The International Journal Of Engineering
And Science (Ijes)
||Volume|| 2 ||Issue|| 2 ||Pages|| 87-92 ||2013||
Issn: 2319 – 1813 Isbn: 2319 – 1805

Reactive Ion Etching of 4H-SiC Using SF_6/O_2 for MEMS Application

Y. Hezarjaribi[1], M. N. Hamidon[2]
[1]*University of Golestan, Department of Engineering, Gorgan, Golestan, Iran*
[2] *University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

---Abstract---

Deep Reactive Ion Etching (DRIE) of 4H-SiC performed using SF_6/O_2 plasma. The etching rates investigated as a function of the ratio of the O_2 flow rate to total gas flow rate under different etching conditions such as the effect of power density, temperature, and the combination of chemistries on etching. The investigation was proven that the contribution and effect of the direct role of Oxygen to deep etching of SiC. An optimum value of O_2 fraction of 60% to 40% Sulfur Hexafluoride (SF_6) used to give high etching rate of 1.2µm/min. for maximum etching.

Keywords: *Deep Reactive Ion Etching (DRIE), Sulfur Hexafluoride (SF_6), 4H-SiC, plasma*

Date of Submission: 2February, 2013 ⟺ Date of Publication: 15, February 2013

I INTRODUCTION

Silicon Carbide (SiC) belongs to the next generation and is a promising material for the development of high temperature solid-state electronics and having various useful properties, such as owing excellent electrical, mechanical, chemical properties due to having wide band gap, and high breakdown voltage [1]. However, due to its chemically and mechanically stable nature, the preparation of SiC wafer is very difficult, particularly for obtaining smooth surface and removing the larger damaged by various mechanical process[2]. For this purpose, sulfur-hexafluoride (SF_6) in combination with O_2 gases used to etch 4H-SiC. SF_6 is one of the most popular insulating gases (next to air). It has a number of nice properties: it is not flammable [3], it is non-toxic, it is inexpensive, and it is a good insulator, with breakdown strength of about 3 times that of air. At normal temperatures, it is non-corrosive, and is inert, although at temperatures above 500ºC, it decomposes, and the decomposition products (Fluorine (!)) react with just about anything, especially any water vapor [4]. In this paper 4H-SiC etching has been studied in various plasma reactors, such as inductively coupled plasma, deep reactive ion etching. As literatures shown, so far there is still lack of understanding of the etching mechanism. This fabrication process has shown unambiguously that sulfur hexafluoride with combination of oxygen gases are the main reactant for the removal of Si and C atoms.

II ETCHING PROCESS

2.1 SAMPLE PREPARATION

The sample used were 4H-SiC, N-type, on-axis with resistivity of 0.013-0.5 ohm-cm range, standard micro pipe, double sided with no epitaxial from Cree research center. Before loading the sample for etching, the following process accomplished, such as cleaning the sample with RCA#1 solution (consists of ammonia/hydrogen per oxide and DI water or de-ionized water with the rate of 1-1-5 respectively) for about 12 minutes. Then place the sample into E-beam evaporation system for depositing masking layer with the thickness of 1 µm of Aluminum (Al), with the pressure of $4*10^{-3}$mTorr, and temperature of 220ºC. The etching carried vertically for deep etching using deep reactive ion etching (DRIE). The DRIE powered at 2-8 W/cm2 with the pressure of 2mTorr and with the gases SF_6 and O_2 introduced into DRIE through mass flow controller. Some polishing was done to obtain a good adhesion of the masking material on SiC for pattern transfer during the etching process [5].

2.2 DRIE PLASMA ETCHING OF SiC

SiC is chemically inert to most of widely used acids and liquid etchant at, or near, room temperature [6]. In order to etch SiC in a plasma reactor, the chemistry used must be reactive with SiC and the species produced by the chemical reactions must be volatile compounds under the operating temperature and pressure condition to avoid residues on the surface. DRIE uses chemically reactive plasma to remove material deposited on wafer, the plasma generated under low pressure by an electromagnetic field and consists of a cylindrical vacuum chamber with a wafer platter situated at the bottom of the chamber [7]. High-energy ions from the plasma attack the wafer surface and react with it. Many etched chemistries such as chlorine-, fluorine-, and bromine-based have been examined for plasma etching of SiC [8]. DRIE of SiC plasma provides the highest etch rates needed for economical deep etching, fluorine-base chemistries are the most effective gases in term of etch rates and easily implemented, dry etching of SiC is usually performed using a primary source of fluorine radicals, with a secondary gases added to control or enhance the etching process [9]. Some primary gases that have investigated are, SF_6, C_2F_6 ,CHF_3,CF_4 and NF_3. Additive includes O_2, Ar, H_2 and N_2. SF_6 and NF_3 exhibit the highest etch rates, because of their rapid dissociation in plasma [10]. An NF3 trend to etch SiC at a faster rate, but SF_6 is more desirable for use as a feed gas because it is less expensive and safer [11]. The reaction mechanism of SiC in F_2-based chemistry is shown (1, 2) [12].

$Si+F_x=SiF_x$ (1)

$C+F_x=XF_x$ (2)

2.3 LOADING SAMPLE FOR ETCHING PROCESS

The effect of loading is the decreasing of etch rate when there are more etch-able substrate material placed in a reactor. The etch rate is usually proportional to etchant concentration, their concentration decreases with the area of the etch-able surface in the plasma. As the process flow of etching process shows in figure 1, the sample to be etches, places at the lower electrode, and upper electrode grounded. The DRIE technique generates the plasma between two parallel plate electrodes in a reaction gases. In order to etch SiC in a plasma reactor, the gases are used must be reactive with the SiC, for that several gases were examined and the most effective gases for etching SiC were used a combination of SF_6 with O_2 to etch via up to 350μm deep in 4H-SiC. Various gas additives can have affect on the etching behavior. Oxygen often has been added under DRIE conditions to increase the SiC etching rate. The process is, gases enters through small inlets in the top of the chamber, and exits to a vacuum pump system through the bottom. The type and amount of gases used varies depending upon the etch process.

III Experiments And Results

One of the most important parts of etching was that to find adequate masking layers to resist the deep etching. The layers consider to be testing formasking are such as Carom, Nickel, Nickel-Aluminum and Aluminum.

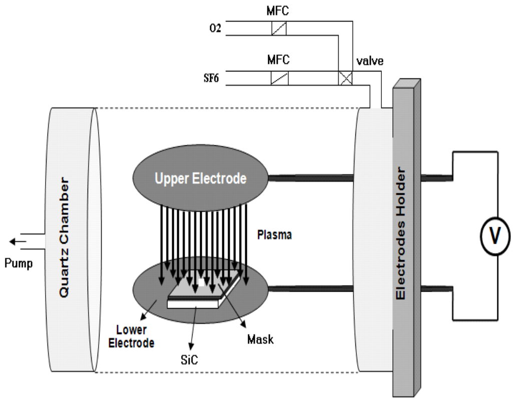

Figure 1: The process flow of etching process.

The results have shown that first three layers could not resist etching against SF_6 and O_2 plasma, just Aluminum could resist with the following conditions, as it shows in figure 2 Aluminum at low temperature like 120 ºC just could resist the etching process for 2.5 hrs and then separated form SiC.

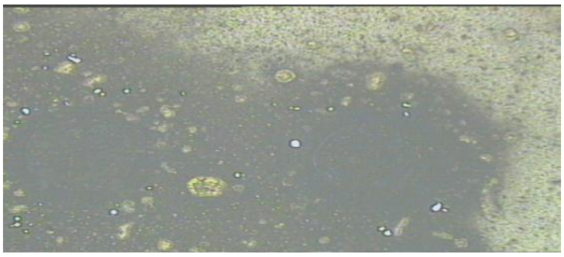

Figure 2: The effect of etching on deposited Aluminum at low temperature (120 °C) for 2.5 hrs.

Figure 3 shows the SEM micrograph of Aluminum deposition with increasing the temperature up to 220 °C, the deposition of Aluminum as of mask tested successfully.

3.1 THE EFFECT OF PLASMA POWER DENSITY ON ETCHING RATES

Power density is inversely proportional to mean free path of particle. At higher power density, the mean free path is shorter and frequently causes collision of electrons. The electrons will lose their energy and generates higher power plasma density. Then the etch mechanism is dominated by chemical reaction rather than sputtering reaction. As power density decreases, the characteristic potentials across the sheaths and the voltage applied to a discharge increase sharply. The rise in potential translates into a higher energy ion flux to substrate surfaces [13].

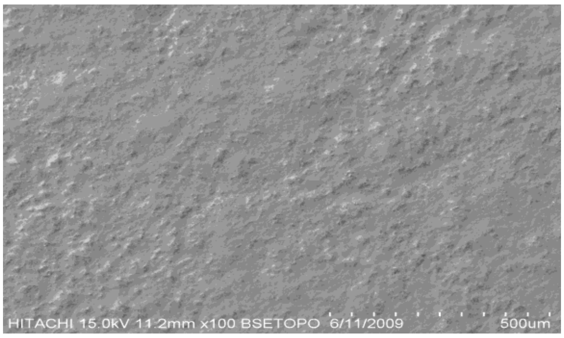

Figure 3: Shows SEM picture of the deposited Aluminum at high temperature (220 °C).

For investigating the effects of power density on etching rates, the etching is been done on different powers. As it shown in figure 4 the etching was done for temperature up to 250 °C, the results shows that the etching rate at low plasma power density is very slow less than 5 nm/min, but with increasing the power density plasma up to 8 w/cm2, the etching rate increases to 1.2 um/min. As noticed from graph that if the power density increases higher than 8w/cm2, the etching rate will saturate.

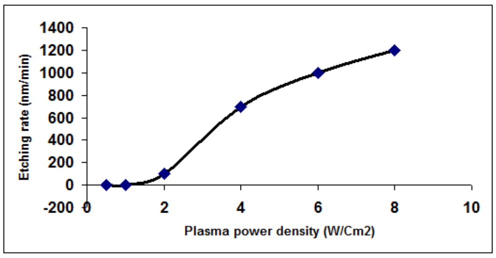

Figure 4: Curve for etching rate due to increasing plasma power density.

3.2 THE PROCESS OF USING PLASMA FOR ETCHING

It is very important that how should we consider of using the combination of gases for etching. SF_6 plasma tested without considering oxygen with power density of 6 W/cm^2. As the result shown in figure 5, SiC starts to be etch, but because of using single gas (SF_6), the etching rate of SiC kept decreasing with increasing the etching depth up to 100µm, and etching stop completely.

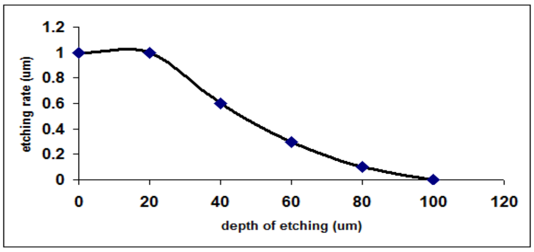

Figure 5: Show the depth of etching vs. etching rate with using just SF_6 .

As shown the result in figure 6(a,b), due to crystallography on the surface of SiC the etching process will stop completely.

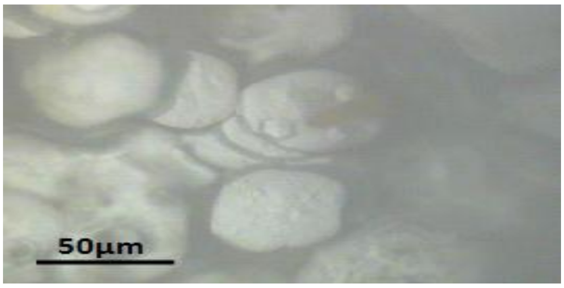

Figure 6(a):Shows crystallography on the surface of SiC in a scale of 50µm with the depth of etching about 100µm.

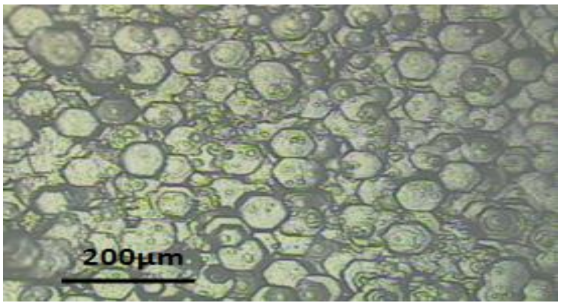

Figure 6(b): Shows crystallography on the surface of SiC in a scale of 200µm with the depth of etching 100µm.

3.3 TEMPERATURE EFFECT ON ETCHING RATES

The effect of temperature is a function of chemical reaction as $e^{-Ea/RT}$, where E is activation energy, R is gas constant and T is temperature. Thus, it has dominated the effect on selectivity; etch rates and the degradation on the resist mask [14].

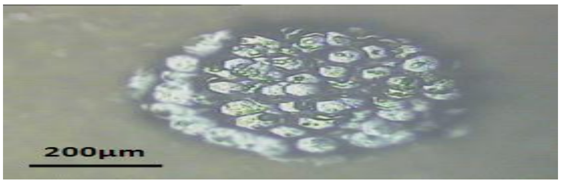

Figure 6(c): Shows crystallography on the surface of SiC in a scale of 200µm.

Etching were done with power density of 6 W/cm2 at the temperatures 25, 150, 250, 350 °C , the results for the etching rates are 2, 500, 1000, 1200, 1700 nm/min respectively. Figure 7 shows patterning Aluminum before etching.Figure 8(a) shows vertical etching of SiC. The result up to 250 ºC was successful as it shows in Figure 8(b) with depth of etching of 0.5µm, but beyond that with increasing temperature, we would not have isotropic

Figure 7: Shows patterning of Al before etching process.

Etching anymore and as it shows in fig. 9, there will be under-etching in process due to increasing temperature above 250 ºC.

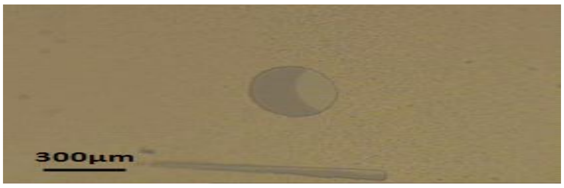

Figure 8(a): Shows vertical etching of SiC used SF_6 and O_2 gases.

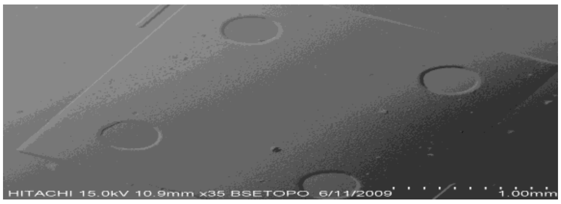

Figure 8(b): Shows SEM picture- Substrate etched for depth of 0.5µm, used SF_6 and O_2.

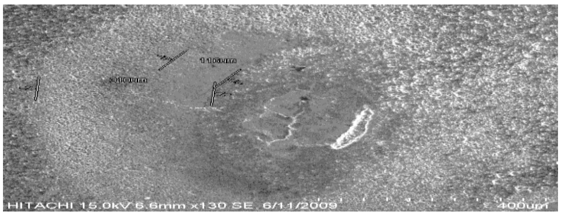

Figure 9: Shows SEM picture of under-etching with increasing temperature for deep etching.

Fig. 10 shows the SEM micrograph of the profile of the surface etched at the optimal etching condition. As it shows rough sidewalls that are almost vertical, along with a clean, smooth and anisotropic etched surface profile was obtained, with no obvious of trenching effect that has been frequently observed in the plasma etching of SiC.

Figure 10: Shows the SEM picture of the etched pattern under the condition of 60% O_2 fraction.

IV Conclusion

There are different approaches to conduct the fabrication process. It is very important that how should one consider of using the chemistries for etching. Various gases addition can have effects on the etch rate behavior. Finally, initial fabrication of MEMS structures by DRIE has shown that sputtering growth of SiC on SiO_2 layer is successful. A physical polishing process 9developed to improve the SiC surface morphology for better etching yield. Under high density DC-plasma, condition SF_6/O_2 gas mixture utilized to produce smooth surface. The vertical sidewall indicates high anisotropy of SF_6/O_2 etching has obtained under certain conditions. The dependability of etching rates conditions such as gases ratio, the effect of plasma power density, and the effect of temperature studied. Aluminum at high temperature evaluated as of masking material for deep etching. In practical time frame the etching of very deep features for MEMS structures in SiC substrates, appears feasible by using combination of SF_6 and O_2, and under some conditions such as increasing chemistry, etch selectivity for SiC over Aluminum, shows better mask performance.

Referrences

[1] M. Mehregany, C.A. Zorman, N. Rajan, C. H. Wu, “Silicon Carbide MEMS for Harsh Environments” *Proceeding of the IEEE,* vol. 86, No. 8, (1998), pp. 1594-1609.

[2] Y. Miura, H. Habuka, Y. Katsumi, S. Oda, Y.Fukai, K. Fukae, T. Kato, H.Okumura, and K. Arai, “Determination of Etch Rate Behavior of 4H-SiC using Chlorine Trifluoride Gas”, *Jpn. J.Appl. Phys.* 46 (2007), pp. 7875-7879.

[3] http://www.himfr.com/d-c114094402715747400- Fujian_Shaowu_Yongfei_Chemical_Co_Ltd. N.

[4] home.earthlink.net/~jimlux/hv/sf6.htm.

[5] N. Moronuk, “Single Crystal SiC Thin-Film Produced by Epitaxial Growth and its Application To Micro-Mechanical Devices”, *Thin Solid Films*, vol. 516, issue 16, (2008), pp. 5344-5348.

[6] P.H. Yih and A.J. Steckl, *J. Electrochem. Soc.* 140.1813 (1993).

[7] en.wikipedia.org/wiki/Reactive-ion_etching.

[8] J. HONG, et at., “Plasma Chemistries for High Density Plasma Etching of SiC”, *Journal of Electronic Materials*, Vol. 28, No. 3, (1999).

[9] G. Saggio et al., “Reactive Ion Etching Characterization for a-SiC: H in CF4/O2Plasma”, *Materials Science and Engineering,*B29, (1995), pp. 176-180.

[10] G. M. Beheim and L. J. Evans, “Deep Reactive Ion Etching for Bulk Micromaching of Silicon Carbide”, *NASA Glenn Research Center,* Taylor &Francis group, LLC, 2006.

[11] M. Gad-el-Hak, “MEMS Design and Fabrication”, www.infibeam.com/**Books**.

[12] C. Iliescu, et al., “Characterization of SiC Films Deposited by Plasma Enhanced Chemical Vapor Deposition” *Thin Solid Films*, 516 (2008), pp. 5189-5193.

[13] L. Jiang, et al., “Dry Etching of SiC inductively Coupled cl_2/Ar plasma”, *J. Phys. D: Appl. Phys.* Vol.37,(2004), pp. 1809-1814.

[14] E. A. Moelwyn-Hughes, “A Theory of Electro- kinetic Effects in Solution Reactions betweenIons”, *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, Vol. 155, No. 885 (Jun. 2, 1936), pp.308-315.