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Reactive ion etching of 4H-SiC with BCl_3 plasma

Streszczenie. *W pracy zaprezentowano wyniki reaktywnego trawienia jonowego (Reactive Ion Etching – RIE) węglika krzemu (4H-SiC) wspomaganego plazmą na bazie gazów roboczych Ar+BCl₃. Przeprowadzono analizę wpływu parametrów procesu trawienia: czasu procesu, ciśnienia w komorze roboczej, mocy i stosunku gazów roboczych (Ar i BCl₃) na głębokość i szybkość trawienia węglika krzemu. Jako maskę w procesach użyto osadzonego plazmowo SiO₂, w którym zostały zdefiniowane okna przy pomocy fotolitografii. Pomiary głębokości po procesach trawienia zrealizowane zostały metodą profilometrii.* ***(Reaktywne trawienie jonowe 4H-SiC przy użyciu plazmy Ar/BCl3)***

Abstract*. The paper presents the results of plasma assisted reactive ion etching (RIE) of silicon carbide (4H-SiC). with a mixture of Ar and BCl_3. The influence of input parameters such as process time, pressure, power and a ratio of working gases (Ar and BCl_3) on the etch rate was investigated. The windows in SiO_2 layer fabricated by PECVD process were patterned by photolithography. A stylus profilometry was a basic method of depth measurements after the etching processes.*

Słowa kluczowe: węglik krzemu, 4H-SiC , trawienie plazmowe, BCl_3, RIE
Keywords: silicon carbide, 4H-SiC , plasma etching, BCl_3, RIE

Introduction

Among typical polytypes of SiC, 4H-SiC is the most interesting one because of its superior physical properties for power devices compared to others and therefore it is indicated as a successor of silicon technology for advanced high power electronic applications[1]–[4]. High breakdown electric field, high thermal conductivity and wide bandgap of 3.26eV are its excellent physical properties [5]–[11]. The strong covalent bonds between silicon (Si) and carbon (C) atoms also makes this material hard, chemically inert and thermally conductive [6]. These properties make this material especially useful for high power electronics working at elevated temperature. Theoretically, the operating temperature of SiC-based semiconductor devices can go far beyond the capabilities of silicon devices [2], [3], [11].

Well–defined, high resolution patterning of SiC surface is a key operation during the device fabrication. The patterning of this material is particularly very difficult process due to extremely high chemical resistance, although it is a fundamental process in semiconductor technology for mesa termination, trench etching or the other spatial structure manufacturing. Additionally, the process should be appropriately selective, anisotropic and fully controlled. Wet etching of 4H-SiC is an ineffective process due to extremely high chemical inertness of this material even in alkaline solutions of KOH or NaOH [12]. High anisotropic reactive ion etching (RIE) using boron trichloride (BCl_3) plasma is one of the techniques that meets these basic requirements. A precise monitoring of the process parameters makes possible a full control of the etching results. Generally, it is a recurring process which is really critical for commercial applications.

This work presents the results of reactive ion etching of 4H-SiC in BCl_3 plasma. Our objective was to increase the etch rate reducing the surface roughness and plasma-generated damages with increased selectivity and anisotropy at fully controlled process. Our main motivation to publish the achieved results is very limited access to experimental data and their analysis for 4H-SiC etching process in RIE systems up to now.

Experimental details

A square (1 cm x 1 cm) samples of 4H-SiC were used for the etching experiments. Silicon dioxide (SiO_2) layer was deposited on clean 4H-SiC surface using plasma-enhanced chemical vapor deposition (PECVD). Silicon dioxide is used as a masking layer in the experiment. Next, the photolithography process was carried out to define windows in the masking layer for 4H-SiC surface etching. The exposed SiO_2 layer was removed in the HF buffer. The etching experiments were performed in BCl_3 plasma environment in OXFORD PLASMALAB 80+ system. Pure argon (Ar) physical sputtering was used as an additional process to BCl_3 plasma etching. Argon was also used as an additive to BCl_3 plasma etching. Total gas flow was fixed at 50 sccm. The influence of power, time, pressure and BCl_3/Ar flow ratio on the etching rate was determined within the range of etching parameters presented in Table 1.

Table 1.The range of input parameters used for reactive ion etching of 4H-SiC with BCl_3 plasma.

Parameter	Range
Power [W]	200-600
Time [min]	5-25
Chamber pressure [mTorr]	30-95
Total gas flow [sccm]	50 (fixed)

Based on the available range of process parameters presented in Table 1, the experimental tables were designed (Table 2). The experiments allowed to determine an influence of the input parameters on the etch rate. Veeco Dektak 150 profilometer was used to measure the etching profiles.

The first measurement was carried out just after the patterning of SiO_2 to determine the thickness of the mask. The next one was made after the etching process to determine the total thickness of the remaining masking material and the depth profile in SiC. The third thickness measurement (after removing the SiO_2 mask) allowed to determine the SiC etching depth. The difference between the second and the third measurements made it possible to determine the thickness of the mask that remained after the etching process.

Results

The analysis of the results shows the effect of the individual parameters of dry plasma-assisted BCl_3 processing on the etch rate. Due to the different duration of processes (5-20 min), the presented graphs have been normalized to 1 min etching for power, pressure and gas flow ratio analysis. Fig. 1 shows the influence of process time on the etching depth of 4H-SiC in pure BCl_3 plasma.

The etching characteristic is almost fully linear that greatly simplifies the process scaling. The estimated etching rate under presented conditions is approximately 15 nm/min.

Table 2. Input parameters and results: etching depth and etch rate.

	Time	Power	Pressure	Gas flow		Etching depth	Etch rate
				BCl_3	Ar		
	min	W	mTorr	sccm	sccm	nm	nm
1	10	200	30	50	0	126	13
2	10	400	30	50	0	253	16
3	10	600	30	50	0	186	19
4	20	400	50	50	0	638	32
5	20	400	70	50	0	772	39
6	10	400	90	50	0	340	34
7	5	400	30	50	0	80	16
8	12	400	30	50	0	178	15
9	15	400	30	50	0	216	14
10	20	400	30	50	0	289	14
11	25	400	30	50	0	386	15
12	20	400	30	50	0	289	14
12	20	400	30	40	10	207	10
13	20	400	30	25	25	149	7
14	20	400	30	10	40	109	5
15	20	400	30	0	50	93	5
16	10	200	30	50	0	126	13

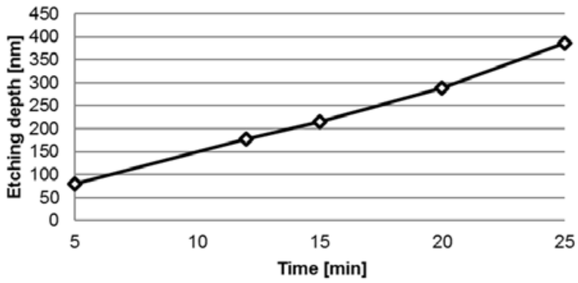

Fig. 1.4H-SiC etching depth as a function of time (flow rate: 50 sccm; RF power: 400 W; chamber pressure 30 mTorr)

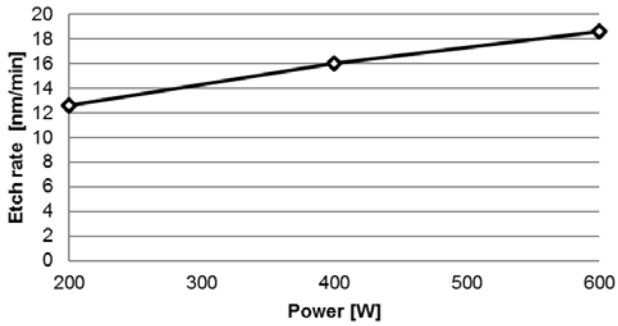

Fig. 2.The etch rate of 4H-SiC as a function of RF-power (flow rate: 50 sccm;; chamber pressure 30 mTorr)

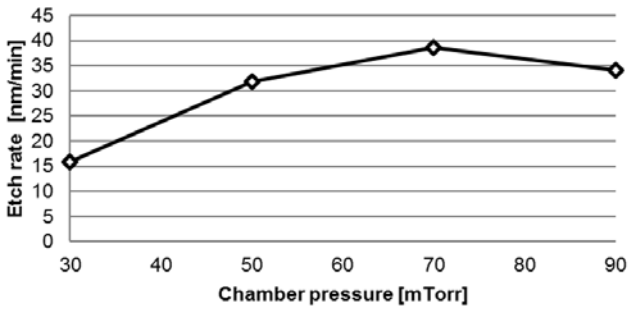

Fig. 3.The etch rate of 4H-SiC as a function of chamber pressure (flow rate: 50 sccm; RF power: 400 W).

Fig. 2 shows the dependence of the etching depth on the RF power used. For selected process parameters, the etching characteristic remains linear within the full range of applied RF power.

The influence of chamber pressure on the etch rate was determined as well (Fig. 3). The maximum value of the etch rate was indicated for a pressure of 70 mTorr.

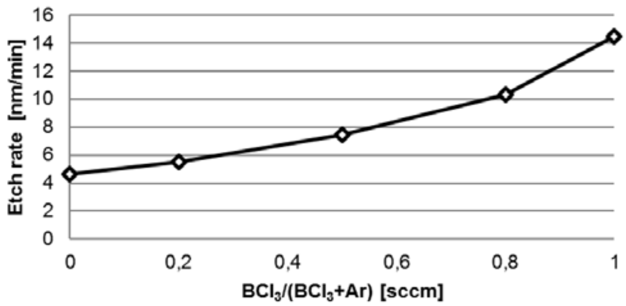

Fig. 4.The etch rate of 4H-SiC as a function of $BCl_3/(BCl_3 + Ar)$ gas-mixing ratio (Total flow rate: 50 sccm; RF power: 400 W; chamber pressure 30 mTorr).

The dry etching process consists of two mechanisms: chemical-based layer decomposition (due to Cl-based chemical etching) and physical sputtering (due to intensified Ar ion bombardment). As can be seen in Fig. 4, the etch rate is increased with increasing content of BCl_3 in the gas mixture. The chemical-based mechanism is more efficient method of 4H-SiC etching than pure sputtering in Ar. Furthermore, the etching in pure BCl_3 ambient is the most efficient way of 4H-SiC patterning.

However, it should be remembered that in this case of the asymmetrical reactor (asymmetrical electrodes) the etching mechanism is not a pure chemical reaction. Chemical etching is always accompanied by process of physical sputtering of the substrate. This is well known common impact of simultaneously occurring chemical and physical mechanisms strongly increasing etch rate for most materials. Usually a highest etch ratio is a result the appropriate gas mixture has been chosen[13]–[16].

Conclusion

In this work, the results of plasma assisted reactive ion etching (RIE) of silicon carbide (4H-SiC) were shown. The influence of BCl_3 plasma-assisted etching parameters such as RF power, chamber pressure, working gas ratio and time on the etch rate was investigated. The etch rate is fully linear for the applied time and power range that allows for relatively simple scaling of the process. The dependency characteristic for reactor pressure was determined (Fig. 2).

In the case of a mixture of working gases, together with an increase in the content of BCl_3 gas, the etch rate increases. The SiO_2 film shows good masking properties and was successfully applied to etching process. At this stage of the research, further directions of work can be indicated. The possibility of changing the mask from SiO_2 to polymer resist, the etching setup on inductively coupled plasma (ICP), and the reactive gas on Cl_2 should be considered.

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