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Enhanced extraction efficiency of fluorescent SiC by surface nanostructuring

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Abstract: Antireflective structures were fabricated on fluorescent 6H-SiC for white LEDs to enhance the extraction efficiency. Average surface reflectance decreased from 22.1 % to 5.1 % over a broad range, and luminescence intensity was enhanced by 41 %.

OCIS codes: (220.4241) Nanostructure fabrication; (250.5230) Photoluminescence.

1. Introduction

White light-emitting diodes (LEDs) consisting of a nitride-based blue LED chip and wavelength converter material are energy-saving and environment friendly light sources for the general lighting applications. Nitrogen (N)-boron (B) doped 6H-SiC has been proven as a high-efficiency wavelength converter with long lifetime [1–3]. Usually, the low extraction efficiency due to the internal reflection loss is a serious problem in LEDs. In the present work, we fabricated antireflective sub-wavelength structures (ARS) on the N-B doped 6H-SiC by reactive-ion etching (RIE) to enhance the extraction efficiency. Low surface reflection over the entire visible spectral range and consequently enhanced luminescence were achieved in the fluorescent SiC with ARS.

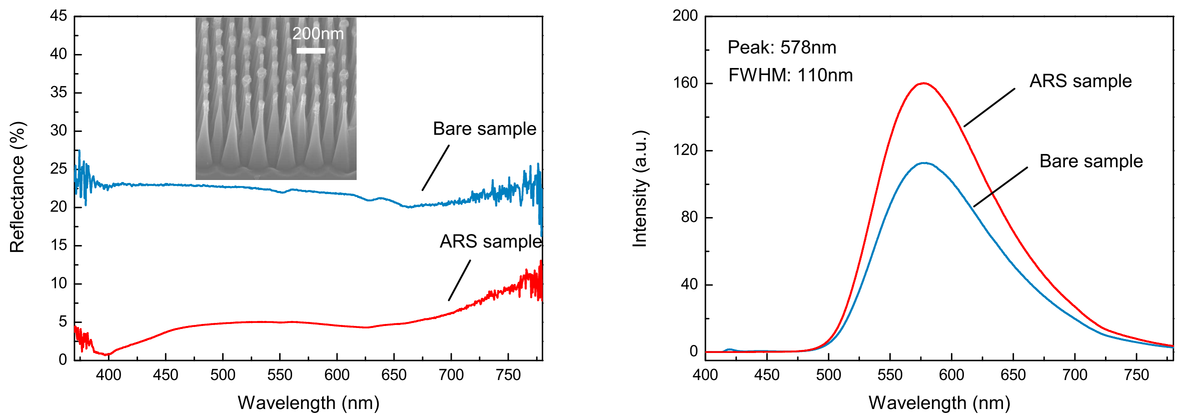
2. Experiments and results

Homoepitaxial layers of 6H-SiC with N and B dopants were grown by Fast Sublimation Growth Process [4]. The growth process is driven by a temperature gradient created between the source, in a form of polycrystalline SiC plate, and the substrate. Boron was introduced into the epilayers by doping from the source and nitrogen incorporation was controlled by adjusting the N_2 gas pressure during the growth. The 6H-SiC epilayers were grown on 6H-SiC (0001) substrates with 1.4 degree off-orientation in the $[11\bar{2}0]$ direction at growth temperature of 1725°C.

To fabricate the ARS on SiC, the positive photoresist (ZEP520) was spin-coated on the 6H-SiC sample and then prebaked on a hot plate at 160°C for 2 minutes. The designed mask pattern was transferred to the photoresist coating by applying the e-beam lithography (JEOL JBX9300FS). After the development, a hard mask material (Chromium) was deposited on the patterned SiC using the e-beam evaporation with a subsequent lift-off process. The dot-shaped pattern was then obtained on the hard mask. The dry etching process using SF_6 and O_2 precursors was carried out in the reactive-ion etching system. During the etch process, the RF-power, process pressure, and gas flow rates of the RIE were carefully chosen. Finally, the cone-shaped ARS with designed configuration (bottom diameter of 120 nm, pitch of 170 nm, and height of 1.2 μm) were formed on the SiC surface. An oblique-view SEM image of the ARS cone pattern is shown in the inset of Fig. 1a.

The normal reflectance cover the entire visible spectral range (370-780 nm) were measured and the results are shown in Fig. 1a. It is seen that the reflection is effectively suppressed by applying the SiC ARS. The average reflectance over the whole measured spectral range decreased from 22.1 % to 5.1 % and the minimum reflectance of 0.69 % was observed at around 400 nm for the sample with ARS. Although the reflectance starts to increase at above 700 nm, the average reflectance level even at the spectral range of the photoluminescence peak is below 6 %. This result indicates that the SiC ARS is an effective way to suppress the surface reflection of the fluorescent SiC sample.

The photoluminescence spectra of the samples with and without the ARS were also acquired at room temperature and the results are shown in Fig. 1b. The donor-acceptor-pair (DAP) band luminescence of the fluorescent SiC is usually broad which is a merit as a wavelength converter material. As a result, an enhanced luminescence intensity as well as the same spectral profile are expected after introducing the SiC ARS. It is found that the luminescence intensity



(a) (b)

Fig. 1: (a) Reflectance curves (inset: SEM image of the SiC antireflective structures) and (b) photoluminescence spectra of the SiC samples with and without antireflective structures.

was dramatically enhanced as high as 41 %. The same peak wavelength of 578 nm was also observed in both spectra. In addition, the same full width at half maximum (FWHM) value of 110 nm was obtained which means that the ARS pattern does not change the luminescence spectral profile.

3. Conclusion

Antireflective sub-wavelength structures have been successfully fabricated on N-B doped fluorescent 6H-SiC by using the reactive-ion etching method. Normal reflection at SiC sample surface was effectively suppressed in the spectral range from 370 to 780 nm which covers the entire visible range. The average reflectance decreased from 22.1 % to 5.1 % and the minimum reflectance of 0.69 % was also obtained. From the acquired photoluminescence spectra, the DAP band luminescence intensity was dramatically enhanced by 41 % after introducing the SiC ARS. Furthermore, the same spectral profile in terms of the peak wavelength and FWHM was also achieved in the fluorescent SiC sample with ARS. The experimental results indicate that ARS is an effective method to improve the extraction efficiency of the fluorescent 6H-SiC as a wavelength converter material in the white LEDs applications.

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