Ultrafast Electron Dynamics in GaAs and InP Studied by THz Emission

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Abstract. Ultrafast dynamics of electrons in GaAs and InP was studied by measuring the THz waveforms emitted by the biased antennas. Subpicosecond intraband relaxation of electrons photogenerated with excess energy and picosecond thermal excitation of electrons generated in the tail states below the band gap were observed.

1. Introduction

Generation of electromagnetic radiation in the terahertz (THz) frequency region by ultrashort optical pulse excitation of biased photoconductive antennas has attracted attention since it supplies a new class of radiation sources that are useful in spectroscopy and many other applications. The generated THz pulses themselves, however, carries rich information on the electron dynamics in the antenna material. In this report, we describe our recent results on the study of the electron dynamics in GaAs and InP revealed by the measurements of the THz waveforms as the pumping photon energy and the bias electric field are changed.

2. Experimental Setup

A schematic of the experimental setup is shown in Fig. 1. In the experiments, tunable 150-fs pulses, which were spatially expanded, obtained from an optical parametric amplifier (OPA) were used to pump a semi-insulating GaAs or InP wafer. The pump photon energy was tuned across the band gap energy of each material. Pulsed electric field of several kV/cm was applied to the wafer across a 3-cm gap between electrodes. Generated THz radiation was focused by a parabolic mirror, and the electric field waveform at the focus was measured by a standard setup of the electro-optic (EO) sampling method using ZnTe as the EO crystal. A small portion of the output of the regenerative amplifier, which served as the input of the OPA, was used as the probe pulse.

3. Results and Discussion

The obtained pump wavelength dependence of the THz waveforms is shown in Fig. 2. For GaAs, the pump photon energy was tuned from 1.393 eV (890 nm) to 1.550 eV (800 nm) across the band gap energy of 1.428 eV (868 nm). For InP, it was tuned from 1.305 eV (890 nm) to 1.550 eV (800 nm) across the band gap energy of 1.351 eV (918 nm). The spectrum of the pump pulses was narrowed using a 10-nm (FWHM) band-pass filter. The experimental results from GaAs and InP showed similar trends as follows. For pump photon energies that are larger than the band gap energy, the observed THz pulses are shorter and larger for smaller excess energy of the photogenerated electrons. On the other hand, below the band gap, smaller THz signals with a long tail were observed.

By a reasonable approximation, the waveform of the focused THz radiation generated from a large-aperture photoconductive antenna is shown to be proportional to the time derivative of the time dependence of the photo-induced current density in the antenna material [1]. The observed

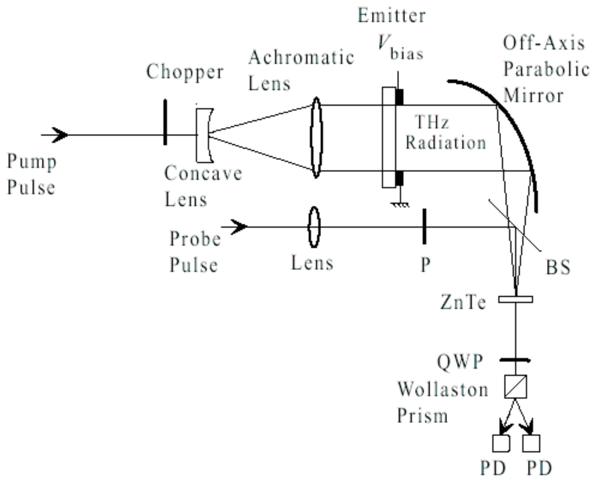

Fig. 1. Schematic of the experimental setup for the measurement of the THz radiation waveforms. P: polarizer, BS: beamsplitter, QWP: quarter-wave plate, and PD: photodiode.

pump photon energy dependence above the band gap is attributed to the ultrafast intraband relaxation of electrons after the photogeneration. Electrons with larger excess energy have smaller mobility due to stronger phonon scattering, which are relaxed to more mobile states at the bottom of the conduction band in the subpicosecond time scale.

Below the band gap energy, fundamentally different dynamics seems to come in. This energy region corresponds to the so-called Urbach tail of the absorption spectrum. Exponential absorption tails (Urbach tail) below the band gap have been observed in a wide variety of materials. The exponential tail has been explained to be caused by randomly fluctuating potential due to electron-phonon interaction and/or crystal disorders. The small density of states, however, of the tail states has prohibited studies of the electron dynamics *after* the transition to these states. The present results of the THz emission measurements show that the electrons photogenerated 35 meV *below* the bottom of the conduction band are thermally excited to the conduction band in a picosecond time scale. The below-gap dynamics shows marked bias field dependence, as shown in Fig. 3 for GaAs. The measurements with InP showed similar results. By increasing the bias field from 1.3 to 9.3 kV/cm, the decay time of the tail for GaAs at 890-nm pump decreases from 1.4 to 0.7 ps, which reflects bias-dependent thermalization dynamics.

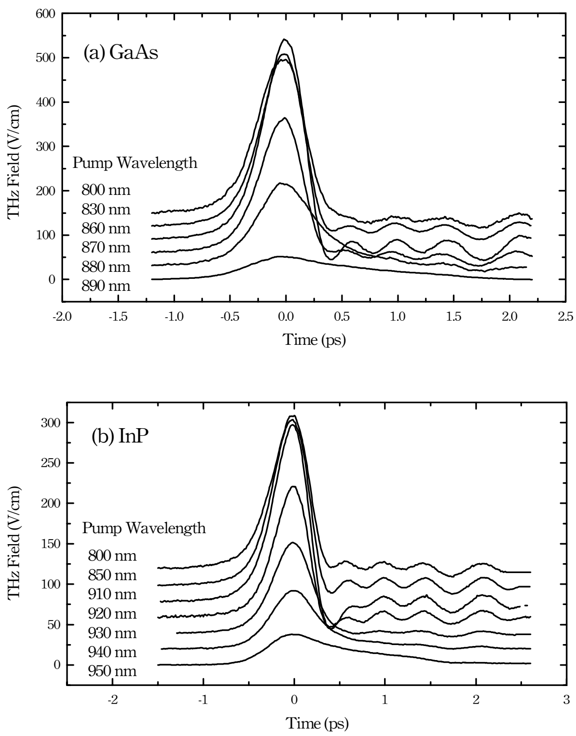

Fig. 2. Pump wavelength dependence of the THz waveforms obtained from (a) GaAs and (b) InP. The bias field applied to the materials was 6.7 kV/cm. The oscillations at positive times are due to absorption by water vapor in the air, and do not reflect electron dynamics.

4. Conclusions

Ultrafast electron dynamics after photogeneration in GaAs and InP was studied by measuring the waveforms of the THz radiation emitted from biased materials. With pump photon energies larger than the band gap energy, subpicosecond intraband relaxation was observed. With below-band-gap pump, picosecond dynamics of the Urbach electrons were observed for the first time. The dynamics showed pronounced bias field dependence.

References

[1] T. Hattori, R. Rungsawang, K. Ohta, and K. Tukamoto, Jpn. J. Appl. Phys. **41** 5198 (2002).

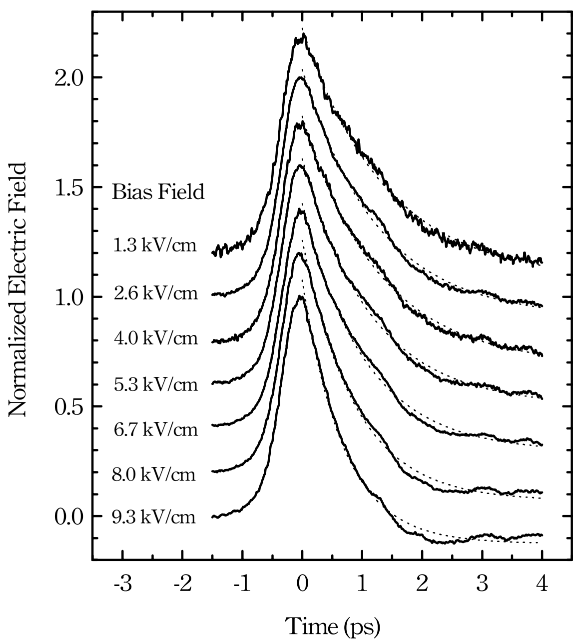

Fig. 3. Bias field dependence of the THz waveforms obtained from GaAs with 890-nm pumping.