Terahertz radiation from InN by femtosecond optical pulses of different wavelengths

Haiyan Wang (王海艳)[1], Guozhong Zhao (赵国忠)[1*], and Xinqiang Wang (王新强)[2]

[1] *Key Laboratory of THz Spectroscopy and Imaging, Department of Physics,*
Capital Normal University, Beijing 100048, China
[2] *State Key Laboratory of Artificial Microstructure and Mesoscopic Physics,*
School of Physics, Peking University, Beijing 100871, China
[*] *Corresponding author: guozhong-zhao@mail.cnu.edu.cn*

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The characteristics of terahertz radiation from an n-type InN excited by femtosecond laser pulses tunable from 750 to 840 nm are experimentally studied. Terahertz emission from InN is closely bound up with the Dember effect. Terahertz emission can be interpreted as being emitted from accelerated photo-carriers excited by a femtosecond pulse in Dember field. Terahertz radiation from InN shows a strong dependence on excitation wavelength. Results show that under laser pulse excitation with a different center wavelength, the terahertz radiation shows different characteristics, such as radiation intensity, radiation efficiency, and spectrum width. This work will be propitious to the development of terahertz time-domain spectrum technology and the optimization of experiment system, as well as being a reference for conducting research on terahertz emission with higher radiation intensity and efficiency.

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The terahertz (THz) region of the electromagnetic spectrum (0.1–10 THz) has potential applications in many fields of science and technology, including THz imaging, THz time-domain spectroscopy (THz-TDS), THz nondestructive materials identification, and so on[1−4]. In 1990, Zhang *et al.* found that ultra-short THz pulses can be generated by illuminating semiconductor surfaces with femtosecond laser pulses[5]. Due to its lowest effective mass and highest mobility, peak and saturation velocities among III nitrides[6], InN is considered as an exciting source of THz radiation. The emission of THz radiation pulses from InN thin films was first observed by Ascázubi *et al.*[7] Afterward, several groups reported THz emission from InN films with different growth orientations[8−10]. Others have also reported that Mg-doped InN samples can enhance THz radiation intensity greatly[11−12]. Recently, Ahn *et al.* reported that THz emission from InN nanorods can be three times stronger than THz emission from InN thin films[13]. Chern *et al.* reported the excitation wavelength dependence of THz emission from InN and InAs in 2006[14]. In the letter, they used an ultrafast laser pulse at wavelengths tuned between 800 and 1 500 nm. The THz amplitude, normalized to pump and probe power, from both narrow band-gap semiconductors remains relatively constant over the excitation wavelength range.

In this letter, we present THz emission from n-InN excited with ultra-fast laser pulses at wavelengths from 750 to 840 nm under the same pump and probe power. The THz radiation generated from InN exhibits great dependence on the excitation wavelength. Its amplitude, radiation efficiency, and spectral width are greatly different.

Our measurements are performed using a Ti:sapphire laser which operates at a center wavelength of 800 nm. The laser has a pulse duration of 100 fs and a repetition rate of 82 MHz. The average output power is about 930 mW. The laser is then split into two beams. The stronger beam being is used as the pump beam being focused on the sample surface with a diameter of 2 mm and an incident angle of 45° from normal. The pump power is ∼250 mW while the probe power is ∼25 mW for all excitation wavelengths. The THz signal is detected by free-space electro-optic sampling in a 2-mm thickness of ZnTe crystal.

To characterize THz emission properties of InN films, a simple THz emission setup is built up in our lab[12]. The n-InN sample used for measurements is a 2.3–2.4-μm-thick InN film grown by molecular beam epitaxy (MBE). Details of the growth technique are described in Ref. [14]. The Hall mobility is 800 cm^2/VS and the carrier concentration is 1.94×10^{18} cm^{-3}.

At lower carrier densities, the optical rectification contribution is no longer the main THz generation mechanism in InN. Due to the difference of the electron

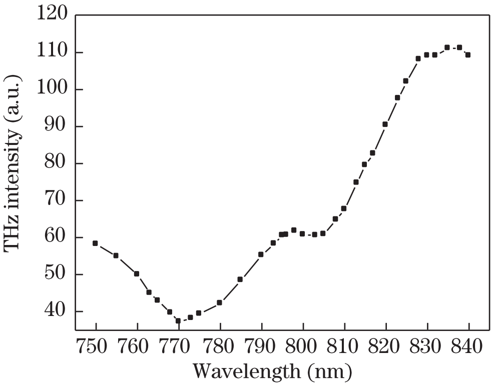

Fig. 1. THz emission intensity from InN with different excitation wavelengths.

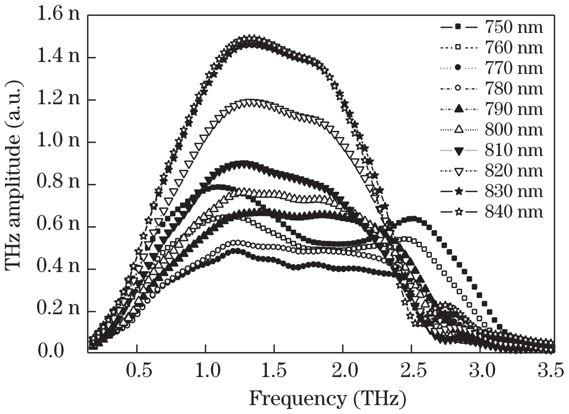

Fig. 2. Frequency-domain spectra of THz radiation from InN film.

and hole diffusion coefficients, called the photo-Dember effect, the carrier motion in the photo-Dember field becomes the main domain for THz radiation. Under laser pulse excitation with a different center wavelength, the terahertz radiation exhibits different characteristics.

Figure 1 shows the THz intensity emitted from InN surface under different excitation wavelengths of the laser pulse. With increasing wavelength, THz radiation intensity from InN shows an obvious change. THz intensity decreases with increasing wavelength in the short wavelength regime (750–770 nm). In the middle wavelength regime (770–795 nm) and the long wavelength regime (805–840 nm), THz emission intensity increases with increasing wavelength. There is a minimum emission at the wavelength around 770 nm. Results illustrate that there is less absorption to femtosecond excitation by InN near the wavelength of 770 nm. In addition, THz emission intensity is basically kept constant in the wavelength range of 795–805 nm. A similar phenomenon appears at the wavelength near 830 nm. These results reflect the band structure of InN and its carrier transition properties, which may be related to the steady state distribution of carriers in the InN film.

By fast Fourier transformation (FFT) of THz time-domain spectroscopy, the frequency-domain spectra of THz radiation from InN are obtained. As is shown in Fig. 2, there is a clear double peak structure under short wavelength (750–765 nm) excitation. Moreover, in the long wavelength regime (815–840 nm) excitation, two peaks appear in the frequency-domain spectrum. However, the emission peak becomes smaller at a longer wavelength. This confirms that the carrier distribution in the InN film undergoes a large change with different excitation wavelengths.

In this letter, we take the full-width of half-maximum (FWHM) as an estimate for the THz spectral width. Figure 3 shows the FWHM dependence on wavelength. Spectral width decreases approximately linearly as wavelength increases. The linear fitting relation can be taken as the following equation: $\mathrm{FWHM(THz)} = -8.454 \times 10^{-3}\lambda(\mathrm{nm}) + 8.626$.

In conclusion, THz radiation from InN film shows a strong dependence on excitation wavelength. THz intensity emitted from InN surface under different excitation wavelengths of the laser pulse reflects the band structure of InN and its carrier transition properties. The frequency-domain spectra of THz radiation from InN confirm that the carrier distribution in InN film undergoes a large change with different excitation wavelengths. The spectral width of THz radiation from InN decreases nea linearly with increasing center wavelength of the femtosecond pulse. This work is significant for investigating THz emission from InN films.

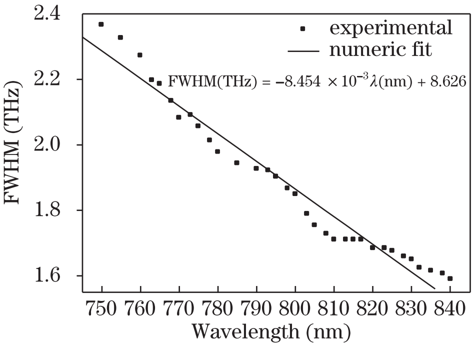

Fig. 3. FWHM of THz emission from InN film with different excitation wavelengths.

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