The ICP etching technology of 3C-SiC films

Ning Jin\textsuperscript{1,2}, Gong Quancheng\textsuperscript{1,2}, Sun Guosheng\textsuperscript{1,2}, Liu Zhongli\textsuperscript{1,2}

\textsuperscript{1} Integrated technology Centre, Semiconductor Institute of CAS, Beijing P.R.China 100083

\textsuperscript{2} State Key Laboratory of Transducer Technology, Chinese Academy of Sciences

E-mail: ningjin@red.semi.ac.cn

Abstract. The dry etching technology is one of the key process in the 3C-SiC MEMS fabrication. In this paper, the 3C-SiC ICP etching technology will be studied. The etching gas components we used include CHF\textsubscript{3}, SF\textsubscript{6} and O\textsubscript{2}. The polycrystal 3C-SiC films deposited on SiO\textsubscript{2} layer were etched in different condition. The effects of the key process parameters such as the etching gas component, the gas flow, the source power, the bias power and the etching pressure on the etch characteristics are studied detailedly. According to the results, the optimal process was obtained. Finally, we used the optimal ICP etching process to fabricate resonator successfully. The work is important and useful to fabricate the 3C-SiC MEMS devices.

1. Introduction

Silicon Carbide is one of the attractive wide band gap semiconductor materials due to its high temperature stability and high thermal conductivity. So it can be used for electronic devices operating at high power, high frequency and high temperature levels. Also, due to its excellent electrical, thermal, and mechanical properties, SiC is used in the field of microelectromechanical system (MEMS). Due to the high hardness, chemical and physical stable properties of SiC, it is very difficult to be etched. “Wet” etching can only be performed at high temperature, which is incompatible with microelectronic process. So the plasma-based etching techniques play a crucial role in SiC device fabrication.

In this paper, inductively coupled plasma (ICP) etching process will be used to etch 3C-SiC. Compare with conventional reactive ion etching (RIE), ICP etching has many advantages, such as higher plasma density, capability for operation at lower pressures, and capability for independent control of the plasma density and the ion bombardment energy with separate electrode. So the ICP process has many superior properties in etching 3C-SiC includes higher etch rate, vertical sidewalls, smooth surface with no residue, and more flexibility in optimizing etch parameters.

Many groups have reported the etching process of SiC before, but most of them studied 4H-SiC and 6H-SiC etching \cite{1}-\cite{3}. 3C-SiC is a kind of important structure material to MEMS devices. In this work, a parametric study of the ICP etching characteristics of polycrystalline 3C-SiC films LPCVD deposited on SiO\textsubscript{2} has been performed. From the experiment results, an optimal etch process has been obtained and used to fabricate 3C-SiC resonator.
2. Experiment

The etched polycrystalline 3C-SiC films were grown on SiO₂ using LPCVD deposition process. The process gases include 0.75sccm SiH₄, 2.25sccm C₂H₄ and 3slm H₂. The grow process was at 1050°C for 60 min and the work pressure was 40 Torr. The thickness of 3C-SiC was about 2µm. 400nm Aluminium was deposited and patterned as etching mask.

The etched samples were located on a He backside cooled chuck biased with 13.56MHz of power. The effects of the key process parameters such as the etching gas component, the gas flow, the source power, the bias power and the etching pressure were studied detailedly. Only one process parameter was changed in all experiments. Etch rates were obtained from step height measurement of the samples after mask removal. Scanning Electron Microscopy (SEM) was used to examine etch anisotropy and surface morphology, while Atomic Force Microscopy (AFM) was employed to quantify the surface roughness.

3. Results and Discussion

The surface roughness of 3C-SiC was examined after etching by AFM. Fig. 1 shows the AFM results of the 3C-SiC surface etched by ICP using different CHF₃ flow. Other source power, bias power, and etching period were set to 500W, 100W, and 2min, respectively. For clarity, we summarize the relation of the surface roughness and CHF₃ flow, which is shown in Fig. 2. From it we can see that when the CHF₃ gas flow increased from 40sccm to 60sccm and from 80sccm to 100sccm, the surface roughness were both decreased evidently. The reason is that when increase the CHF₃ gas flow, the chemic etching is enhanced and the physic etching is reduced. But when the CHF₃ gas flow increased from 60sccm to 80sccm, the surface roughness was slightly increased, this is because the chemic etching and physic bombardment play equivalent role in etch mechanism. The physic bombardment is the primary factor to damage surface smoothness.
Fig. 1. AFM results of the 3C-SiC surface etched by ICP using different CHF$_3$ flow.
(a) 40sccm, (b) 60sccm, (c) 80sccm, (d) 100sccm

Fig. 2. The effects of the flow of CHF$_3$ on the etched sample surface roughness

Fig. 3 shows the 3C-SiC etch rate as a function of the CHF$_3$ gas flow for fixed source power, pressure and bias power. As depicted in Fig. 3, the etch rate was slightly increased when CHF$_3$ gas flow increased from 40sccm to 60sccm, which suggests that ion bombardment plays a role in the etch mechanism. Then increased CHF$_3$ gas flow more, from 60sccm to 100sccm, the etch rate was found to decrease considerably. The reason is that when ion flux increased, the ion collision increased while the ion bombardment energy is reduced, then the chemi etching plays a role in the etch mechanism.

Fig. 3. The effect of the flow of CHF$_3$ on the etch rate

When we added O$_2$ into the etching gas properly, the etch rate was increased evidently, and the etching residual material was reduced. The reason is that O$_2$ can react with CHF$_3$ and release more F free ion, at the same time O$_2$ can react with C and produce volatile CO and CO$_2$. But once added too much O$_2$, the etch rate was decreased because the F concentration was diluted so the etching effect was reduced. The effect of the O$_2$ percentage on the SiC etching was observed, with the etch rate...
experiencing a maximum of 400nm/min at around 10% O₂ and then decreasing with increasing O₂ percentage.

When we increased the etching power, the etch rate was increased. But the effecting principle of the two electrode plate power to the etch rate is different. Increasing the source power can increase the F free ion concentration, so the chemic etching is the primary etching, then the surface roughness is changed little and the etch rate is increased slightly. Increasing the bias power can increase the ion energy bombarding the sample, so the physic etching is the primary etching, then the surface roughness and the etch rate are both increased evidently. Peak etch rates of almost 400nm/min were obtained at 900W source power, 150W bias power, the etch gases include 11 sccm CHF₃, 43 sccm SF₆ and 6sccm O₂. Using the optic microscope to observe, the surface is cleanliness and smoothness, no debris or residue. A typical SEM photo is shown in Fig 4. From it we can see that the 3C-SiC etch is anisotropic, no chemical or metallic residue aggregate on the etched surface and the sidewall, but the sidewall is not vertical.

![Fig.4 The SEM photograph of the 3C-SiC mesa etched by ICP](image)

**4. Application of the optimal 3C-SiC ICP etching technology**

An anisotropic ICP process for the 3C-SiC has been developed which possesses a relatively high etch rate of about 400nm/min, while leaving a smooth, residue-free surface. The process has many advantages, such as low cost, simplicity, safety gas component (CHF₃, SF₆ and O₂) and excellent repeatability. We have used it to fabricate 3C-SiC resonator successfully (Fig.5). The work is very important and useful to the SiC MEMS technology.

![Fig.5 The 3C-SiC resonator structure fabricated using the optimal ICP technology](image)
5. Acknowledgment
This work is supported by National Natural Science Foundation of China. The project No. is 60406010.

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