

# Selective-area room temperature visible photoluminescence from SiC/Si heterostructures

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SiC/Si heterostructures have been patterned by reactive ion etching with  $\text{CHF}_3/\text{O}_2$  to produce SiC-covered and Si-exposed regions with lateral dimensions of 2.5 to  $\sim 500 \mu\text{m}$ . The patterned samples were then anodized in HF/ethanol solutions. Short anodization times ( $< 3 \text{ min}$ ) result in selective-area UV-induced visible photoluminescence (PL), with a peak located at 650 nm, being observed at 25 °C from only the SiC-covered regions. The emission is generated by porous Si (PoSi) selectively formed under the SiC cap and transmitted through the wide band-gap SiC layer. Longer etching times result in nonselective PL.

The discovery of visible photoluminescence (PL) from porous  $\text{Si}^{1-4}$  (PoSi) at room temperature has generated renewed interest in light-emitting Si devices structures. In this letter, results are presented on visible light emission from 3C-SiC/Si heterostructures. 3C-SiC (or  $\beta$ -SiC) is a semiconductor with a band-gap energy of 2.2 eV, which makes it transparent to visible light.  $\beta$ -SiC and Si have the same cubic crystal structure. In spite of a rather large lattice mismatch, heteroepitaxial growth of SiC films on Si has been achieved by several groups.<sup>5-8</sup> In addition, SiC can be heavily doped to produce a low resistivity and it is impervious to most, if not all, common chemicals. This combination of properties makes SiC an ideal candidate for a transparent electrode to PoSi. For example, polycrystalline SiC deposited on Si after it is rendered porous has been utilized<sup>9</sup> in the fabrication of electroluminescent  $p$ - $n$  junction diodes. A similar approach for a wide band-gap injector into PoSi has been reported<sup>10</sup> by Campbell *et al.* using GaP/Si structures.

The SiC/Si structure is initially formed by carbonization of 5–7  $\Omega \text{ cm}$  (100)  $n$ -Si substrates with propane at 1300 °C for 90 s using rapid thermal chemical vapor deposition (RTCVD) resulting in a 2000-Å-thick SiC film. RTCVD of SiC has been shown<sup>8</sup> to produce monocrystalline thin films, while minimizing the high temperature exposure. The SiC film is then patterned by reactive ion etching using  $\text{CHF}_3/\text{O}_2$  under conditions designed<sup>11</sup> to provide a residue-free etch field. This step defines exposed Si regions and complementary Si regions protected by the SiC film. Finally, anodization is performed at 25 °C in a 1:2:1 solution of HF:ethanol:H<sub>2</sub>O. As shown in Fig. 1, during anodization the SiC-patterned surface is exposed to the electrolyte. The anodization current density was typically varied from 2 to 10  $\text{mA}/\text{cm}^2$  and the anodization times from 1 to 10 min.

The pattern of the SiC/Si heterostructure is shown in the scanning electron microscope (SEM) photograph of Fig. 2(a) for a sample which had been anodized for 2.5 min. SiC-covered and Si-exposed regions of various dimensions are evident. For the conditions that we have used, the SiC surface after anodization does not reveal any evidence of a porous structure. Under a UV fluorescence microscope at 25 °C with a Hg lamp emitting at 360–370 nm, the anodized SiC/Si structure exhibits selective-area visible photoemission only in those regions where SiC is present, as shown in Fig. 2(b).

Uniform emission is obtained in the larger SiC-covered regions and well-resolved emission is produced by the 2.5- $\mu\text{m}$  lines. To identify the source of the PL, unpatterned SiC/Si samples were exposed to the same anodic solution. No emission was observed for these samples, even when higher current densities and longer times were used.

The emission patterns from SiC/Si samples anodized for different times were obtained. Figures 3(a) and 3(b) show the reflected white light and UV-induced images of the same SiC/ $n$ -Si sample anodized for 2 min. In the UV-induced image it appears that, while the smaller (20- $\mu\text{m}$ ) features emit fairly uniformly, the larger (80- $\mu\text{m}$ ) features have a central region which does not emit. Extending the anodization time to 2.5 min, Fig. 3(c), the nonemitting (dark) regions in the center of the large SiC-covered regions disappear, resulting in uniform emission. For 3-min anodization the PL selectivity is lost, with the entire surface emitting, as shown in Fig 3(d).

PL spectroscopy was performed on various SiC/Si samples using the same Hg UV source. As shown in Fig. 4(a), selective-area emission from the SiC/Si region (obtained for 2.5-min anodization) produces a broad spectrum peaked at 650 nm. This PL spectrum is very similar to that obtained with PoSi.<sup>3,4</sup> The Si region of the sample only produces a “background” spectrum. Increasing the anodization from 2.5 to 3 min produces the PL spectra contained in Fig. 4(b). Under this anodization condition the emission was observed [see Fig. 3(d)] to be no longer area selective. Indeed,

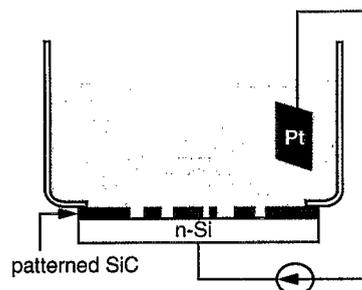


FIG. 1. Experimental setup for anodization of the SiC/Si heterostructure.

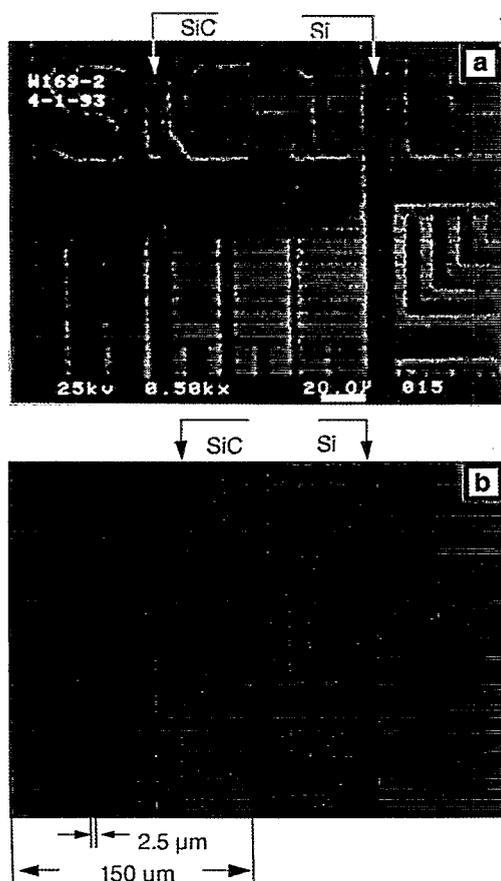


FIG. 2. Microphotographs of a patterned SiC/Si sample anodically etched for 2.5 min: (a) SEM photograph; (b) UV-induced photoemission image.

we observe in Fig. 4(b) that the PL spectra from the two regions are now nearly identical.

Anodization in the SiC/Si structure appears to occur first along the interface. The process apparently starts at the exposed edge of the SiC/Si mesa and proceeds preferentially under the SiC-covered region. For a sufficiently long anodization time, the entire surface area (including both Si-exposed and SiC-covered regions) becomes photoemissive. The PoSi formed underneath the SiC layer appears to be the

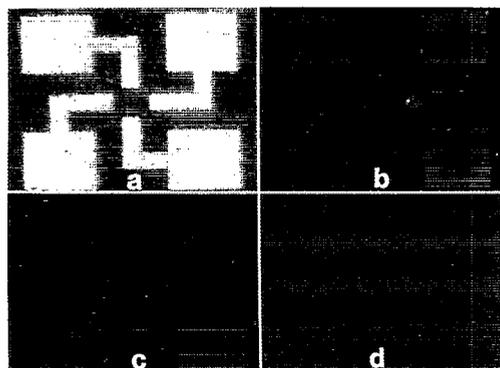


FIG. 3. Optical images of anodically etched SiC/Si samples as a function of anodization time: (a) reflected white light, 2 min; (b) UV-induced emission, 2 min; (c) UV-induced emission, 2.5 min; and (d) UV-induced emission, 3 min.

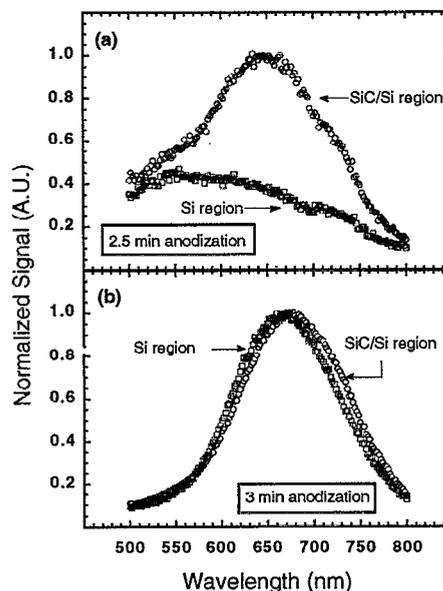


FIG. 4. Photoluminescence spectra from Si and SiC/Si regions anodically etched for 2.5 and 3 min.

source of the photoluminescence. This conclusion is supported by the fact that when both regions emit they exhibit an essentially identical spectrum. A possible reason for the initial preferential anodization of the SiC-covered regions is stress-induced charge carrier generation at the interface.

In summary, selective-area visible photoemission under UV excitation from anodically etched SiC/Si structures has been reported. The emission is associated with PoSi preferentially formed in the Si substrate under the SiC-covered regions. The localized visible light is readily transmitted through the SiC layer, which has twice the band-gap energy of Si. The SiC/Si heterostructure appears to be a promising candidate for the fabrication of electroluminescent PoSi devices.

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