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Spatial Mapping of the Carrier Concentration and Mobility in SiC Wafers by Micro Fourier-Transform Infrared Spectroscopy

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Abstract. Micro Fourier-transform infrared (FTIR) spectroscopy has been used to investigate the spatial distribution of the carrier concentration and mobility in SiC wafers. The carrier concentration and mobility were independently derived from the reflectance spectra based on the dielectric function taking into account the effect of phonons and plasmons. The carrier concentration profile obtained for an intentionally inhomogeneous N-doped 6H-SiC wafer coincides well with the spatial distribution of color in the wafer. For commercially available wafers, carrier concentrations are found to increase with approaching the center of the wafers. These results demonstrate that micro FTIR is a nondestructive and noncontact technique to spatially characterize the carrier concentration and mobility in SiC wafers.

Introduction

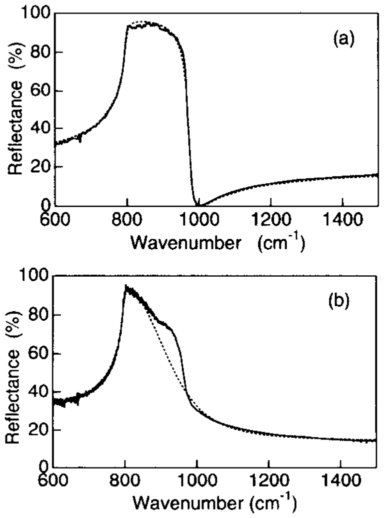

Fig.1 Reflectance spectra obtained from (a) lightly and (b) heavily doped regions in an inhomogeneously doped SiC wafer.

Silicon carbide is a promising material for applications in high-temperature, high-power, and high-frequency electronic devices due to its wide band gap, high saturated electron velocity and high breakdown electric field. Since spatially inhomogeneous doping into SiC wafers results in nonuniform thermal properties and thus poor quality epitaxial layers and poor device performances, highly uniformly doped SiC wafers is necessary for practical use. However, it is reported that heavily doped SiC wafers are often not so uniform.[1] In order to characterize the carrier concentration, electrical measurements such as Hall and resistivity measurements are usually used. In these techniques, however, electrical contact with the sample is needed and is inappropriate for the subsequent epitaxial growth. Raman scattering spectroscopy has been used to characterize carrier concentrations in SiC wafers as a noncontact technique [1]. Reflectance measurements have been also used to characterize the inhomogeneities in the carrier concentration in GaAs [2]. In the present study, we have, for the first time, demonstrated that micro Fourier-transform infrared (FTIR) spectroscopy can reveal the spatial distribution of carrier concentrations and mobilities in SiC wafers in a nondestructive and noncontact way.

Experimental Procedures

The samples used in this study were an intentionally inhomogeneous N-doped 6H-SiC wafer grown by the modified Lely method, and commercially available 2-inch, n-type 4H- and 6H-SiC wafers. Reflectance measurements were carried out using a micro FTIR spectrometer at room temperature. The spectral resolution was set to 1 cm^{-1}. The light was incident normally on the (0001) surface of SiC wafers. The spatial resolution was 50-100 μm.

Results and Discussion

Figures 1 (a) and (b) show reflectance spectra obtained from lightly doped and heavily doped regions, respectively, in the intentionally inhomogeneous N-doped 6H-SiC wafer. From the lightly doped region a typical reflectance spectrum due to lattice vibrations was observed, i.e. the reflectance was nearly 100% between the TO and LO phonon frequencies. On the other hand, the deep minimum in the reflectivity around 1000 cm^{-1} was not observed from the heavily doped region, as shown in Fig. 1 (b). This is mainly due to the high carrier concentration and large damping for free carriers, as described later. Thus, the reflectance spectra are strongly affected by the carrier concentration, showing that FTIR measurements can be used for the determination of the carrier concentration.

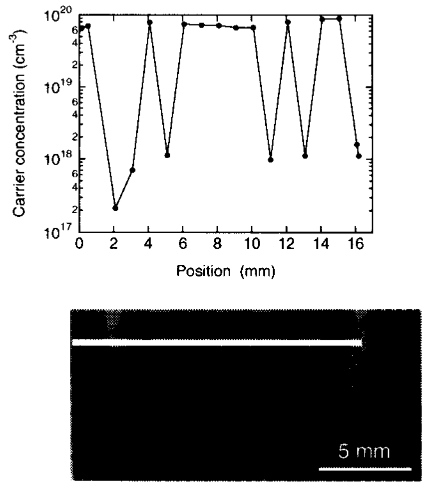

Fig. 2 Line profile of carrier concentration in an inhomogeneously doped SiC wafer.

To analyze quantitatively these reflectance spectra we have used the following dielectric function considering the contributions from phonons and plasmons,

$$\varepsilon(\omega)=\varepsilon_\infty\left(1+\frac{\omega_L^2-\omega_T^2}{\omega_T^2-\omega^2-i\omega\Gamma}-\frac{\omega_p{}^2}{\omega^2+i\gamma\omega}\right), \qquad (1)$$

where ε_∞ is the high frequency dielectric constant, ω_T and ω_L are the TO- and LO-phonon frequencies, respectively, Γ is the phonon damping constant, γ is the free-carrier damping constant, and ω_p is the plasma frequency of the free carriers, which is given by

$$\omega_p=\left(\frac{Ne^2}{m^*\varepsilon_\infty}\right)^{1/2}. \qquad (2)$$

In Eq. 2, N, e, and m^* are the free carrier concentration, charge, and effective mass, respectively. The free-carrier damping constant γ is the inverse of the scattering time τ and therefore the free-carrier mobility can be derived using the following relation,

$$\mu = \frac{e}{m^* \gamma}. \tag{3}$$

Assuming that the SiC wafers are uniform in the depth direction, we used the normal-incidence reflectance of a semi-infinite medium R, which is expressed as

$$R(\omega) = \frac{(n-1)^2 + \kappa^2}{(n+1)^2 + \kappa^2}, \tag{4}$$

where n is the refractive index, κ is the extinction coefficient, and $(n+i\kappa)^2$ is equal to $\varepsilon/\varepsilon_0$. When the light is normally incident on the (0001) surface of the samples, ε_∞, ω_T, ω_L, Γ, m^*, and γ are all for the planer-type mode. For the analysis of the reflectance spectra, we fixed $\varepsilon_\infty = 6.56\varepsilon_0$, $\omega_T = 798$ cm^{-1}, $\omega_L = 966.4$ cm^{-1} and $m^* = 0.3\ m_0$ for 4H-SiC and $\varepsilon_\infty = 6.52\ \varepsilon_0$, $\omega_T = 797$ cm^{-1}, $\omega_L = 969.4$ cm^{-1} and $m^* = 0.35\ m_0$ for 6H-SiC [3], and chose ω_p, Γ, and γ as adjustable parameters. Dashed lines shown in Fig. 1 (a) and (b) were obtained by the least-squares fit based on Eq. 1 and 4 to the experimental data. Although a bump is observed around 900 cm^{-1} shown in Fig. 1 (b), the reason for this is not clear at the present time. Thus, the fit was performed with removing the bump. From the analysis, electron

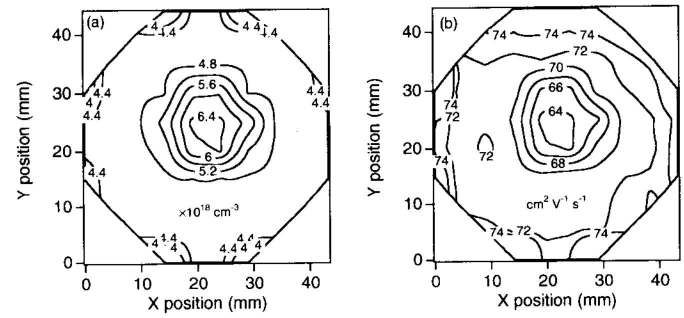

Fig. 3 (a) Electron concentration map and (b) mobility map for an n-type 4H-SiC wafer.

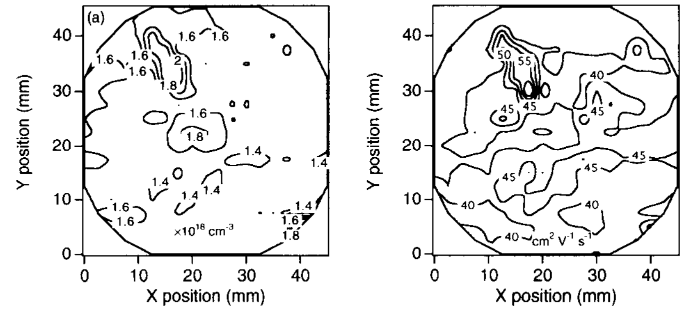

Fig. 4 (a) Electron concentration map and (b) mobility map for an n-type 6H-SiC wafer.

concentrations and mobilities were estimated to be $N = 9.7\times10^{17}$ cm^{-3} and $\mu = 73$ cm^{2}V^{-1}s^{-1} for the reflectance spectrum shown in Fig. 1 (a), and $N = 7.2\times10^{19}$ cm^{-3} and $\mu = 11$ cm^{2}V^{-1}s^{-1} for that shown in Fig. 1 (b). Figure 2 shows the electron concentration profile and the photograph of the inhomogeneously doped 6H-SiC wafer. The photograph was taken with a transmitted light, where dark areas correspond to heavily doped regions. The FTIR measurements were carried out at various points along the white line in the photograph. Compared with the photograph, the carrier concentration profile is found to well coincide with the spatial distribution of light and shade in the SiC wafer.

Figures 3 (a) and (b) show the electron concentration and mobility maps, respectively, for the commercially available n-type 4H-SiC wafer. As can be seen from this figure, the electron concentration is higher within an about 10-mm radius and increases with approaching the center of the wafer. On the other hand, the electron concentration is found to be almost constant outside the radius. Considering that the mobility decreases with increasing carrier concentration, the spatial distribution of the electron mobility shows a similar tendency in the spatial distribution. The relation between the electron concentration and mobility will be discussed elsewhere.

The electron concentration and mobility maps for the commercially available n-type 6H-SiC wafer are shown in Fig. 4 (a) and (b), respectively. Compared with the 4H-SiC wafer, the electron concentration in this 6H-SiC wafer was found to be more uniform. Although the electron concentration shows the maximum in the vicinity of the center of the wafer, another maximum also is located ~10 mm away from the center. Interestingly, the electron mobility is highest in this high electron concentration region although the reason is not clarified.

Conclusions

We have used, for the first time, micro FTIR to investigate the spatial distribution of the carrier concentration and mobility in SiC wafers. The carrier concentration profile obtained from the reflectance spectra corresponds well with the spatial distribution of color in the intentionally inhomogeneous N-doped 6H-SiC wafer. For commercially available 4H-SiC and 6H-SiC wafers, carrier concentrations are found to increase with approaching the center of the wafers. These results demonstrate that micro FTIR is a nondestructive and noncontact technique to spatially characterize the carrier concentration and mobility in SiC wafers.

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