6 plasma decreased GaAs etch rate slightly. Etch rate of GaAs dropped from 1700 Å/min to 1400 Å/min with 10 sccm of N_2 . Meanwhile, it is noticed that N_2 addition enhanced sidewall passivation and produced very anisotropic pattern transfer of GaAs. The result was extremely important for deep etching (> 2 micron thick) of GaAs. Contrast to He, N_2 addition will enhance plasma stability. Optimization of N_2 flow to BCl_3/SF_6 (more strictly, BCl_3) is also very important to achieve residue-free surface as well as sidewall passivation. $\text{BCl}_3/\text{SF}_6/\text{N}_2$ chemistries may create organic polymer in the plasma, which will cause a chance to deposit it on both of the photoresist and the etched surface as well as sidewall of the feature. Residues on the etched surface might bring the issue of reliability of the HBT device because clean surface of AlGaAs stop layer is very important for metal contact or re-growth after etching.

Figure 2 shows SEM photos after ICP etching. A Photo at the top of Figure 2 shows GaAs feature after etching with a pure BCl_3/SF_6 ICP plasma without any dilution. Notice that undercutting on the sidewall is significant. It implies passivation from BCl_3

component is not enough. More BCl_3 needs to be added. However, increase of BCl_3 flow will reduce selectivity of GaAs. The basic mechanism of selective etching of GaAs over AlGaAs is utilizing the formation of AlF_x on the AlGaAs layer. The AlF_x has high bond strength and is non-volatile at room temperature. The AlF_x surface on the AlGaAs plays a role as a protecting layer, which prevents underlying AlGaAs from being etched. Addition of more BCl_3 means reduction of % SF_6 in plasma composition. Also BCl_3 reacts as a more physical component than chemical. These effects increase ion bombardment on the thin ($\leq 200 \text{ \AA}$) AlGaAs layer. This will reduce selectivity of GaAs over AlGaAs due to incomplete AlF_x coverage on AlGaAs. Another way to control sidewall passivation is to add N_2 into the BCl_3/SF_6 plasma, as we discussed earlier.

Combined addition of N_2 and He into BCl_3/SF_6 plasma made it possible to have a new process window for high selective etching with clean surface and anisotropy. Results after plasma etching with an optimized condition in ICP $\text{BCl}_3/\text{SF}_6/\text{N}_2/\text{He}$ plasma showed that extremely high selectivity, quite clean surface and anisotropy, and reasonably fast etch rate (Figure 2, middle and bottom). Sidewall angle of the etched GaAs was measured as close to 90° ($\geq 87^\circ$), which indicated excellent control on critical dimension. Selectivity of GaAs to photoresist was also noticed to be very high ($> 10:1$) after etching.

In conclusion, a new ICP plasma chemistry was developed for extremely high selective etching of GaAs over AlGaAs with excellent anisotropy, residue-free clean surface and fast etch rate. The recipe brought a significant breakthrough for high rate and selective etching of Ga-based materials. The result will also bring more attention on the high density ICP source for selective etching process for other compound semiconductor structures like GaAs/InGaP.

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FIGURE CAPTIONS

Figure 1. Etch rate and selectivity of GaAs and AlGaAs as a function of % N₂ in N₂ + He with fixed BCl₃/SF₆ flow in ICP BCl₃/SF₆/N₂/He etching .

Figure 2. SEM micrographs of GaAs after etching with BCl₃/SF₆ (top) and BCl₃/SF₆/N₂/He. Photoreisist is still in place (top and middle) and has been removed with acetone (bottom).



