# TeraHertz Emission and Detection From Ion-irradiated In$_{0,53}$Ga$_{0,47}$As Gated at 1.55 µm

N. Chimot, J. Mangeney, P. Crozat, K. Blary, J.F. Lampin

***Abstract*— We investigate terahertz (THz) emission and detection from heavy-ion-irradiated In$_{0.53}$Ga$_{0.47}$As photoconductive antennas excited at 1550 nm. The spectrum of the electric field radiated from the Br$^+$-irradiated In$_{0.53}$Ga$_{0.47}$As antenna extends beyond 2 THz. The THz electric field magnitude is investigated and shown to saturate at high optical pump fluence.**

***Index Terms*—photoconductive devices, electromagnetic radiation, telecommunication, antenna measurements**

## I. INTRODUCTION

The generation and detection of coherent terahertz radiation from photoconductive antenna has attracted considerable interest as it is a way to reach the intermediate THz frequency range. The best terahertz performance is achieved by a photoconductive antenna, excited by ~800nm optical pulses, and made from low-temperature-grown (LTG) GaAs material [1]. Efforts are currently made to extend the spectral window of the excited signal to the 1.55 µm region. The major benefits of using optical telecommunication wavelengths are the access to optical-fiber technologies, the stability of optical sources and cost reduction. High radiation conversion efficiency for 1.55 µm wavelength requires narrow band gap material with short carrier lifetime and high resistivity. It has been shown that Fe-implanted In$_{0.53}$Ga$_{0.47}$As lattice matched to InP is an efficient terahertz emitter [2] and detector [3] using 1560 nm optical command. We present Br$^+$-irradiated In$_{0.53}$Ga$_{0.47}$As photoconductive antenna excited at 1.55 µm as an emitter and detector of terahertz radiations. Ionic irradiation is an efficient method to introduce defects, which act as efficient trap and recombination centers for free carriers. Br$^+$-irradiated In$_{0.53}$Ga$_{0.47}$As is found to have both sub-picosecond carrier lifetime and relatively good electrical properties [4].

## II. PHOTOCONDUCTIVE ANTENNAS

Undoped 1-µm-thick n-type In$_{0.53}$Ga$_{0.47}$As layers were epitaxially grown by gas-source MBE on semi-insulating InP:Fe substrates. A mesa etching process was used to define an In$_{0.53}$Ga$_{0.47}$As absorbing area of 7x14 µm$^2$ on the InP substrate. The layers were then irradiated by 11 MeV heavy ions (Br$^+$) at irradiation doses up to 2.10$^{12}$cm$^{-2}$. With their high initial energy, the ions used for the bombardment are implanted in the InP substrate at a depth superior to 3 µm, and, according to calculations using " Stopping Range of Ions in the Matter" [3] software uniform damage profiles through the In$_{0.53}$Ga$_{0.47}$As layer are created. The In$_{0.53}$Ga$_{0.47}$As layers are then free from ions used for bombardment and the damages are only host atom displacements distributed in defect condensates. Previous studies have shown that these defect clusters have deep energy levels that act as efficient capture and recombination centers for free carriers. Degenerated pump-probe experiments and Hall effect measurements were performed. In figure 1 are shown the electron lifetime and the electron mobility deduced from these measurements.

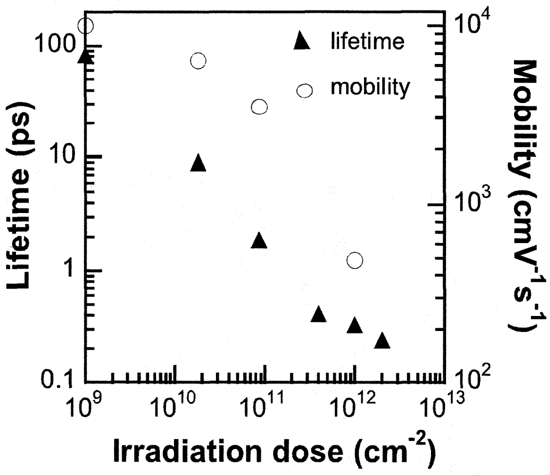

Fig. 1. electron lifetime and electron mobility as a function of irradiation dose.

Ionic irradiation is an efficient way to tune the carrier lifetime and to achieve subpicosecond values. When In$_{0,53}$Ga$_{0,47}$As is irradiated at 1.10$^{12}$ ions / cm$^2$, the carrier lifetime is as short as 330 fs. A relatively good Hall mobility of 490 cm$^2$/V.s and a resistivity of 3.1 Ω.cm are also measured. Antenna structures were fabricated by metal evaporation and a conventional lift-off photolithographic technique on this layer. In this work, Ti/Au coplanar electrodes of our emitter and detector are separated by gaps of 80 and 30 µm, respectively. Each electrode is 5 µm wide and 20 mm long. The detector presents a 5 µm gap dipole antenna.

## III. MEASUREMENTS

In the experiment, 200 fs optical pulses with a repetition rate of 14.3 MHz, delivered by a passively mode-locked fiber laser (Calmar Optcom) operating at 1550 nm were used to excite the both photoconductive switches via an optical fiber. The excitation beam was focused on our photoconductive antenna on a spot size of about 5 µm near the anode of our antennas. We used high-resistivity silicon hyper-hemispherical lens attached to the backs of the emitter and detector antennas. Emitter and detector antennas are separated by 5 cm. In$_{0.53}$Ga$_{0.47}$As photoconductive antenna used for detection was irradiated by 1.10$^{12}$ ions / cm$^2$ and is gated by 3 mW. Figure 2 shows the signal waveforms emitted by un-irradiated and 1.10$^{12}$ ions / cm$^2$ irradiated photoconductive antenna. They are respectively biased at 5 and 25 volts. The average optical excitation power is 3 mW.

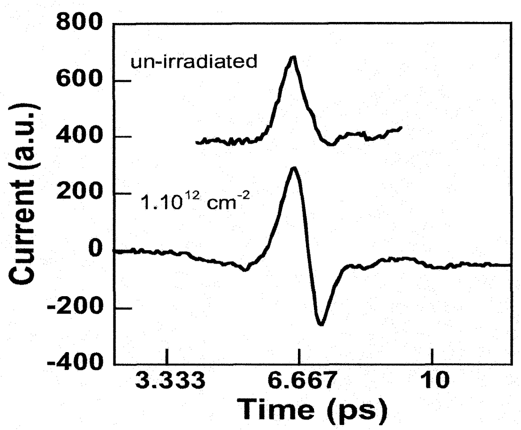

Fig. 2. normalized terahertz radiation waveforms emitted by un-irradiated and 1.10$^{12}$ ions / cm$^2$ irradiated In$_{0.53}$Ga$_{0.47}$As photoconductive antenna.

We observe a clear difference between the two waveforms presented in figure 2. The amplitude of negative peak of the signal emitted by the irradiated photoconductive antenna is higher than for the un-irradiated photoconductive antenna. Using the dipole radiation approximation in the far field, these typical waveforms result from the temporal derivative of the transient photocurrent. The main positive peak is attributed to the rises of the surge current by photocarrier injection and the carrier acceleration under the bias field. The second negative peak is attributed to the decay of the current governed by the carrier trapping time. This time is clearly shorter in the irradiated photoconductive antenna. This explains the difference between the two waveforms. The positive peaks of the waveforms show a full-width-at-half-maximum (FWHM) of 0.6 ps.

Figure 3 displays the radiation power spectra calculated from the fast Fourier transform of the waveforms in figure 2.

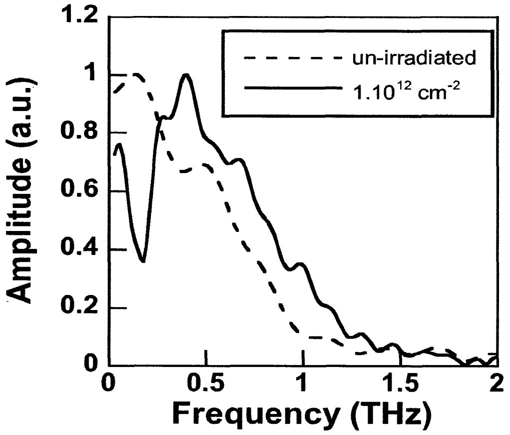

Fig. 3 Fast Fourier transforms of the temporal waveforms emitted by un-irradiated and 1.10$^{12}$ ions / cm$^2$ irradiated In$_{0.53}$Ga$_{0.47}$As photoconductive antenna.

These spectra extends up to 1.6 THz. The maximum of the spectrum is shifted from 0.15 THz for the un-irradiated emitter to 0.40 THz for the 1.10$^{12}$ ions / cm$^2$ emitter. The fastest recovery of the photocurrent in the irradiated photoconductive antenna explains this spectrum shift to the higher frequency side [4]. The 30 dB dynamic range of the spectrum is limited by the signal to noise ratio of the experiment. The absolute amplitudes are not compared because of the critical positioning of the hyper-hemispherical lens.

## IV. CONCLUSION

We have shown the generation and the detection of electromagnetic terahertz radiation from ion irradiated In$_{0,53}$Ga$_{0,47}$As photoconductive antennas illuminated by 1,55 µm wavelength. This result opens new perspectives for the realization of terahertz spectroscopic bench using the telecommunication wavelength.

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