3E1-2

Proceedings of Symposium on Ultrasonic Electronics, Vol. 37 (2016)

16-18 November, 2016

Monitoring of carrier dynamics in GaN during disappearance of piezoelectricity by resonant ultrasound spectroscopy

共振超音波法による GaN の圧電性消失過程のキャリアダイナミクスのモニタリング

Kanta Adachi[1‡], Hirotsugu Ogi[1], Akira Nagakubo[1], Nobutomo Nakamura[1], Masahiko Hirao[1], Mamoru Imade[2], Masashi Yoshimura[2], and Yusuke Mori[2] ([1]Osaka Univ. Grad. Sch. of Engineering Science; [2] Osaka Univ. Grad. Sch. of Engineering)

足立 寛太 [1‡]，荻 博次 [1]，長久保 白 [1]，中村 暢伴 [1]，平尾 雅彦 [1]，今出 完 [2]，吉村 政志 [2]，森 勇介 [2] ([1] 阪大院 基礎工，[2] 阪大院 工)

1. Introduction

Gallium nitride (GaN) has been recognized as a suitable material for high-frequency and high-power electronic devices such as a high-electron-mobility transistor. The device can operate at high frequencies with high-speed transportation of electrons through the two-dimensional electron gas generated by piezoelectricity of GaN. However, the device performance deteriorates at elevated temperatures because of disappearance of the apparent piezoelectricity of GaN due to the hopping conduction of carriers [1]. It is thus important to clarify the carrier dynamics in GaN. Because the energy barrier of the charge transfer process is small, it would be difficult to use optical spectroscopy methods, which provide excessive energy to the carriers, for studying the phenomenon. In this study, we utilize a low-energy acoustic-resonance spectroscopy method for realizing the direct observation of the hopping conduction.

Free carriers are trapped by deep acceptors in a semi-insulating GaN, where the conduction is principally achieved by site-to-site hopping of trapped carriers with assistance of phonons. The hopping conduction is a thermally activated phenomenon, and the hopping rate becomes higher with increasing temperature. Carrier movement is also accelerated by dynamic polarization change caused by mechanical vibrations via piezoelectricity. Thus, the hopping conduction is significantly enhanced when the hopping rate matches the acoustic vibration frequency, at which internal friction shows a maximum because a part of acoustic energy is spend on the carrier movement, and the resonance frequency decreases due to disappearance of the piezoelectric stiffening [2]. Hence, the resonance-frequency and internal-friction change at high temperatures reflect the carrier dynamics during disappearance of the apparent piezoelectricity due to the hopping conduction.

2. Experiment Procedure

The material we used is a high-resistance wurtzite GaN, where a small of Fe atoms are doped as deep acceptors to achieve the semi-insulating state. A rectangular-parallelepiped specimen was prepared, and its dimensions along the three principal axes are about 3.5 mm, 3.0 mm, and 0.4 mm. (The *c* axis is parallel to the 0.4-mm side.) The mass density determined by the Archimedes method is 6.080 g/cm^3.

To measure the resonance frequency and internal friction of various vibrational modes at high temperatures, we developed the tripod-type resonant ultrasound spectroscopy (RUS) as shown in Fig. 1. The specimen is set on a tripod, consisting

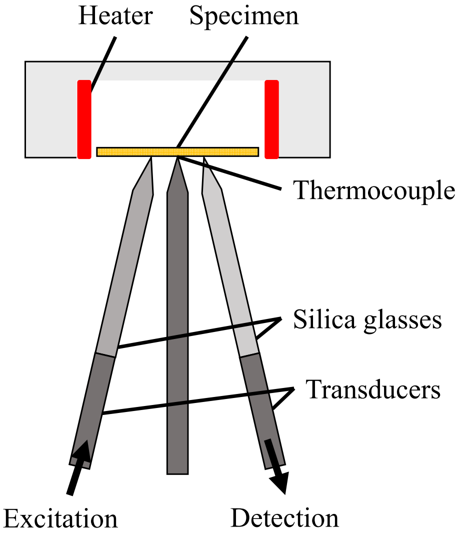

Fig. 1 Schematic of the high-temperature RUS measurement system.

E-mail:ogi@me.es.osaka-u.ac.jp

of two needle-type transducers for excitation and detection of specimen vibrations and one needle-thermocouple support for measuring the specimen temperature. Silica glasses are attached on the transducers to protect them from heat. No external force was applied to the specimen, except for gravity, realizing the measurement of resonance frequencies of ideal free vibrations. The weak acoustic contact situation is essential for the accurate internal-friction measurement because the vibrational energy of the specimen leaks to contacting transducers in conventional contact methods, increasing apparent internal friction [3]. The measurement system can observe an enough small frequency change (~0.01 %) for monitoring the total resonance-frequency decrement (~0.1 %) due to disappearance of the apparent piezoelectricity.

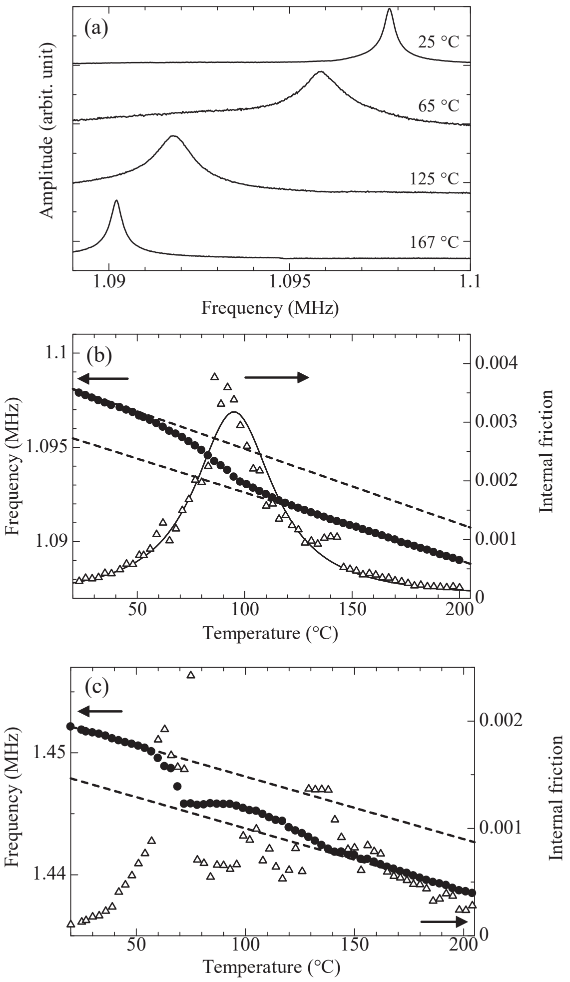

Fig. 2 (a) Examples of resonance spectra at several temperatures, and (b) the resonance frequency and internal friction of the resonant mode versus temperature. (c) An example of temperature dependence of the resonance frequency and internal friction.

3. Result and Discussion

Figure 2 (a) shows an example of change of the resonance spectrum during increasing temperature; the spectrum becomes broader and then sharp again with increasing temperature, indicating a internal-friction peak appears. We succeeded in observing the high-temperature resonance-frequency decrement due to disappearance of piezoelectricity as shown in Fig. 2 (b) and revealed that this phenomenon is caused by hopping conduction, that is, internal friction shows a peak at the matching temperature. Internal frictions of some resonant modes exhibit several peaks; for example, Figure 2 (c) shows two peaks. This indicates that some electron transport behaviors exist in the disappearance process of the apparent piezoelectricity, depending on vibrational modes.

4. Conclusion

We developed the high-temperature RUS measurement system for monitoring carrier dynamics in an insulated semiconductor during disappearance of piezoelectricity due to the hopping conduction. The measurements indicate that it is possible to observe the hopping conduction using the high-temperature RUS method, and carrier behavior in the phenomenon is different in each resonant mode.

References

1. O. Aktas *et al.*, Appl. Phys. Lett. **69**, 3872 (1996).
2. A. R. Hutson *et al.*, Appl. Phys. Lett. **33**, 40 (1962).
3. H. Ogi *et al.*, J. Acoust. Soc. Am. **106**, 660 (1999).