Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp285-286

Temperature Dependence of Local Electronic Properties of N-type GaN Crystals by Micro-Raman Imaging and Dielectric Dispersion at High Temperatures

Motoki Kawase[1] and Jun Suda[1]

[1] Department of Electrical and Electronic Engineering, School of Engineering, Chukyo University.
101-2 Yagoto Honmachi, Showa-ku, Nagoya-shi, 466-8666, Japan
Phone: +81-52-835-8671 E-mail: suda@sist.chukyo-u.ac.jp

Abstract

LOPC mode Raman spectra for 2D-imaging areas (30μm×30μm) in n-type GaN crystals were measured from room temperature to 200°C by micro-Raman spectroscopy. The average values of the center frequency for the LOPC mode in the imaging region changed slightly with increasing temperature. We calculated the electron density and resistivity values of the sample by spectra analysis fitting the imaginary part equation of dielectric dispersion to the observed LOPC mode profiles using adjustable parameters in n-type GaN at high temperatures. The results showed that the electron density values in n-type GaN tend to increase slightly with increasing temperature while resistivity decreases.

1. Introduction

Gallium nitride (GaN) semiconductors, which are ideal for blue light-emitting diodes (LEDs) [1] and are one of the most promising wide-gap semiconductors, are power-electronics materials [2] for high voltage and high temperature applications. For power metal-oxide-semiconductor field-effect transistors (MOSFETs) using GaN, a vertical inverter element for high power with low loss and high-speed switching characteristics is being developed [3]. Since wide-gap semiconductors operate at high temperatures (about 200°C) in power MOSFETs in electric vehicles (EVs), there would be thermal stress due to the difference in the coefficient of thermal expansion between the electrode contact and the surface of the GaN crystal. Thermal stress will lead to reduced reliabilities such as threshold fluctuations, mechanical delamination, and cracks in power device chips [4]. Therefore, to further the development of power devices, it is necessary to obtain information on the electronic properties of these crystals at high temperatures as well as on thermal stress changes. We recently measured the temperature dependence of Raman spectra for the E_2 mode of GaN crystals with electrodes in the high-temperature region [5]. The thermal stress distribution near electrodes was compared with finite element method (FEM) analysis results [6,7]. In the present study, longitudinal optical phonon-plasmon coupled (LOPC)-mode Raman spectra of n-type GaN crystals were measured, and the electron density and resistivity values for GaN in the high-temperature region (from room temperature to 200°C) were calculated.

2. Experimental Procedure

A confocal micro-Raman NRS-4100 spectrometer with a 2400 l/mm grating was used to measure the Raman spectra of GaN samples at high temperatures up to 200°C. The spectral resolution of our Raman spectrometer was up to 0.4 cm^{-1}, and the wavenumber accuracy was within ±0.1cm^{-1}. An n-type GaN sample (10mm×10.5mm×0.35mm (c axis)) by NTK Co. Ltd. was used. For the 2D-Raman imaging measurement for the imaging area (30μm×30μm), an incident laser (λ=532 nm; P=17.4 mW) was emitted to the GaN surface along the c-axis. Three peaks, at 146cm^{-1}(E_2^L), 565cm^{-1}(E_2^H), and 780cm^{-1} (LOPC, (A_1(LO))), were observed at room temperature (Fig. 1(a)). The intensity of the polarized LOPC-mode Raman spectra changed with the polarized angle of a 180° period (Fig. 1(b)). The average values of the center frequency for the LOPC mode in the imaging region changed slightly with increasing temperature (Fig.2).

3. Calculation Method for Local Electronic Properties by Dielectric Dispersion at High Temperatures

According to Harima *et al.* [8], using the imaginary part equation of dielectric dispersion, the Raman light intensity $I(\omega)$ for LOPC mode at room temperature can be written as

$$I(\omega) = SA(\omega) \cdot \mathrm{Im}[-1/\varepsilon(\omega)], \quad (1)$$

where $\boldsymbol{\omega}$ is the Raman frequency shift, S is a proportional constant, $\boldsymbol{\varepsilon}(\omega)$ is a dielectric function, and $A(\omega)$ is a function that includes the plasma frequency ω_p, the plasmon damping constant γ, the LO- and LO phonon frequencies ω_{LO} and ω_{TO}, and the phonon damping constant Γ. In the present study, using the values of center frequency ω_{LO} and ω_{TO} in Raman measurement, we have developed Eq. (1) for the temperature dependence of dielectric dispersion at high temperatures. We have fitted Eq. (1) to the observed LOPC mode profiles using ω_p, γ, and Γ as adjustable parameters. Figure 3 shows a calculated spectrum for LOPC mode at room temperature. The electron density n, electric mobility μ and resistivity ρ can be written as

$$n = \varepsilon_\infty m^* {\omega_p}^2 / 4\pi e^2, \quad (2)$$

$$\mu = e/m^*\gamma, \quad (3)$$

and

$$\rho = 1/e\mu n. \quad (4)$$

Here, ω_p is the plasma frequency, m^* is the electron effective mass, and ε_∞ is the optical dielectric permittivity. Thus, the electron density and resistivity can be calculated using Eqs.

(1)-(4). The electron density value of the n-type GaN crystal was obtained as 9.7×10^{16}cm^{-3} at room temperature and 1.3×10^{17}cm^{-3} at 200°C. The calculated results demonstrate that the electron density values tend to increase slightly with increasing temperature while resistivity decreases with increasing temperature with $\mu \cong 780\text{cm}^2/\text{Vs}$. (Figs. 4 and 5).

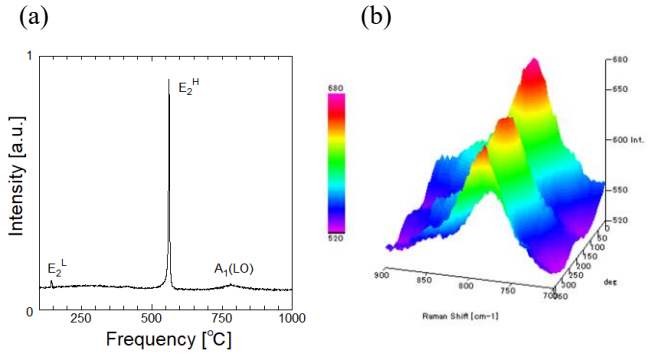

Fig. 1 (a) Raman spectra observed at room temperature and (b) polarized LOPC mode Raman spectra with polarized angles from 0˚ to 360˚.

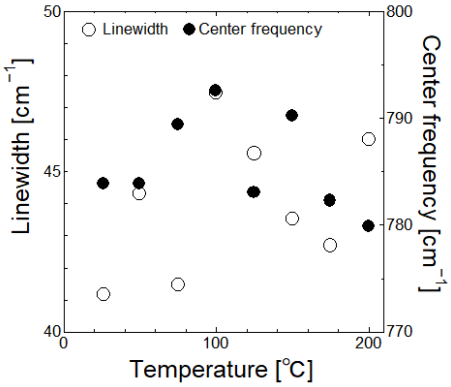

Fig. 2 Temperature dependence of center frequency and linewidth for the LOPC mode of n-type GaN crystals.

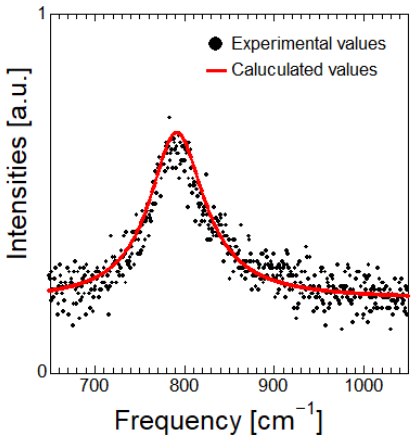

Fig. 3 Comparison of the calculated spectrum for the LOPC mode and experimental spectra at room temperature.

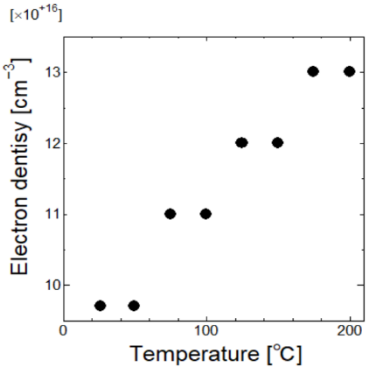

Fig. 4 Temperature dependence of electron density in GaN.

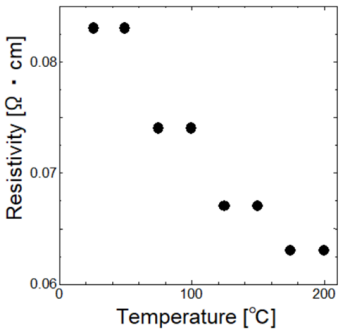

Fig. 5 Temperature dependence of resistivity in GaN.

4. Conclusions

The center frequency values for the LOPC mode in the imaging region change slightly with increasing temperature from room temperature to 200°C. We calculated the electron density and resistivity values of the sample by spectra analysis fitting the imaginary part equation of dielectric dispersion to the observed LOPC mode profiles using adjustable parameters in n-type GaN at high temperatures. The electron density of n-type GaN crystals showed a tendency to increase slightly with increasing temperature. We believe that this occurs because of slight electron transfer from the valence band to the conduction band in the saturation region with increasing temperature from room temperature up to 200°C.

Acknowledgements

This work was supported in part by a Grant-in-Aid for Scientific Research (C) from the Ministry of Education, Science and Culture of Japan (Grant No. 19K05296).

References

[1] H. Amano *et al.*, Appl. Phys. Lett. **48** (1986) 353.
[2] H. Harima, J. Soc. Mat. Sci., Jpn. **51** (2002) 983.
[3] J. Suda, *NE Selection, NIKKEI ELECTRONICS* (2013) 90.
[4] J. Suda *et al.*, Spectrochim A **193** (2018) 393.
[5] J. Suda *et al.*, *Proceedings of the 80th JSAP Autumn Meeting* (2019) 13-197.
[6] J. Suda, *Conference Papers in Solid-State Lighting (OSA)* (2018) SW2D.2-1.
[7] M. Kawase *et al.*, *Outline of the 75th Annual Meeting of the Physical Society of Japan* (2020).
[8] H. Harima *et al.*, J. Appl. Phys. **78**(3) (1995) 1996.