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Structural Investigations of Pore Nucleation after Electrochemical Porosification of 4H-SiC for MEMS

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Summary:

The study emphasises the advantages of using electrochemical porosification to fabricate SiC-based MEMS devices, specifically focusing on improving pore nucleation control while preserving surface integrity. The results indicate that surface roughness plays a crucial role in pore nucleation, demonstrating the potential for improved MEMS device performance through carefully controlled substrate and etching conditions.

Keywords: SiC, electrochemical etching, nucleation layer, MEMS, resonator

Background, Motivation and Objective

Micro-electro-mechanical systems (MEMS) based resonators are pivotal in advancing technologies across various applications, such as precision timing devices, filters in communication systems, and sensors for automotive and aerospace industries [1, 2]. Silicon carbide (SiC), renowned for its exceptional material properties, including high thermal conductivity, mechanical robustness, and chemical stability, stands out as an ideal candidate for fabricating resonating MEMS devices, mainly when high quality factors are critical [3]. Despite the advantages of SiC, significant challenges remain in the cost-effective production of high-quality MEMS devices using this material. The integration of the cubic polytype 3C-SiC on silicon substrates has been vastly investigated. Still, SiC technology faces challenges such as significant differences in the coefficient of thermal expansion (CTE) of 8 % at room temperature and a lattice mismatch of about 20 %, leading to inherent stress and defects in the devices. These limitations hinder exploiting SiC's beneficial properties in MEMS applications [4]. As the cost of 4H-SiC wafers is anticipated to decrease in the foreseeable future, there is a growing interest in shifting focus towards manufacturing techniques that capitalise on 4H-SiC bulk wafers for MEMS device fabrication. One promising technology is photoelectrochemical etching [5], which facilitates the fast formation of porous 4H-SiC with tailored degrees of porosity. This technique enables the subsequent growth of a polycrystalline or even epitaxial 4H-SiC layer, potentially overcoming previous material integration challenges and paving the way for more cost-effective and high-performance SiC-based MEMS devices. With this technique, in combination with a thermal annealing step, mechanical structures such as membranes have already been reported [6]. During PEC etching of SiC and other semiconductors like silicon, a so-called cap layer is commonly observed in the initial few tens of nanometers of etching. This cap layer contributes to an irregular and difficult-to-control pore formation front, which has historically led researchers to develop nucleation layers to facilitate more controlled porosification. However, forming a nucleation layer with specific surface roughness can impede the deposition of subsequent epitaxial layers. The compromised surface quality induces certain defects during the growth of the epitaxial layer, negatively impacting both the layer quality and, hence, the quality factor of MEMS devices constructed from it [7].

Description of the New Method or System

The focus of this study is to provide deeper insights into the pore nucleation during the electrochemical etching of SiC to enable better control over porosification while maintaining a high degree of surface integrity for later epitaxial growth. This understanding is crucial to enhance the fabrication quality of MEMS devices, ensuring high performance and reliability.

4-inch wafers of n-type 4H-SiC with a 4 ° off-axis and a bulk resistivity of 0.02 Ω·cm were cut in $2.5 \times 2.5\ \text{cm}^2$. The surface roughness of the C-face and the Si-face before EC etching is < 2 nm and < 0.1 nm, respectively. Electrochemical etching was performed in a tabletop etching cell from AMMT, shown in Fig. 1 a). The samples are placed between two etching cell compartments, acting as a separation wall between the two electrodes. When a bias is applied, SiC is oxidised at the cell's anode and dissolved by hydrofluoric acid (HF), etching pores on the face adjacent to the electrode with the negative potential. A solution consisting of 5.52 mol/L HF and 1.7 mol/L ethanol was used. The corresponding etching profile is shown in Fig 1 b). Due to the relatively high conductivity of the used sample, no additional UV light illumination was required. Plasma etching from 10 s up to 30 s was conducted on porosified samples stepwise to expose the pore formation during the first 150 nm using 25 sccm O_2, 5 sccm SF_6 and a plasma power of 300 W in a parallel plate plasma etcher from STS.

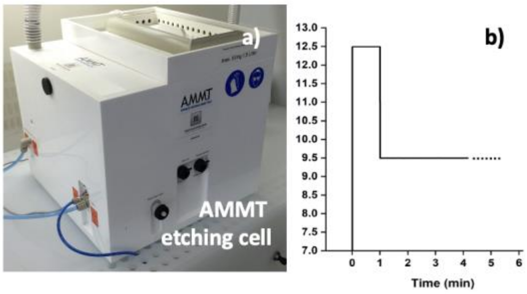

Fig. 1 a) Picture of the tabletop etching cell from AMMT, and b) Illustration of the applied voltage profile during electrochemical etching.

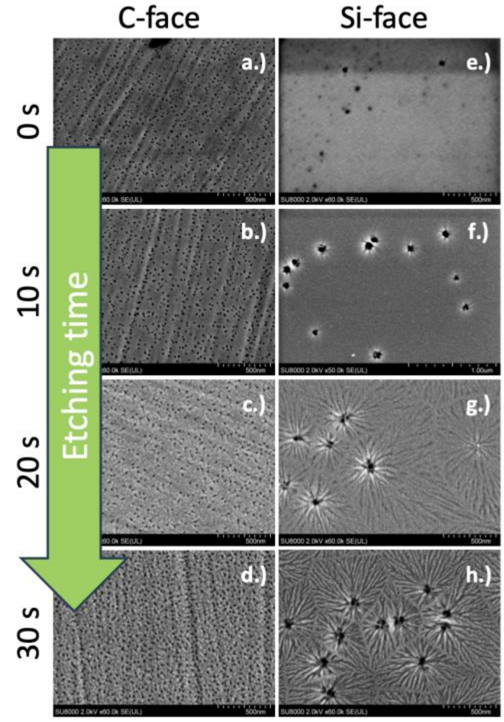

Fig 2 Results from plasma etching of a.-d.). the C-face etched sample and e.-h.) the Si-face etched sample. Etching rates of 300 nm/min and 225 nm/min were observed for the C- and the Si-face, respectively.

Results

Fig 2 shows the top-view SEM images for the C-face (a-d) and the Si-face (e-h). On the C-face etched samples, as shown in a.), extensive pore nucleation occurred, which can be explained by the minimal but sufficient surface roughness of < 2 nm. It can be seen that pore nucleation predominantly takes place along the nanometer-deep polishing scratches. No significant change in the porous structure was observed when the top surface was etched for 10-30s, as seen in Fig 2 (b-d). It is worth noticing that side branching was observed after 20 s of plasma etching. Furthermore, a significant increase in pore density from 250 pores/µm^2 (0 s) to 400 pores/µm^2 (30 s) took place. However, only scattered but larger pores were observed on the atomically flat Si-face with surface roughness values below 0.1 nm (Fig 2 e). After plasma etching of 20 s, a significant change in pore propagation was observed. Lichtenberg figures could be observed (see Fig 2 g and h).

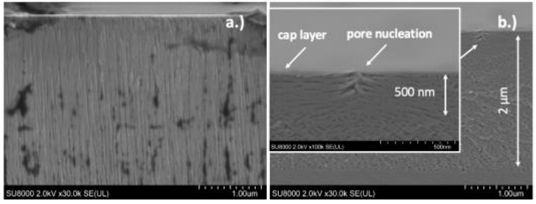

Fig 3 Cross-sectional SEM images of the samples etched from a.) the C-face and b.) the Si-face.

In Fig 3 cross-section SEM images of porosified samples for a) the C-face and b) the Si-face are shown. Continuous and cylindrical pores could be observed for the C-face, which are typical of C-faced etched samples. For the Si-face etched sample shown in b.), the impact of pore nucleation and the corresponding Lichtenberg figure are visible and cause a chaotic porosification profile. These findings indicate that even low energetic plasma surface treatment can facilitate pore nucleation on SiC.

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