THz Emitters and Detectors Based on Ion Implanted III-V Semiconductors

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***Abstract*- Ultrafast charge carrier dynamics in semiconductoring materials ultimately determine the performance of photoconductive terahertz (THz) emitters and receivers. Ion implantation of III-V semiconductors allows carrier dynamics to be tailored for a particular application, and thus the technique is increasingly being applied to the development of advanced materials for terahertz photonics. In this talk I will briefly introduce the technique of ion implantation and review some recent applications in THz photonics. I will then present time resolved conductivity studies of GaAs:As$^+$, InGaAs:Fe$^+$, InP:O$^+$ and InP:Fe$^+$ and relate these results to improved terahertz emitter and detector performance.**

A detailed understanding of hot charge carrier dynamics near the surface of semiconductors allows for the design of new and improved THz devices. To a first approximation the ideal material for photoconductive THz emitters (detectors) would have a very *high photoconductivity* to maximize emitted power (response), and a very *short charge carrier lifetime* in order to the maximize bandwidth. To this effect, low temperature grown (LT) GaAs, in which As precipitates and trapping centers result in short carrier lifetime, has been used in many THz devices. However, ion implantation of bulk semiconductors offers a number of advantages over low temperature grown materials. In particular ion implantation is a highly reproducible process, and can be applied to a huge range of materials. Furthermore, by choice of ion energies and doses, it is possible to produce customized depth dependent damage profiles.

In order to study carrier dynamics in implanted materials we use a combination of optical-pump terahertz-probe spectroscopy (OPTPS) [1] and Monte Carlo simulation [2,3]. OPTPS is a non-contact experiment that allows photo-induced conductivity to be measured on a picosecond time scale [1]. The technique does not require the sample to luminesce and it avoids many of the difficulties associated with interpreting time-resolved reflectivity data. We have utilized OPTPS to study GaAs:As$^+$, InGaAs:Fe$^+$, InP:O$^+$ and InP:Fe$^+$ as a function of ion dose and anneal temperature. Typical time-resolved conductivity data from a measurement of implanted semi-insulating InP as a function of Fe$^+$ dose is shown in Fig. 1. Note that as the ion dose is increased the carrier lifetime drops significantly. At low dose the peak conductivity is similar to that for the unimplanted reference. However at higher dose the peak conductivity starts to drop, which can be deleterious when used in THz devices. Clearly

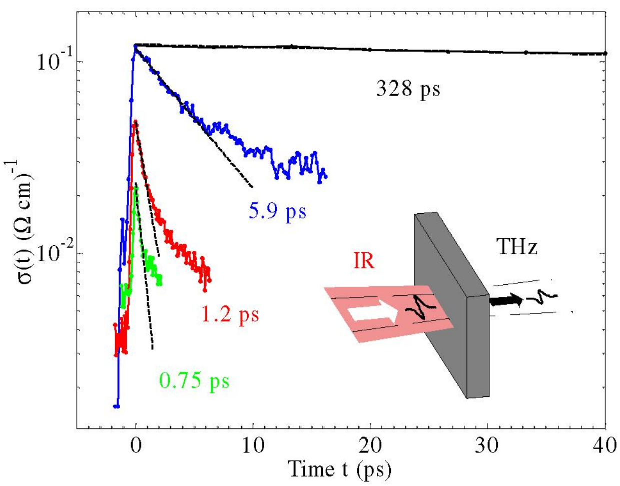

Figure 1. Measured photoconductivity of bulk InP implanted with Fe$^+$ ions, excited by 10fs pulses at 790nm. The inset indicates the experimental geometry. Data from the top were from implanted with Fe$^+$ ions at 2MeV with an ion does of 0 (black - reference), 1x10^{13}cm^{-2} (blue), 5x10^{13}cm^{-2} (red) and 1x10^{14}cm^{-2} (green). All four samples were annealed at 500°C for 30 mins. The dashed lines represent single-exponential fits to the data, which are used to extract the carrier lifetimes (shown).

OPTPS provides an excellent method of characterizing and optimizing materials for device applications.

We have extensively tested optimized ion implanted materials as THz photoconductive emitters, surface field emitter and photoconductive receivers. For example the materials show in Fig. 1 were used to develop a novel photoconductive receiver [4], which is capable of measuring the full polarization state of a THz pulse in a single scan.

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