Influence of the Masking Material and Geometry on the 4H-SiC RIE Etched Surface State

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Abstract. The roughness of etched SiC surfaces must be minimized to obtain surfaces with a smooth aspect, avoiding micromasking artifacts originating from re-deposited particles during the etching process. Four varieties of masks, Al, Ni, Si and C, were deposited on the SiC surface by photolithographic process. The C structures were formed by annealing conversion of patterned thick photoresist. On these surfaces, dry etching was performed with an SF_6/O_2 plasma produced in a Reactive-Ion-Etching (RIE) reactor. Although a better aspect of the surface is obtained with Ni in comparison with Al mask, micromasking could also occur even with Ni if the mask design was not enough spaced out. With C and Si masks, which produce fluorides species with negative boiling temperature, smooth etched surface was obtained without micromasking, even for tight masks covering up to 90% of the SiC surface.

Introduction

Silicon carbide device process requires a local SiC etching by dry process, due to the strong inter-atomic Si-C bonds. A photolithographic process is applied by patterning a mask at the SiC wafer surface. The mask is locally opened to form the zones to be etched. Different masks are utilized, their nature and thickness being determined by the etching depth in SiC, plasma chemistry induced by the mask presence, and the selectivity, i.e. the ratio between the SiC etching depth and the mask consumed. SiC etching is usually performed with fluorinated plasma chemistry, few results being published with chlorides plasma chemistries. Fluorinated plasma are prefered due to the higher etching rates obtained in this case.

In order to fabricate power and high temperature devices, the roughness of the etched areas must be minimized to a smooth aspect close to the initial state. Rough surfaces increase locally the electric field, generating leakage current and decreasing the breakdown voltage of the junctions.

Micromasking artifacts originate from re-deposited particles which locally reduce etching and lead to rough surfaces with a grass aspect (also named "black silicon" zones in Si etching studies) and a relief of pillar - column. Figure 1 presents examples of etched SiC surfaces with micromasking artifacts. In Figure 1a micromasking is produced by deposited particles extracted from the mask close to an etched trench. In Figure 1b, a more uniform micromasking repartition is shown, the re-deposited particles being in provenance of the cathode electrode made in Al.

In this paper we present results that show how to control the micromasking phenomenon during local etching of the SiC by choosing an adequate mask that is patterned in order to delimit the areas to be etched. This experimental study should be also helpful for works on micro-nanostructures that need to manage rough surfaces [1].

Experimental

4H-SiC samples with a surface area of 5 cm^2 were cut from 3 inches diameter SiCrystal wafers. Four varieties of masks, Al, Ni, Si and C, were formed on the SiC surface by photolithographic process. Al, Ni and Si have been deposited by electron-beam evaporation. Structures have been patterned by lift-off process, using a reversible photoresist for the Ni, wet etching with positive photoresist mask for the Al and dry etching with positive photoresist mask for the Si. The C structures were formed by annealing conversion at 600°C during 30 min of patterned thick (~10µm) AZ nLOF 2070 photoresist.

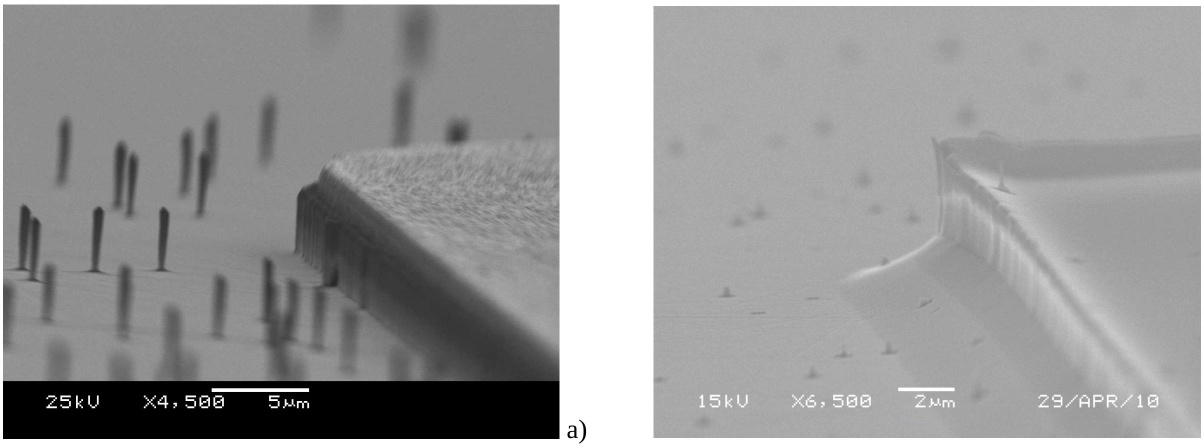

Fig. 1. Examples of micromasking artifacts produced by deposited particles extracted from the mask close to an etched trench (a) and from the cathode electrode made in Al (b).

On these SiC surfaces partially covered with the mentioned masks, dry etching was performed with an SF_6/O_2 plasma chemistry produced in an Alcatel Nextral NE110, a Reactive-Ion-Etching (RIE) reactor with a plasma source generated at 13.56 MHz and a quartz cathode electrode of 4 inches diameter. Particular attention was paid in order to obtain accurate and reproducible processes, by cleaning and passivating the reactor before the SiC samples etching, as well as keeping the reflected power in the reactor at minimal values and protecting the quartz cathode. The plasma parameters (power, pressure, gas flows) were defined in order to obtain a relatively high etching rate of the SiC, 0.2 to 0.33 µm/min [2], avoiding thus "trenching" phenomenon on sharp bottom corners [3].

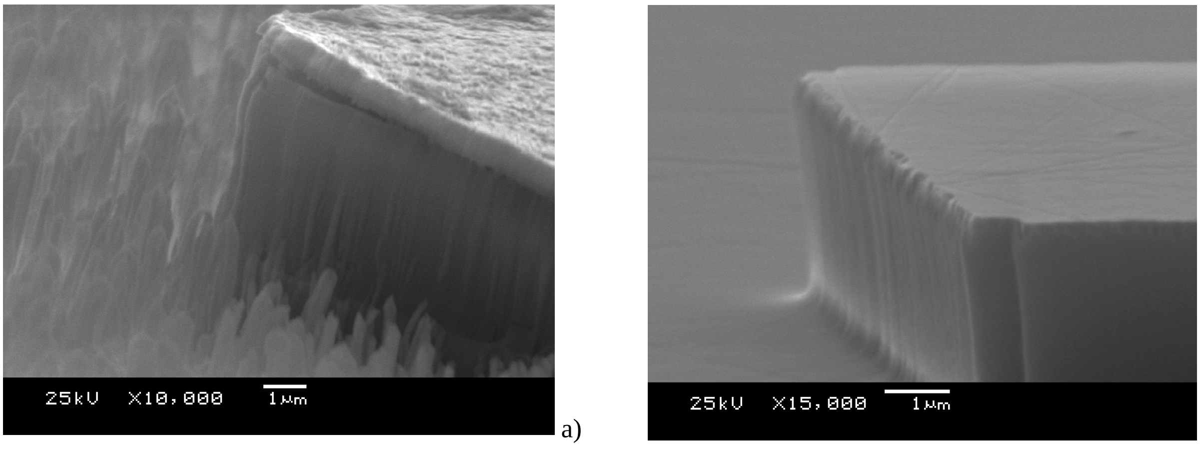

Fig. 2. 4H-SiC surfaces after RIE etching: (a) a rough SiC surface with grass aspect, (b) smooth SiC surface obtained with a Ni mask

The morphology of the etched patterns was characterized by scanning electron microscopy (SEM) observations and the etching depth and mask thickness were measured using a Tencor Alpha Step 500 profilometer.

Results and discussions

Fig. 2 presents SEM micrographs of locally etched 4H-SiC surfaces. On the left (Fig.2a), a rough SiC surface is obtained, typical of those obtained with Al mask when the micromasking phenomenon occurs. On the right (Fig 2b) a smooth surface is obtained, like in the non etched area that can be observed at the top of the trenches where mask were removed. In this case we used a Ni mask that covered 35% of the SiC surface.

Despite the better aspect of the surface obtained with Ni in comparison with Al mask (using the same mask geometry for the Ni and Al), micromasking could also occur even for Ni if the mask design was not enough spaced out. This means a low coverage of the SiC surface is needed, as well as a spaced distribution of the patterns, allowing non volatile species produced by the RIE plasma to evacuate.

Table 1. Melting and boiling temperature of RIE reaction products.

Element	Reac. Prod.	Melting Temp. (℃)	Boiling Temp (℃)
Al	AlF_3	1297	
	Al_2O_3	2072	2977
Ni	NiF_2	1370	1750
	$NiSO_4$	100	840
C	CF_4	-183.6	-127.8
Si	SiF_4	-121	-38

Table 1 shows the melting and boiling temperatures of the species produced by the RIE SF_6/O_2 reaction on the masks. These values are directly related to the volatility of these species during the SiC etching. Comparing Ni to Al, if high and close values correspond to the fluorides species (NiF_2 and AlF_3), Ni chemical compounds with lower boiling temperature values can be produced. This may explain the smoother surface obtained with the Ni masks. Nevertheless, open mask geometry is needed to avoid deposition of Ni non volatile species (as NiF_2) on the SiC surface, that leads to micromaking during the etching process.

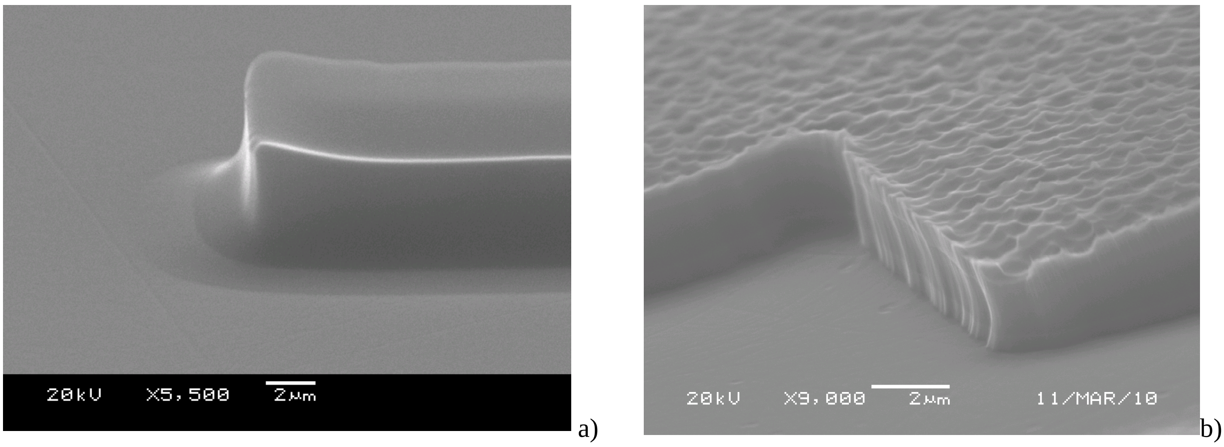

Fig. 3. 4H-SiC surfaces after RIE etching with C mask (a) and Si mask (b)

We notice that C and Si masks produce fluorides species with negative boiling temperature (table 1). With such masks, covering up to 90% of the SiC samples surface, we obtained smooth etched surface without micromasking. SEM micrographs are presented in the Fig. 3a and 3b for the SiC samples etched with C respectively masks and Si masks.

The photomasks geometries used for the lithographic definition of the Ni, Si and C mask structures at the SiC sample's surfaces are presented in figure 4. The dark-grey zones represent the non etched, mask-protected surface and the white-clear zones correspond to the SiC etched areas. The design of the Ni mask shown on Figure 4a covered 35% of the SiC surface, while Si and C masks covered up to 90% of the surface (Figure 4b).

However, compared to the Ni, the selectivity of Si and C masks are significantly lower. The selectivity of SiC to Ni mask was 40-50:1, and 0.5-2:1 to C or Si masks. The etching depth on the

SiC is limited by the mask's consumption during the process. Thus, Si and C masks can be utilized to etch tight structures (limited in the depth to a few µm) to fabricate high temperature, low voltage, on-chip integrated control circuitry [4]. On the other hand Ni masks are suitable to etch the deeper trenches (up to tens of µm) required to fabricate vertical high power SiC devices. In this case, however, the structures must be spaced enough in order to evacuate the non-volatile species.

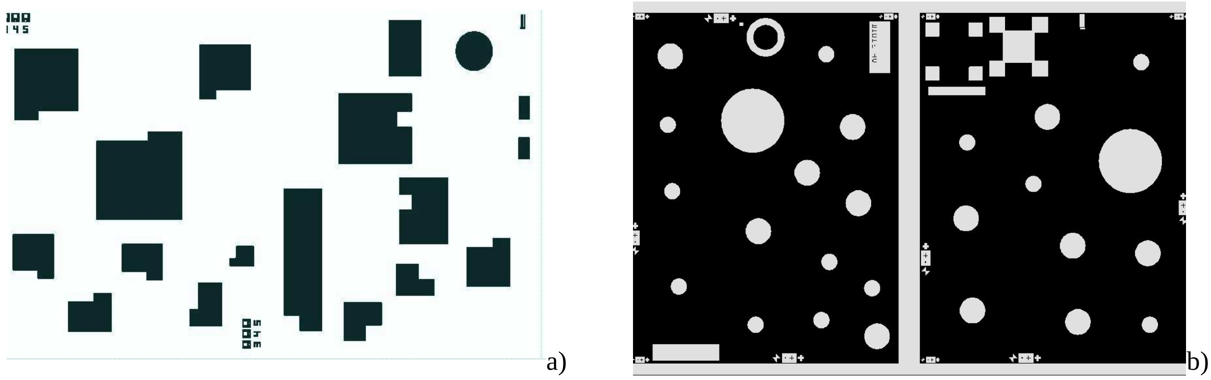

Fig. 4. Photomasks geometries used for the lithographic definition of the Ni (a), Si and C (b) mask structures. Field sizes are 6 by 10 mm^2.

We also notice, for the samples etched with the C mask (Fig 3a), a tapered transition at the bottom trenches, due to the initial geometry of the C mask, with tilted walls formed during the annealing conversion of the photoresist. This geometry could be used in the design of new SiC devices with sloped mesa structures.

Conclusion

Managing SiC surfaces in order to fabricate discrete or integrated devices requires to choose an appropriate mask (in terms of geometry and nature). When deep SiC etched structures are needed, Ni mask can be used thanks to its high selectivity, if particular attention is paid to limit the micromasking phenomenon by increasing the space between structures. With negative boiling temperatures of the fluorides species produced during the RIE reaction, C or Si are a better option for structures with confined surfaces, like interdigitated fingers of SiC switches. The C mask allows also to obtain sloped trenches which can for example facilitate making contacts.

Conversely, the non-volatile species produced from the Ni or Al masks can be used to increase the roughness of the SiC surface and to control the generation of new SiC micro-nanostructures.

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