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# Technology development for nano-pillars fabrication in silicon carbide to enhance light collection from color centers

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Over the past decade, the advancements in fabrication techniques and material purity for silicon carbide (SiC) power devices have led to the growing interest in using optically active point defects, also called color centers, within SiC for quantum applications at room temperature [1-2]. One promising application is the development of near-infrared (NIR) single photon sources (SPS), using color centers within SiC, such as the silicon vacancy ( $V_{Si}$ ). Recent research indicates that the fabrication of micro/nano-pillar arrays in SiC can significantly enhance the light collection efficiency of SPS [3-4] and while studies have explored the optimization of pillar diameter and height, the impact of pillar spacing on light collection remains, as far as we are aware, unexplored experimentally.

This work focuses on fabricating nano-pillar arrays of varying diameters and spacings in 4H-SiC to enhance the light collection of the silicon vacancy ( $V_{Si}$ ) and the divacancy carbon-silicon ( $V_C V_{Si}$ ). We realized ion implantation of hydrogen and helium in n-doped 4H-SiC samples to generate the point defects. Photoluminescence (PL) measurements of the un-etched samples confirm the presence of the  $V_{Si}$ . (Fig. 1).

To fabricate the nano-pillars, e-beam lithography was used with the eLINE system of Raith to pattern a PMMA resist spin-coated on the sample's surface. The resist was developed for 1min20s in a MIBK/IPA solution and 150nm of chromium was deposited on the sample's surface, in the evaporator Plassys MEB400, to form the etching mask. Nano-pillars were then etched using reactive ion etching (RIE) with inductively coupled plasma (ICP) in a Plassys MU400 reactor. SiC plasma etching was performed at 100W RIE and 1000W ICP power, under 8mTorr pressure, using  $SF_6$  and  $O_2$  gases. Finally, the rest of the Cr-masks was removed by immersion of the sample for two days in a chromium wet etchant solution.

According to the calculations of F.A. Inam and S. Castelletto [6], a maximum of light collection is reached for a pillar's diameter close to half the wavelength of emission ( $\lambda/2$ ) of the color centers. To respect this condition for the  $V_{Si}$  and  $V_C V_{Si}$  defects [2], [5], we chose to vary the diameter of the nano-pillars between 350 and 700nm with 50nm increments. The diameter of the Cr-masks' base ( $D_B$ ) respects these dimensions but the top of the masks ( $D_T$ ) is about 150nm narrower (Fig. 2). This is certainly due to heating of the resist during deposition of the Cr-mask which affected the geometry of the resist sidewalls. Nano-pillars' spacing was determined based on simulation results obtained in the article of M.A. Ahamad *and al* [4]. The calculations are done for one particular wavelength of emission of the  $V_{Si}$  at 917nm.

In the end after plasma etching, we obtained nano-pillars arrays (Fig. 3) with 1.4 $\mu$ m tall pillars at an etch rate of 280nm/min. The SiC pillar's width ( $D_P$ ) is close to the top of the Cr-mask diameter. More vertical etched trenches are obtained in SiC compared to the Cr mask geometry, without under-etching at the bottom part ("trenching phenomenon" [7]). This is due to the good selectivity of the Cr mask and our optimized process. However, expanding the spacing between pillars resulted in a more prominent lateral etching of the nano-pillars, as depicted in Table I. Moreover, when the spacing between the pillars is too important (945nm), the lateral etching increases when the diameter decreases. One solution to prevent this lateral etching is to modify mask diameters or to adjust RIE and ICP power settings, by increasing the RIE one. But in this case, the selectivity of the Cr-mask will decrease and probably less vertical and smaller pillars will be obtained due to the mask consumption. This lateral etching phenomenon seems to not be taken into account for the fabrication of SiC power devices. It may be because of the larger dimensions of the devices ( $\mu$ m-scale). As a next step, we will fabricate SiC nano-pillars in 4H-SiC samples implanted with helium and hydrogen and PL and cathodoluminescence results will be presented at the conference and compared to those obtained from flat un-etched samples.

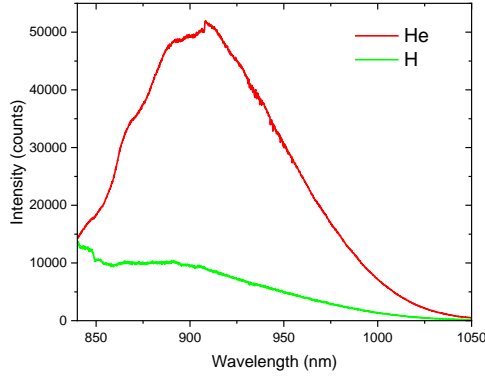


Fig. 1. PL spectra of the un-etched 4H-SiC samples implanted with He and H ions. For the H-implanted sample the signal is multiplied by 3.

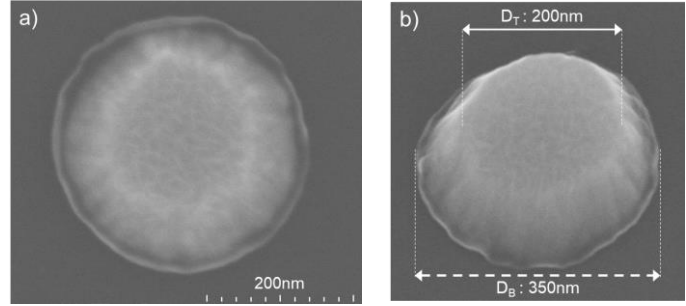


Fig. 2. SEM images of the 150nm high Cr-mask with no angle (a) and with an angle of  $30^\circ$  (b). The theoretical diameter ( $D_{th}$ ) is 350nm.

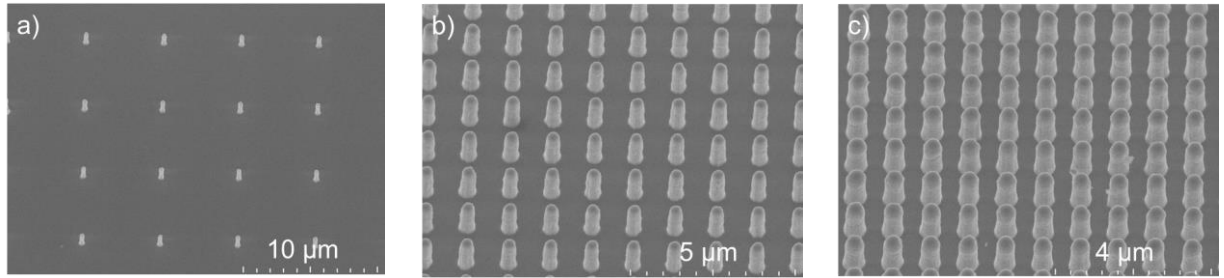


Fig. 3. SEM images of nano-pillars arrays with a tilt of  $30^\circ$ .  $D_{th}$  is 700nm and the theoretical spacing between pillars is  $5\mu m$  (a), 540nm (b) and 245nm (c).

Table I. Evolution of the nano-pillars' diameter for a theoretical diameter of 700nm.  $D_{P1}$ ,  $D_{P2}$ ,  $D_{P3}$ ,  $D_{P4}$  and  $D_{P5}$  are the measured nano-pillars diameters for a theoretical spacing of 245, 335, 540, 945 and 5000nm respectively.

Diameters (nm)							
$D_{th}$	$D_B$	$D_T$	$D_{P1}$	$D_{P2}$	$D_{P3}$	$D_{P4}$	$D_{P5}$
700	700	550	550	530	500	470	410
650	650	500			490	410	
600	600	450			450	350	
550	550	400			390	260	

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