Infrared Physics & Technology 72 (2015) 95–100

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Notes on the plasma resonance peak employed to determine doping in SiC

J.A.A. Engelbrecht [a,*], I.J. van Rooyen [b], A. Henry [c], E. Janzén [c], B. Sephton [a]

[a] Physics Department, Nelson Mandela Metropolitan University, PO Box 77000, Port Elizabeth 6031, South Africa
[b] Fuel Performance and Design Department, Idaho National Laboratory, PO Box 1625, Idaho Falls, ID 83415-6188, USA
[c] Department of Physics, Chemistry and Biology, Linköping University, SE-581 83 Linköping, Sweden

HIGHLIGHTS

- The article provides a review of past research and information about the plasma resonance in silicon carbide.
- Attention was given to all parameters involved for the three most common polytypes of SiC.
- The second plasma resonance was investigated.
- An explanation for not observing the 2nd plasma minimum in 3C-SiC is provided.

ARTICLE INFO

Article history:
Received 13 March 2015
Available online 23 July 2015

Keywords:
Infrared reflectance
SiC
Plasma resonance
Doping concentration

ABSTRACT

The doping level of a semiconductor material can be determined using the plasma resonance frequency to obtain the carrier concentration associated with doping. This paper provides an overview of the procedure for the three most common polytypes of SiC. Results for 3C-SiC are presented and discussed. In phosphorus doped samples analysed, it is submitted that the 2nd plasma resonance cannot be detected due to high values of the free carrier damping constant γ.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The use of the plasma resonance frequency ω_p to establish the carrier concentration, and hence doping level, in semiconductors is well established and has been applied to a range of semiconducting materials [1–9]. The plasma resonance frequency is obtained from infrared reflectance spectroscopy, and the procedure is very simple and non-destructive, enabling crystal growers a quick method of obtaining an indication of the level of doping they are achieving. The method has also been applied in the case of bulk and epilayers of SiC [10–19], as well as irradiated samples [20], with varying degrees of success.

This paper aims to provide a brief overview of the use of the plasma resonance frequency to determine the carrier concentration in SiC, and includes the three most common polytypes, viz. 3C-SiC, 4H-SiC and 6H-SiC.

2. Theory

The plasma resonance frequency ω_p is related to the carrier density N by the following relation [1,3]:

$$\omega_p^2 = \frac{4\pi N e^2}{m^* \varepsilon_\infty} \tag{1}$$

where ω_p is the bulk plasma resonance frequency in cm^{-1}, N the free carrier density, e the electron charge, m^* the effective mass and ε_∞ the high frequency dielectric constant.

The carrier density N can be obtained by determining the plasma resonance minimum ω_{min} where the reflectivity tends to zero on the ω_L side of the reststrahlen peak, and substituting the value into Eq. (1). However, when considering the complex dielectric function [2]

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

and setting this equation equal to 1 (ignoring plasma damping, i.e. $\gamma = 0$), the reflectivity will have two possible minimum values,

* Corresponding author. Tel.: +27 41 504 2186; fax: +27 41 504 2573.
E-mail address: Japie.Engelbrecht@nmmu.ac.za (J.A.A. Engelbrecht).

http://dx.doi.org/10.1016/j.infrared.2015.07.007
1350-4495/© 2015 Elsevier B.V. All rights reserved.

Table 1
Reported values for dielectric constant ε_∞.

Polytype	Reference															
	[6]	[10]	[12]	[13]	[14]	[17]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]	[35]
3C	6.7	6.7					6.7		6.52	6.7						6.52
4H				6.56	6.56								6.56	6.56	6.78	6.52
$4H_\perp$						6.56						7				
$4H_{\parallel}$						6.78						7.14				
6H			6.52					6.7			6.52			6.52		6.52
$6H_\perp$									6.52			7.01				
$6H_{\parallel}$									6.70			7.16				

Table 2
Reported values for effective mass m^*.

Polytype	Effective mass (m_0)	Electrons												Holes			
		References												Reference			
		[6]	[12]	[13]	[14]	[17]	[33]	[23]	[24]	[34]	[35]	[36]	[37]	m^*_{eff} [a]	[27]	[28]	m^*_{eff} [a]
3C		0.31															
	$m_{M\Gamma}$											0.42			~1.15	1.11	
	m_{MK}											0.23		0.31[c]			
	$m_\perp$							0.23	0.24		0.25			0.31[b]			
	$m_{\parallel}$							0.68	0.73		0.68						
4H				0.42	0.42		0.30			0.48							
	$m_{M\Gamma}$							0.57	0.61			0.59		0.42[c]			
	m_{MK}							0.28	0.29			0.29					
	$m_\perp$					0.42					0.42		0.30	0.37[b]	0.61	0.59	0.75[b]
	$m_{\parallel}$					0.29					0.29		0.48		1.62	1.60	
6H			0.35				0.35										
	$m_{M\Gamma}$							0.75	0.81			0.76		0.45[c]			
	m_{MK}							0.24	0.25			0.26					
	$m_\perp$										0.42		0.35	0.31[b]	0.60	0.58	0.74[b]
	$m_{\parallel}$										0.20		1.40		1.65	1.59	

[a] Calculated.
[b] Using the applicable formulas of Holm et al. [6].
[c] Using the applicable formulas of Oishi et al. [13].

depending on ω_p (and hence the carrier concentration N). These values are given by [6,21]:

$$\omega_\pm^2 = \frac{\varepsilon_o(1+\omega_p^2/\omega_L^2) - 1 \pm \left\{ \left[\varepsilon_o\left(1+\omega_p^2/\omega_L^2\right) - 1\right]^2 - 4\varepsilon_o(\varepsilon_\infty - 1)\omega_p^2/\omega_L^2 \right\}^{1/2}}{2(\varepsilon_\infty - 1)/\omega_T^2} \tag{3}$$

where $\varepsilon_0 = \varepsilon_\infty (\omega_L/\omega_T)^2$ and ω_+ and ω_- are the maximum and minimum values of the reflection minima, with ω_+ larger than ω_L, and ω_- less than ω_T.

A slightly different formula was proposed by Sunkari et al. [22],

$$\omega_{LPP}^\pm = \left\{ \frac{1}{2}\left[\omega_L^2 + \omega_p^2 \pm \sqrt{\left(\omega_L^2 + \omega_p^2\right)^2 - 4\omega_p^2\omega_T^2}\right]\right\}^{1/2} \tag{4}$$

However also required are the values of the high frequency dielectric constant, ε_∞ and the effective mass m^*. The latter is dependent upon the density of states in the materials, which for SiC is quite complex [23,24]. Both ε_∞ and m^* also depend on the particular polytype of SiC, the polarization of the incident radiation, and, in the case of m^*, the free carrier type (electron or hole). This complex nature makes it difficult to decide which particular value to use in simulations of the variation of the plasma resonance frequency with carrier concentration.

Assuming the constant-energy surfaces in the Brillouin zone of SiC to be ellipsoidal, the surfaces can be described by effective masses in the longitudinal optical (m^*_L) and transverse optical (m^*_T) branches. Formulas to determine the "average effective mass" have been suggested by Holm et al. [6] and Oishi et al. [13]. Previously published values for ε_∞ and m^*, together with calculated values of the average effective masses, are presented in Tables 1 and 2, while Table 3 contains the dielectric parameter values used in this study.

Table 3
Dielectric parameters used to calculate plasma minima from Eqs. (3) and (4).

Dielectric parameter	3C [6]	4H [13,14]	6H [12,32]
ε_∞	6.7	6.56	6.52
Γ	8.5	5.8	4.76
ω_L	973	972	969
ω_T	794	799	793
γ	0	0	0
m^*	0.31	0.42	0.35

Finally, the reflectance of a material can be obtained from the complex dielectric function given in Eq. (2) by using the relation [25]:

$$R = \left|\frac{\sqrt{\varepsilon} - 1}{\sqrt{\varepsilon} + 1}\right|^2 \tag{5}$$

3. Experimental procedure

Theoretical values of the plasma resonance ω_p were calculated from Eq. (1) as function of the doping concentration of phosphorous, ranging from 1×10^{12} to $1 \times 10^{20}\ \text{cm}^{-3}$. Likewise, calculations for the reflection minima ω_- and ω_+ as well as the longitudinal-optical phonon–plasmon coupled modes LPP^- and

Download English Version:

https://daneshyari.com/en/article/1784034

Download Persian Version:

https://daneshyari.com/article/1784034

Daneshyari.com