Growth of Cubic Silicon Carbide on Silicon Nano-Mesas

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Abstract:

Silicon pillars and tips were fabricated with 2, 3, 4, and 5 μm spacings. The bases were 1 μm with the pillars having an aspect ratio of 7:1 and the tips 1:1. A growth mask was applied to the tips only, and CVD was used to grow SiC on the structures. 2, 4, 6, 8, 12, 15, 30, and 60 minute growths were performed and characterized.

The 2 μm spaced tips and pillars have exhibited the best terrain on which silicon carbide can grow, as the film seems to have coalesced to a further degree than on other spacings. Characterization is done using SEM and XRD to see the growth and determine the crystal structure.

Introduction:

Silicon carbide is one of the strongest materials known, with a Young's modulus of 420 GPa (Si_3N_4 - 320 GPa), and a rating of 9.5 on the Mohs hardness scale. It is already used as an abrasive in industry (carborundum), and is beginning to replace cubic zirconium as a cheaper alternative to diamond (moissanite). Silicon carbide is corrosion resistant and has a very high melting point (2700°C), making it suitable for MEMS or piezoresistive applications in harsh and extreme environments. With its bandgap ranging from 2.36 to 3.2 eV, it has obvious applications in high temperature, high power electronics. It also has a high refractive index, and so, along with exhibiting other novel electro-optic properties, silicon carbide has many theoretical applications in optics and photonic engineering. No other semiconductor material can boast this resiliency and robustness, making the growth of high quality silicon carbide films a very promising endeavor.

The cost of manufacturing it at present, however, is quite prohibitive. 2 inch wafers of silicon carbide can cost as much as \$2000, whereas a 4 inch wafer of silicon can be obtained for as little as \$8. This makes finding a way of growing silicon carbide on silicon a very attractive alternative to the current processing technology. Hence, the reason for attempting to grow on silicon pillars and tips.

There are two main reasons for growing silicon carbide on silicon pillars and tips: the large lattice mismatch (~20%) and the mismatch in the thermal expansion coefficients (~8%). The lattice mismatch should have a reduced effect on the grown crystal as a small nucleation area is provided by the pillars (1 μm) and tips (~10 nm). This should help reduce defect density and provide a higher quality crystal than what is grown on planar silicon. The pillars also serve another purpose; as the two materials are cooled after growth, they will contract at different rates. Rather than introduce dislocations in the silicon carbide film, the pillars should buckle to relieve much of the strain that will inherently be caused by the mismatch in the thermal expansion coefficients.

Procedure:

Silicon wafers were oxidized in a wet ambient until 900 nm of oxide was grown. Photolithography was then performed using a 10X i-line stepper to step the pillar/tip pattern into 140 die. The pattern was transferred into the oxide using a RIE plasma system. After stripping off the photoresist, the wafers were either subjected to a chlorine plasma ICP RIE, or the Bosch process. The Bosch process was used to fabricate pillars with flat tops and high aspect ratios, whereas the chlorine

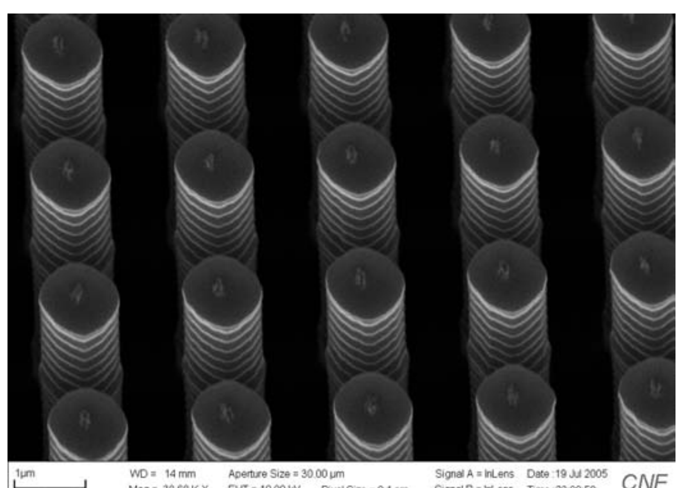

Figure 1

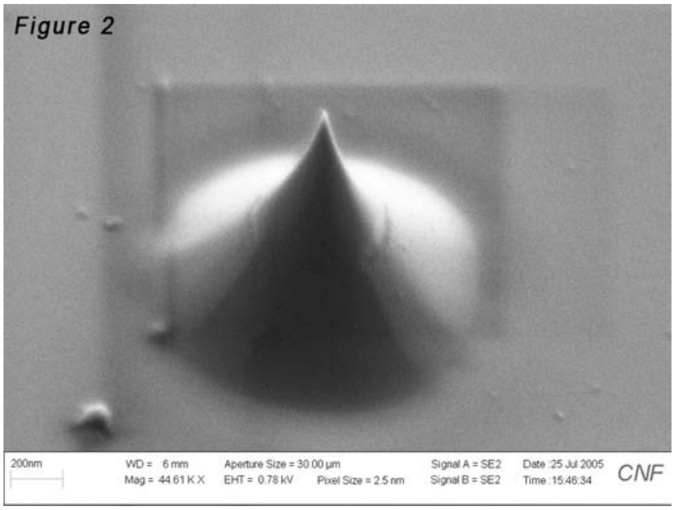
Figure 2

plasma etch was used to fabricate tip precursors 1 μm in diameter. (See Figures 1 and 2.)

After fabricating the tip precursors, the wafers were re-oxidized for 90 minutes in a wet ambient, creating tips. An etch-back process was then used to apply a growth mask and strip the oxide from a suitable area of the tips. Growth was performed by CVD at a temperature of 1350°C and a pressure of 200 torr. The carbon to silicon ratio was 3:1 using the gases propane (C_3H_8) and silane (SiH_4). 2, 4, 6, 8, 12, 15, 30, and 60 minute growths were performed on both tips and pillars. The resulting film was characterized using SEM and XRD.

Results and Conclusions:

It was originally hoped to characterize the growth process, which is why so many short growths were performed. However, the longer growths seemed to yield more promising data, and thus much of the attention was focused on these longer growths. It was determined that the 2 μm spaced tips were most suitable for growth, as there was clear coalescence of the film after 1 hour of growth. (See Figure 3.) However, scanning electron micrographs that were taken on other spacings do suggest that coalescence is but a matter of time.

The pillars proved to be the more successful endeavor, as all spacings look to be able to experience coalescence. The 2 μm spacings exhibited coalescence, but it is only a matter of time before the other spacings will follow suit. (See Figure 4.)

X-ray diffraction was performed on tip growth, post growth, and growth on planar silicon. Rocking curves were performed around the <100> crystal direction on tip growth and planar growth. The FWHM value for planar growth was around 2.7 degrees, while that of the tip growth was around 1.7 degrees, proving that this technique yields a better oriented crystal.

Future Work:

More work can certainly be done to optimize each growth process. With processes optimized for both tip and pillar scenarios, perhaps higher quality films can be grown in less time. The periodic spacing of the pillars may also lend itself to growth of a silicon carbide photonic crystal, although much more research is needed to pursue this idea.

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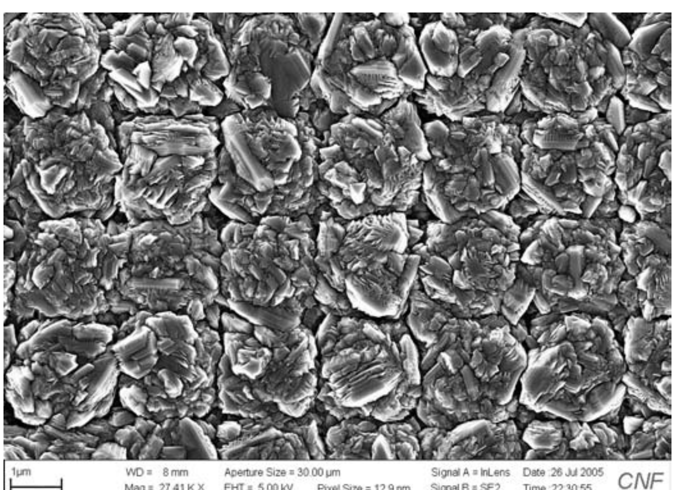
Figure 3

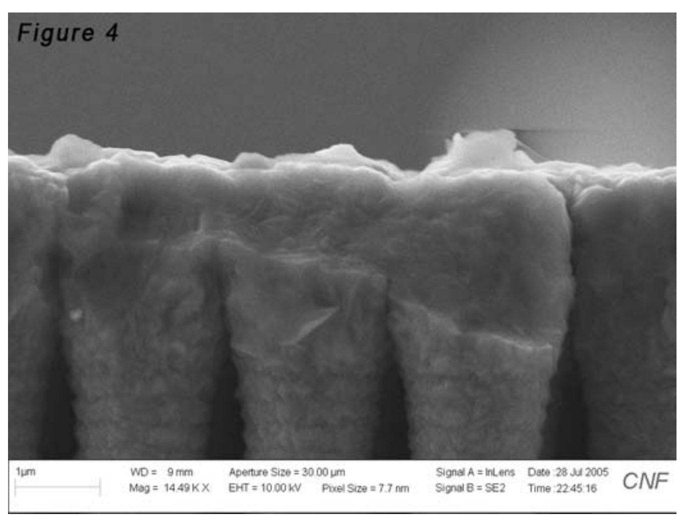
Figure 4