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Novel Evaluation Technique of GaN Surfaces Using Laser-induced Terahertz Emission

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Abstract

We have investigated *c*- and *m*-plane GaN substrates by using laser-induced terahertz (THz) emission measurement. Comparing with photoluminescence measurements, we found that the enhancement of THz emission from GaN surface by YL-related defects, and this phenomenon is explained through the modification of band structures in the surface depletion layer owing to trapped electrons at defect sites. The results suggest the evaluation of the distribution of non-radiative defects, which are undetectable with photoluminescence, and it contributes to the realization normally-off GaN devices.

1. Introduction

Semiconductors are widely used as detectors or emitters of Terahertz (THz) waves. The origin of THz emission from semiconductor surface is explained by following mechanisms: nonlinear optical effect, photo-Dember effect and surge current by the band bending. Except for nonlinear optical effect, the electric field of THz wave is proportional to time derivative photocurrent. Therefore THz emission spectroscopy has attracted much attention as a complementary evaluation tools that can evaluate non-radiative defects, which are undetectable with photoluminescence (PL).

Here, we measured THz emission from GaN surfaces excited by ultraviolet femtosecond laser pulses and found the enhancement of THz emission due to defects in the GaN surface by comparing the PL measurements. The enhancement is explained by modification of the band bending induced by the accumulated negative charges in the surface depletion layer. Accordingly, the present results suggest that terahertz emission is capable of measuring not only the defect density but also the local surface potential.

2. Experimental Methods

We used *c*- and *m*-plane GaN purchased from Sumitomo Electric Industries, Ltd. Figure 1 is a schematic illustration of our measurement system. Third harmonic generation of Ti:sapphire laser was used as an excitation laser for PL and THz emission measurement, and the excitation wavelength was 260 nm. Excitation laser pulses were focused on GaN surface by an objective lens. THz wave emitted from GaN surface was collimated and focused on a detector by a pair of parabolic mirrors. Fundamental wave of Ti:sapphire laser was used as an excitation source of a photoconductive detector and as a trigger signal for optical sampling technique.

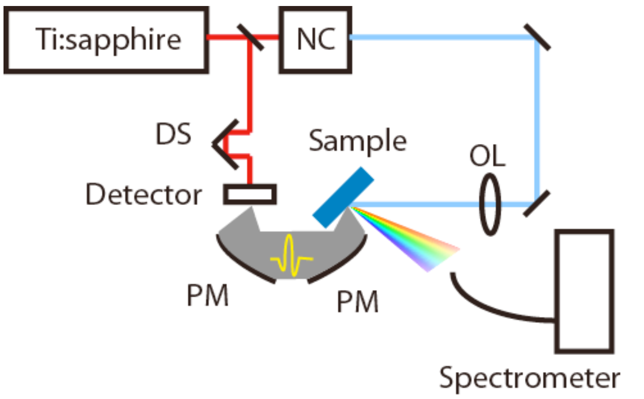

Fig. 1 Schematic illustration of a measurement system. NC, OL, PM and DS represent nonlinear crystal, objective lens, parabolic mirror and delay stage, respectively.

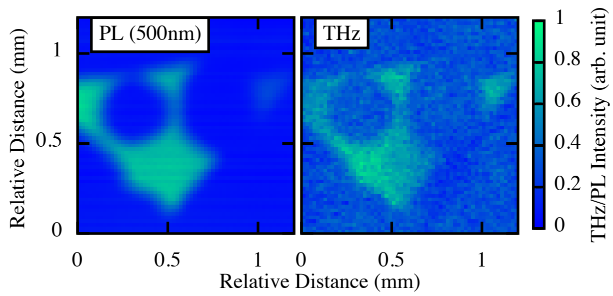

Fig. 2 THz wave peak image and PL images of 500 nm in *c*-plane GaN.

3. Results and Discussion

c-plane GaN

Figure 2 respectively shows the PL image and the THz emission image of the surface of the *c*-plane GaN. As shown in Fig. 2, a noticeable distribution of the THz amplitude can be observed in the terahertz emission image. On the other hand, PL image of 500 nm in Fig. 2, which corresponds to “Yellow luminescence (YL)”, has almost the same contrast as the THz emission image. Several studies have reported that YL is due to carbon-impurities or Ga vacancy defects [1-3] and that they play as deep acceptors. These results show that THz emission obviously is enhanced by YL-related defects.

m-plane GaN

We have also investigated the *m*-plane GaN surface. Figure 3 show the PL image and THz emission image, respectively. The PL and THz emission images have almost same contrast as well as *c*-plane GaN, which means that THz intensity is enhanced by YL-related defects. The high intensity areas of the PL image and the THz emission image form the straight lines normal to *c*-axis as shown in Fig. 3. This line including high density of defects is considered to be boundary of GaN crystals that was grown in the *c*-direction. Note that *m*-plane GaN substrate used in this measurement is fabricated by slicing GaN crystal that grown in the c-direction.

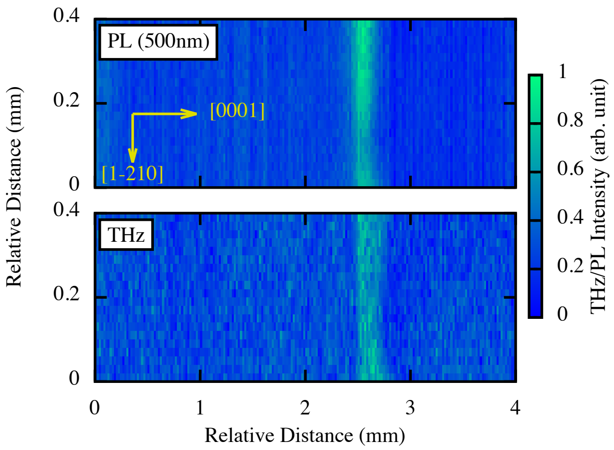

Fig. 3 THz wave peak image and PL images of 500nm in *m*-plane GaN.

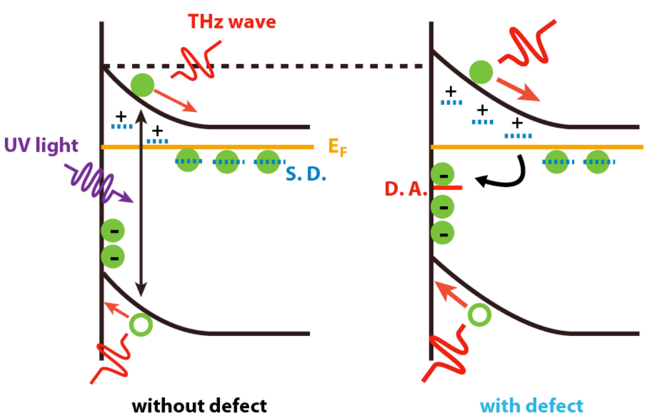

Fig. 4 Schematic illustration of potentials near the surface with and without YL-related defects. S. D., D. A. and EF represent shallow donor level, deep acceptor level and Fermi level, respectively. Solid and empty circles are electron and hole, respectively.

Discussion

We confirmed that THz signals rapidly decreased under excitation with wavelengths above 360 nm, which indicated that THz radiation was triggered by photoexcited carriers that were excited from the valence band to the conduction band.

Figure 4 shows a schematic illustration of potentials near the surface of GaN with and without YL-related defects. Van de Walle *et al*. reported that *c*- and *m*-plane n-type GaN have upward band bending [4]. The mechanism of THz radiation from n-type GaN is primarily considered to be the current surge effect [5]. The YL-related defects plays as a deep acceptor approximately 2.2eV below the minimum the conduction band [6].

Therefore, the defect levels in n-type GaN are almost fully occupied by electrons in the equilibrium state. Consequently, the net negative charge density is increased by the YL-defects, and the surface potential is increased by negative space charges trapped at YL-related defects, as shown in Fig. 4. Since photocarriers are accelerated at the surface electric field, the amplitude of THz emission is enhanced by YL-related defects. As explained above, we confidently conclude that LTEM is able to evaluate the relative surface potential.

4. Conclusions

We have measured the THz emission from *c*-plane and *m*-plane GaN excited by femtosecond pulsed laser and performed two-dimensional (2D) mappings with the intensity of the THz emission. Comparing the LTEM image with PL image, the THz emission was clearly enhanced by YL-related defects in the GaN surface. The result suggests that the enhancement of THz emission can be explained by the change of surface potential induced by deep acceptors consisting of YL-related defects. Our results demonstrate that LTEM can evaluate not only the relative density of the defect as well as PL but also the “local” surface potential of wide-gap semiconductors.

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