Thickness determination of 4H-SiC Epitaxial Films by Infrared Reflectance

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Abstract The refractive index of n-type 4H-SiC as a function of the wave number is calculated. The results show that the epi-films with doping ranges lower than 10^{18} cm^{-3} are the necessary condition of appearing interference fringes in the infrared reflectance spectra of SiC homoepitaxial films. A modified method is proposed based on the refractive index model varying with frequency which is more accurate and stable than the original method in a wide spectra range.

Key words 4H-SiC, Infrared reflectance, Refractive index

I. INTRODUCTION

SiC is an attractive semiconductor for high frequency, high temperature, and high power electronic devices. Progress in the growth of high quality SiC epi-films requires accurate and rapid method to determine the thickness of the samples. Infrared reflectance provides a simple, nondestructive characterization technique. The conventional technique [1] of calculation thickness by interference fringes in the infrared reflectance spectra has been widely applied for Si and GaAs homoepitaxial films. But the technique is based on the assumption that the refractive index is constant in the range of interference fringes chosen. In fact the index of refraction is variable with frequency, by which the accuracy and the stability of the measurement results is influenced, especially for the thinner epi-films. In this paper, a modified method is proposed in which the refractive index as a frequency dependent function is considered. Estimation of thickness for the 4H-SiC epi-film is more accurate and stable by the modified method.

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II. REFRACTIVE INDEX FUNCTION OF 4H-SIC

The refractive index (n) of SiC in the infrared region is derived from the relative dielectric constants (ε) as a function of the frequency (ω) using the following equation [2].

$$n=\sqrt{\operatorname{Re}\left(\varepsilon(\omega)\right)} \tag{1}$$

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

ε_{∞} is the high-frequency relative dielectric constant, ω_T and ω_L are transverse and longitudinal optical phonon frequencies of the crystal, respectively, Γ is the damping parameter for the crystal vibrations. The third term in Eq.2 is related to the plasma oscillation of free carriers, where the plasma frequency ω_P is given as [3]

$$\omega_P=\sqrt{\frac{Nq^2}{m^*\varepsilon_0\varepsilon_{\infty}}}, \tag{3}$$

where N, m^*, q and ε_0 are the free-carrier concentration, effective mass, electron charge and vacuum dielectric constant respectively. γ is the damping parameter for the free electrons as follows[3]:

$$\gamma=\frac{q}{m^*\mu(N)} \quad . \tag{4}$$

The free-carrier mobility μ is a function of the

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free-carrier concentration which is given by Caughey-Thomas mobility model [4].

$$\mu = \mu_{\min} + \frac{\mu_{\max} - \mu_{\min}}{1 + (N / C_r)^{\alpha}} \quad (5)$$

We express all frequencies in wave numbers (cm^{-1}), i.e., ω (in cm^{-1}) = ω (in rad/s)/$2\pi c$. These parameters used for these models are given in Table I.

Table I

Parameters for n-type 4H-SiC

Parameter	Unite	4H-SiC	Reference
ε_∞	1	6.56	[3]
ω_L	cm^{-1}	970.1	[2]
ω_T	cm^{-1}	793.9	[2]
Γ	cm^{-1}	5.501	[2]
m^*	Kg	$0.4m_0$	[3]
Caughey-Thomas mobility model			
$\mu_{\max}$	$cm^2.V^{-1}.s^{-1}$	950	[4]
$\mu_{\min}$	$cm^2.V^{-1}.s^{-1}$	40	[4]
C_r	cm^{-3}	2×10^{17}	[4]
α	1	0.76	[4]

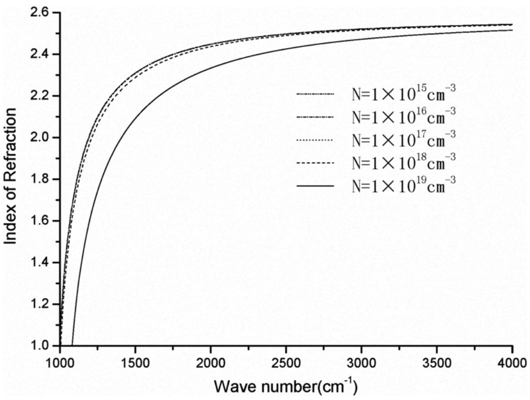

Fig.1.Calculated refractive index as functions of wave numbers for various free-carrier concentrations

Figure 1 shows the refractive index of the wave number dependent function of n-type 4H-SiC for several different orders of magnitude of free carrier concentration. Notice that the refractive index function does not vary appreciably for free-carrier concentrations between 10^{15} cm^{-3} to 10^{18} cm^{-3}. However, the 10^{19} cm^{-3} ranges show quite significant differences from the lower concentration ranges. Since most commercially available SiC substrates are doped in 10^{19} cm^{-3} range, the epi-film with doping content lower than 10^{18} cm^{-3} and the substrate are basically different optical materials, which is necessary condition of appearing interference fringes in SiC homoepitaxial films. Also, notice that the refractive index of the epi-films is greater than that of the substrate and air, so the half-wave loss has occurred.

III.CALCULATION OF EPI-FILMS THICKNESS

Reflectance spectra of n-type 4H-SiC epi-film ($1\times10^{15}cm^{-3}$) grown on a 4H-SiC substrate ($5\times10^{18}cm^{-3}$) is shown in Figure 2. The spectrum between 1900 cm^{-1} to 2700 cm^{-1} is used to calculate the thickness, in which interference fringes is more distinct.

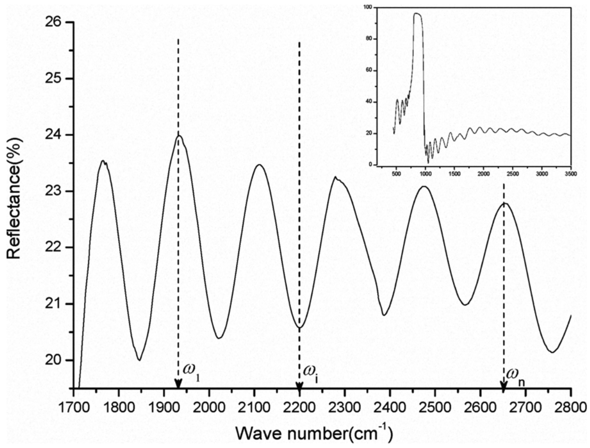

Fig.2. Reflectance spectra of 4H-SiC epi-film ($1\times10^{15}cm^{-3}$) grown on a 4H-SiC substrate ($5\times10^{18}cm^{-3}$).

The conventional technique is used with Eq.6 to calculated thickness. ω_1 and ω_i are wave numbers of extreme point (including wave peak and trough), i is their fringe order difference, and incident angle $\phi = 16^\circ$. The refractive index is a fixed value $\sqrt{\varepsilon_\infty}$.

$$d_i = \frac{i}{2(\omega_i - \omega_1)\sqrt{n^2 - \sin^2\phi}} \quad (6)$$

However the refractive index is not a constant in the spectrum range chosen which is shown in Fig.1. The problem induced by a constant refractive index is more obvious with increase of the difference between ω_1 and ω_i . On the contrary if their fringe order difference is less than 2, the error of extreme wave number induced by noise is more serious. So it is a modification that $n_i(\omega_i)$ is substituted for a constant n in optical path difference expression. In addition, the fringe order m_i corresponding with ω_i is converted to integer for wave peak or half-integer for wave trough (m_i') which is substituted into Eq.8 for decreasing the error of extreme wave number.

$$m_i = \frac{i\omega_i\sqrt{n_i^2-\sin^2\phi}}{\omega_i\sqrt{n_i^2-\sin^2\phi}-\omega_1\sqrt{n_1^2-\sin^2\phi}}+\frac{1}{2} \tag{7}$$

$$d_i = \frac{\left(m_i'-\frac{1}{2}\right)}{2\omega_i\sqrt{n_i^2-\sin^2\phi}} \tag{8}$$

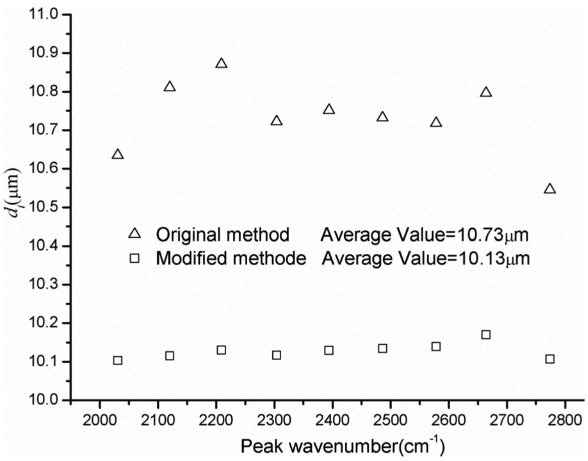

Fig.3. Calculated thickness by original and modified method for various ω_i

Calculated results for various ω_i by original and modified method are shown in Fig.3. The thickness value of 10.13μm by the modified method is in agreement with 10μm of SEM measurement made after cleavage of sample. Also the results of the modified method are quite stable in a wide spectra range. This point is more important for thinner sample because interference fringe would broaden with decrease of the thickness.

IV. CONCLUSION

The conventional technique of calculated epi-film thickness using the infrared reflectance spectra is limited by the assumption of a constant refractive index. The refractive index of n-type 4H-SiC as a function of the wave number for several different orders of magnitude of free carrier concentration is calculated. The results show that the refractive index in the 10^{19} cm^{-3} ranges is obviously less than that of the lower concentration ranges. So it is the necessary condition of appearing interference fringes in the infrared reflectance spectra of SiC homoepitaxial films that free carrier concentration of the epi-films is lower than 10^{18} cm^{-3} ranges. A modified method is proposed based on the refractive index model varying with frequency instead of an absolute constant. It is shown that the new method is more accurate by comparison of results calculated using the modified and the original method. Also its results are quite stable in a wide spectra range, which is more important for thinner sample.

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REFERENCES

[1] The infrared interference measurement technique of the thickness of homoepitaxials, SJ2758-87.

[2] M. F. MACMILLAN, A. HENRY, and E. JANZÉN, “Thickness Determination of Low Doped SiC Epi-Films on Highly Doped SiC Substrates” Journal of Electronic Materials, Vol. 27, pp.300, 1998

[3] Shingo Oishi,Yasuto Hijikata and Hiroyuki Yaguchi, “Simultaneous determination of carrier concentration, mobility, and thickness of SiC homoepilayers by infrared reflectance spectroscopy” Japanese Journal of Applied Physics, Vol. 45, pp. L1226-L1229, 2006.

[4] A. Pe′rez-Toma′s, P. Godignon, N. Mestres b, J. Milla′n “A field-effect electron mobility model for SiC MOSFETs including high density of traps at the interface” Microelectronic Engineering Vol.83, pp. 440–445, 2006