Deep SiC etching with RIE

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Abstract

SiC is currently an important topic in power devices. This new technology leads to lower power losses, faster switching, and higher working temperature. The design of SiC power devices requires the integration of edge termination techniques to obtain a high blocking voltage. The mesa structure is one of the well-established methods. It could be used alone or in combination with a Junction Termination Extension (JTE). The mesa consists in a structure that removes material around the pn-junction. Due to the strong Si-C bonds, conventional chemical-wet etching solutions are inefficient on SiC, so plasma methods are required to etch SiC.

The presented work is based on the use of an RIE reactor with an SF_6/O_2 plasma. Its geometry structure and parameters were optimized. An etch rate of 0.35 µm/min was obtained without any trenching phenomenon. Trenches deeper than 10 µm deep were realised with a nickel etching mask that shows a high selectivity. AFM analysis revealed an etched surface as smooth as the initial one.

Introduction

Nowadays, silicon carbide (SiC) is promised to be the next generation of power semi-conductors. Due to its great physical properties, with a critical electrical field six times higher than the silicon, it enables to reduce on-state losses and higher blocking voltage capability. With a thermal resistance as good as the copper and a bandgap three times greater than Si, SiC devices could work in high temperature ambient [1]. All these advantages could lead to minimized systems size with smaller devices and cooling efforts.

Etching is one of the critical technological steps in power devices fabrication: edge termination, contact to buried layers, … In this study, investigations are targeted on the mesa structure formation that protects the component at high voltage. The mesa structure consists in cutting the blocking PN junction and by this way it induces a straight repartition of the equipotential lines which improves the breakdown voltage.

Due to the high chemical inertness of the Si-C liaisons, wet etching is not efficient to reach deep trenches. Dry methods are more appropriate with plasma etching which is commonly used. Several plasma reactor configurations are visible in the literature: standard Reaction Ion Etching (RIE) [2] or high density plasma like an Inductively Coupled Plasma (ICP) [3] or an Electron Cyclotron Reactor (ECR) [4].

In this paper, investigations are focused on an RIE reactor in a gases mixture of sulfur hexafluoride (SF_6) with oxygen (O_2). The first aim is the research of a strong etching mask to reach deep trenches. Then, several parameters and configurations are adjusted to obtain a clean etching, smooth etched surface without any micromaskings and straight walls without trenching phenomenon usually observed in SiC etching.

Experimental

4H-SiC samples from SiCrystal and Cree Research wafers were used in these experiments. The materials were n-type substrates. The samples were first cleaned in solvents followed by a standard “piranha” solution and finally dipped in a buffer oxide etch (BOE) commercial solution. Then, they were patterned with photoresist and placed into an electron-beam evaporator. Aluminium or Titan/Nickel bilayer were evaporated onto the samples. A lift-off process in acetone revealed the exposed surfaces. SiC dry etching was performed in an Alcatel Nextral NE110 reactor, an RIE reactor with a plasma source generated at 13.56 MHz operating at a maximum power of 300 W. The work pressure is modulated in the range 1.33 to 13.33 Pa. The plasma chemistry investigated here is composed by SF_6 and O_2 gases.

The depth, etch rate and selectivity of the masks were determined by profilometry measurements with a Tencor Alpha Step 500. Surface morphology analyses were performed by atomic force microscopy (AFM) with a machine from Thermomicroscope.

Results and discussion

Etching mask

To realize deep etching in the SiC, it is necessary to get a high selective mask. Three kinds of masks were investigated: photoresist, aluminium and nickel. The conditions in the reactor were an SF_6/O_2 plasma at a work pressure of 8 Pa with an RF power of 250 W.

Table 1 gives a summary of the different masks selectivity. The first mask was the photoresist. The first advantage is the easiness of the application and secondly photoresists are often and commonly used in silicon technology to get deep trenches especially in Bosch process (Deep RIE). And this case, the photoresist selectivity could be greater than 100. In our investigations, two photoresists were tested: AZ5214 (standard) and TI 35 ES (special photoresist for Deep RIE Si etching). In both case, with the SiC, the selectivity was very low, less than 1. Thus, in these conditions, photoresists are not suitable for SiC deep etching.

Table 1.
Selectivity of the etching masks.

Mask	Selectivity
Photoresists (AZ5214 and TI35ES)	<1
Aluminium	12
Nickel	46

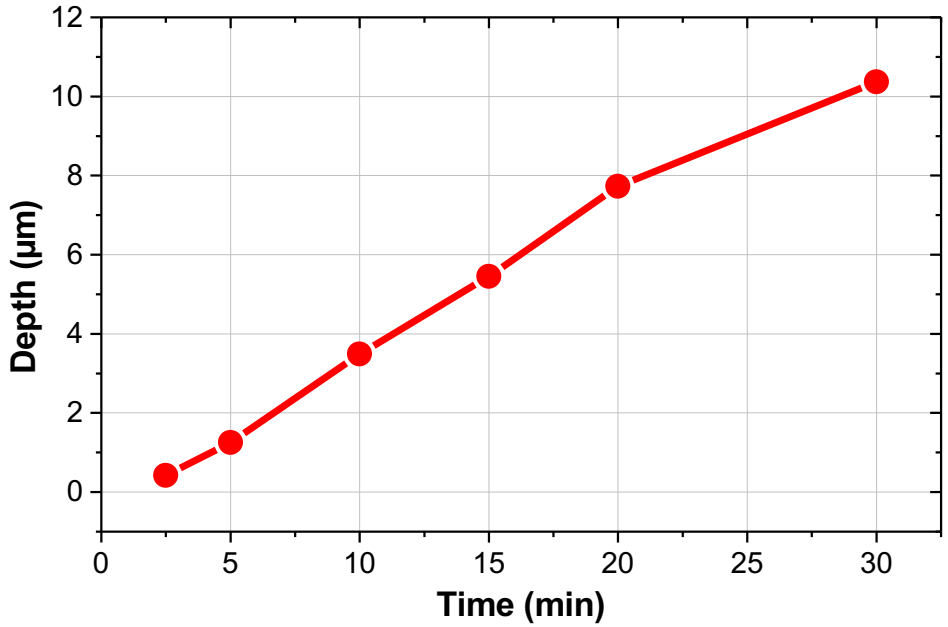

Fig. 1. Etching depth versus process duration

The second mask was the Aluminium which is a well-used metal in several technological steps [5]. This mask shows selectivity about 12 but the real problem is the apparition of micromasking. During the process, the etched matter from the mask that is non-evacuated by the pumping is deposited on the exposed surface. This induces a soft mask and appears the phenomenon of the micromasking. So this mask is not suitable for our application.

The last one is the nickel which is actually a bilayer which is composed of titanium and nickel. The thin titanium layer (5 nm) role is to increase the peel strength of the nickel layer, by this way the nickel layer would not be removed mechanically. The selectivity of the nickel with the plasma conditions is greater than 40. This high selectivity will permit reaching deep trenches.

Etch mechanism

The configuration of reactor is a work pressure of 8 Pa, an RF power of 250W and a gas mixture of SF_6 and O_2 with gas flows of 25 sccm and 6.7 sccm respectively. The figure 1 presents the depth obtained for a process duration from 2.5 to 30 minutes. The trenches are 0.65 nm up to 10.35 µm deep with a maximum etch rate of 0.39 µm/min and an average etch rate of 0.35 µm/min.

The plasma is based on the two gases SF_6 and O_2 with an oxygen ratio of 20%. In SiC plasma etching investigations, this ratio was often demonstrated as the optimal mixture to get the highest etch rate [6]. The addition of oxygen in the plasma enables the increase of fluorite ion generation and in another hand it enhances the etching of the rich carbon layers by the formation of CO and CO_2 volatile species.

The plasma etching involves two dominant etch mechanisms: physical and chemical [7]. The physical mechanism is the high energy ion bombardment that erodes the matter. And the chemical mechanism is the formation of volatile species from the induced reactions on the material surface with the species from the plasma. In the case of the SiC, it is necessary to generate first a physical mechanism in order to break the bounds Si-C and then a chemical mechanism to interact the fluorite ions with the silicon atoms to form SiF_X ($1<x<4$) volatile species and the oxygen ions with the carbon atoms to form CO or CO_2. With the aluminium etch mask, there are two possible reactions that form AlF volatile species and non volatile species, the Al_2O_3 that is the origin of the micromasking. And in comparison, the nickel is non reactive, it is inert with a chemical reactions to the species from the plasma. The etching of the nickel mask is typically caused by the ion bombardment.

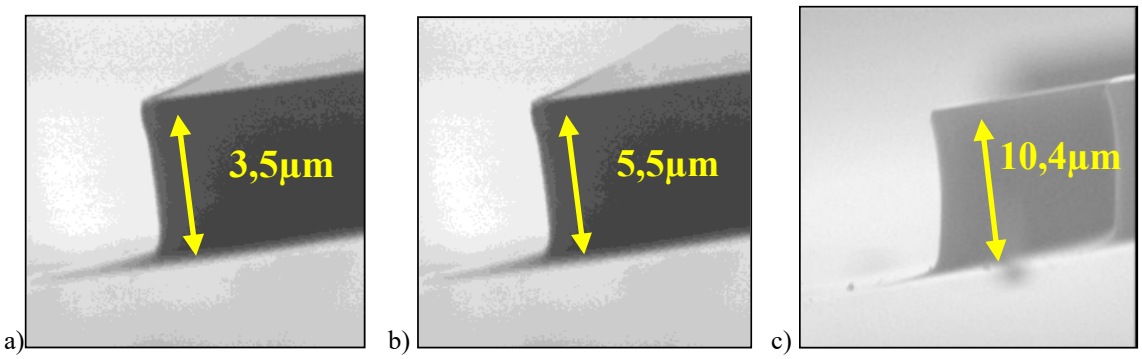

Fig. 2. SEM pictures of etching profile for a) 10, b) 15 and c) 30 minutes.

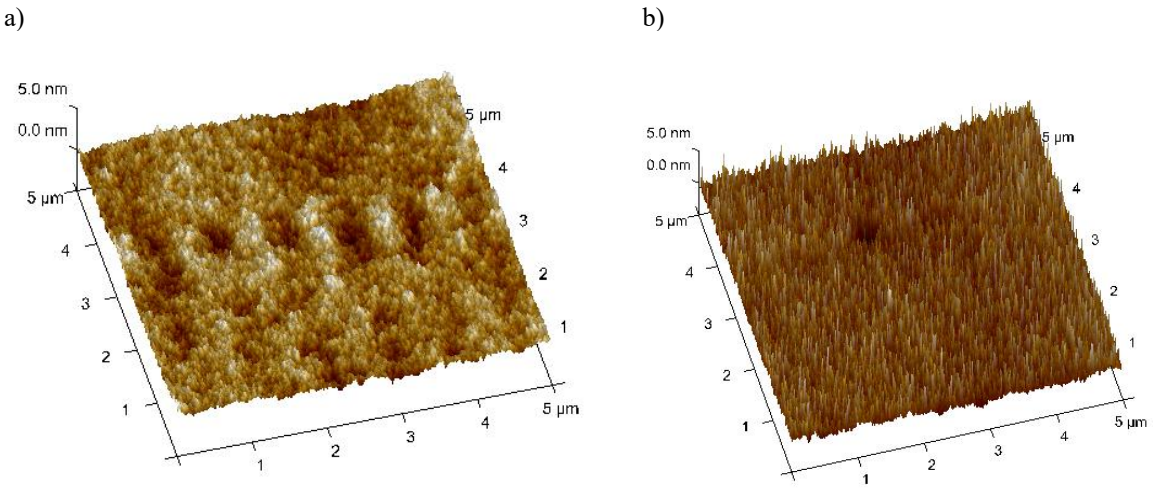

Fig. 3. AFM micrograph of etching process for a) 10 and b) 20 minutes

The figures 2a, 2b and 3c show the pictures of the trenches steps profile from scanning electron microscope (SEM) for a process time of 10, 15 and 30 minutes respectively. The observation of the wall morphology shows a dominant chemical etching process with the sides curving. In addition, there is no trenching phenomenon on the foot of the trenches that is usually observed in SiC etching.

Etched surface morphology

The table 2 presents the comparison between the virgin surface and the etched surface roughness for a process of 10 and 20 minutes. The measurements were performed by AFM in an area of 1×1 μm^2 large. The virgin surface morphology is very smooth with an RMS roughness of 0.2 nm. After an etching of 10 minutes, a 3 µm deep trench is obtained and the etched surface became worse with a roughness about 0.32 nm. The etched surface roughness is still more deteriorated with an etching time of 20 minutes with a roughness twice to four times greater than the original surface (0.3 to 0.8 nm). The deeper etching, the rougher is the surface. The figure 3 shows the 3D representation of the

two etched surface morphology. The etching process roughens the surface. For a duration of 10 minutes, it is not yet really visible while for a 20 minutes process the AFM micrograph shows some peak microstructures which have been formed. Theses peaks are the results of a non equal effect between the two etching mechanisms. As seen earlier, the chemical etch mechanism seems to be dominant in this etching process. But with the micrographs observation, ion bombardment that causes the peaks is the dominant mechanism on the direct exposed surface. Thus, the chemical etch mechanism is more efficient on the lateral direction while the ion bombardment attacks directly the exposed surface. To reduce the peak apparition, a high density plasma would be more appropriate.

Table 2.
Roughness measurements

Duration (min)	Depth (µm)	1×1 µm² RMS roughness (nm)
0	0	0.19 - 0.23
10	3.2	0.31 - 0.35
20	6.5	0.30 - 0.83

Conclusion

An etching RIE process is optimized and an etch rate of 0.35 µm/min is achieved with an SF_6/O_2 plasma. This high etch rate combined to a high selective nickel mask permits to obtain trenches deeper than 10 µm. The etched surface morphology is as smooth as the original surface until 20 minutes afterwards it begins to be degraded with the apparition of microstructures.

Further analyses will be held and especially on the electrical properties of the etched surface to determine if the process is suitable for SiC power device fabrication.

References

[1] J.W. Palmour, R. Singh, R.C. Glass, O. Kordina and C.H. Jr Carter, IEEE ISPSD'97, 1997, p. 25

[2] M.S. So, S.G. Lim and T.N. Jackson, J. Vac. Sci. Technol. B, 17 (1999), p.2055

[3] J.J. Wang, E.S. Lambers, S.J. Pearton, M. Ostling, C.-M. Zetterling, J.M. Grow, F. Ren and R.J. Shul, Solid-State Electronics, 42 (1998), p.2283

[4] P. Chabert, J. Vac. Sci. Technol. B, 19 (2001), p.1339

[5] A. Szczesny, P. Sniecikowski, J. Szmidt and A. Werbowy, Vacuum, 70 (2003), p.249

[6] L. Jiang, R. Cheung, R. Brown and A. Mount, Journal of applied physics, 93 (2003), p.1376

[7] P.H. Yih, V. Saxena and A.J. Steckl, Phys. Stat. Sol. B, 202 (1997), p.605