Optical Characterization of GaAs with MSM Stuctures

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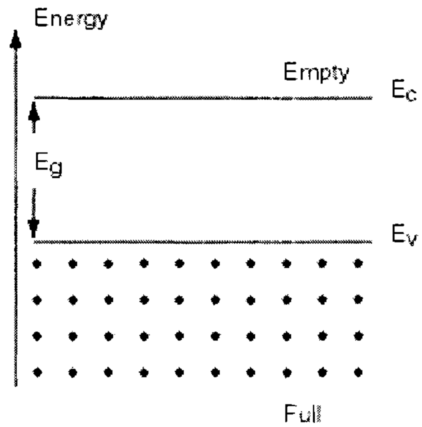
1. Abstract

There is a great demand for the ultrafast testing of high-speed electronic/optoelectronic devices in various fields of science and engineering. Such testing can be achieved by electro-optic (EO) sampling systems that are capable of sampling picosecond voltage signals with subpicosecond time resolution. Samples of gallium arsenide (GaAs), a semiconductor, with metal-semiconductor-metal (MSM) diodes were tested on the EO sampling system. The fastest sample tested produced an electrical transient with a rise time of 330 fs and a full-width at half-maximum (FWHM) of approximately 510 fs.

2. Introduction to Semiconductors

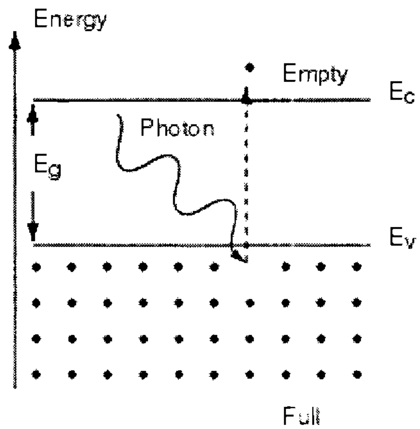
Semiconductors are a group of materials that exhibit conductive properties of both metals and insulators. Their conductive properties depend on material fabrication and temperature. At low to medium temperatures, semiconductors are insulators, while at high temperatures they are good conductors. Interesting optical properties of semiconductors occur at the energy band gap edge. GaAs is the semiconductor of interest in this study. A standard energy-band diagram at not too high-temperatures that can be applied to this particular III-V compound is shown below (figure 2.1).

Figure 2.1- A generic energy-band diagram illustrates that the energy difference between the conduction band and the valence shell is known as the band gap energy.



The energy-band diagram shows the conduction-band edge (E_c) above which all states are empty, the valence-band edge (E_v) below which all states are occupied by electrons. The energy difference between (E_c) and (E_v) is the band gap energy (E_g). The following diagram (figure 2.2) represents the same semiconductor exposed to light with photon energy (hv) at least equal to E_g.

Figure 2.2- In order for a semiconductor to be excited into its conductive state, its electrons must absorb photons with energy (hv) at least equal to the band gap energy (E_g).

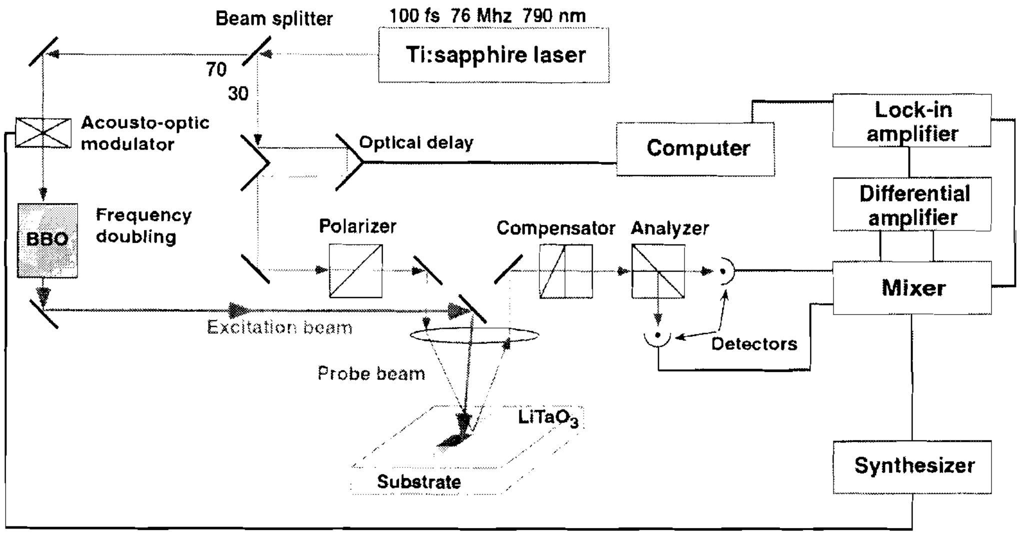


Absorption of photons with energy greater than that of the band gap results in generation of excited electrons that are now free to flow in the conduction band. These conditions allow a semiconductor to exhibit conductive properties when excited by light of the wavelength > E_g.

3. Introduction to Electro-Optic Sampling

The ultrafast testing of MSM structures on GaAs was conducted on an EO sampling system based on a commercial Ti:sapphire ($TiAlO_3$) laser (Coherent Mira 900) pumped by an argon ion laser (Coherent Innova 420). EO sampling allows voltage waveforms of electronic/optoelectronic devices to be measured with subpicosecond resolution in a non-invasive manner. Such resolution cannot be achieved with any conventional oscilloscopes.

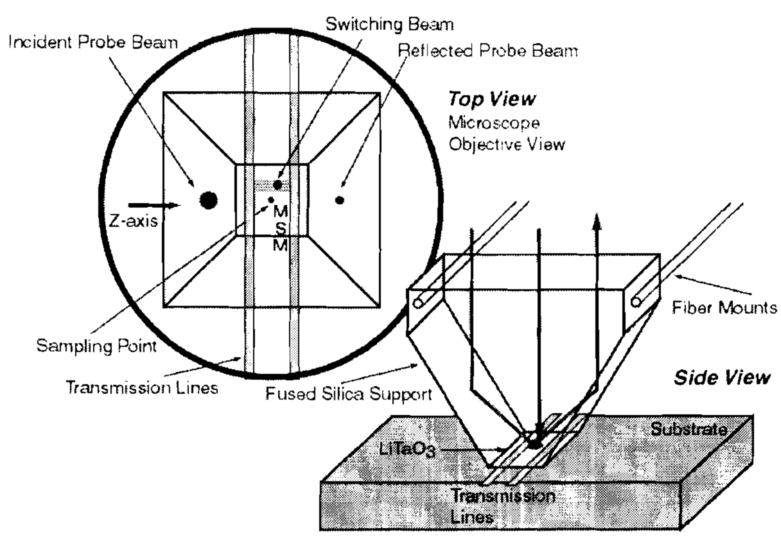
Figure 3.1- A schematic of the EO sampling system used.



The laser beam emitted by the Ti:sapphire laser has a pulse width of ~100 fs and a repetition rate of 76 MHz. The beam is split by a 30/70 beam splitter into an excitation beam and probe beam. Most of the power is diverted to the excitation beam to activate the photoconductive sample. A series of optics is used to direct the excitation beam to an acoustic-optic modulator to reduce noise. A BaB_2O_4 crystal is then used to frequency double the beam to a wavelength of 395 nm. The conversion efficiency is dependent on the quality of the crystal and is low at best, resulting in the need for infrared filters. Each pulse of the beam is directed to the sample through a microscope and excites the photoconductive switch to generate an electrical transient along the transmission lines on the sample.

A set of optics and a computer-controlled translation stage ensure that the paths of both beams are equivalent and synchronized to begin. then the stage delays each successive pulse train of the probing beam to allow the probe beam to sample the electrical transient on the transmission lines. The probe beam is 45° linearly polarized according to the optical axis of the EO crystal ($LiTaO_3$). The beam is directed to the sample by the microscope through the EO crystal. As a result of the electric field on the transmission line, the refractive index of the EO crystal is altered, known as the Pockels effect. The change in refractive index modifies the polarization of the probe beam. Guided by the process of total internal reflection, the beam is returned to an analyzer, a pair of balanced photo detectors, and a series of electronic instruments that converts the change in polarization to intensity modification, then intensity modification to the strength of the voltage signal. In this manner, the amplitude of the electrical transient on the transmission line is measured.

Figure 3.2- An EO finger probe allows the characterization procedure to be non-invasive.

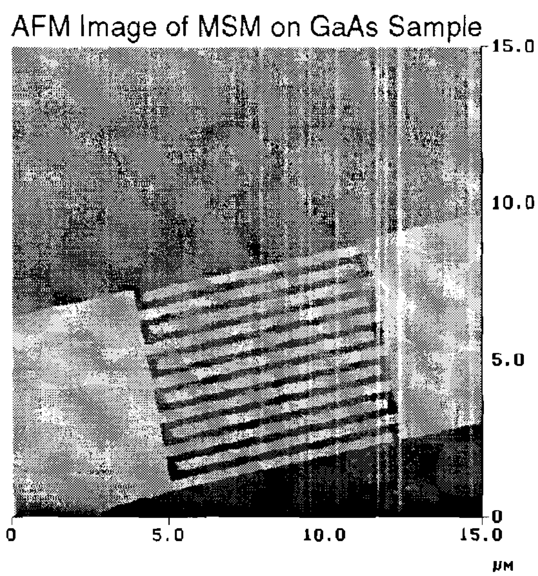


The diagram in Fig. 3.2 is a representation of the finger probe. A finger probe consists of an EO crystal with a fused silica support mounted to it in such a way that the angles of the support can provide total internal reflection for the probe beam entering the cavity. The $LiTaO_3$ can be mounted directly to a sample, but the use of the finger probe enables the process to be non-invasive.

4. Analysis of MSM on GaAs Photoconductive Switch

A metal-semiconductor-metal (MSM) structure is a planar device, made by forming Schottky diodes on a semiconductor substrate. MSM laced switches play important roles because of their very high speeds and very sensitive responses. The following is an image of an MSM structure characterized in this study.

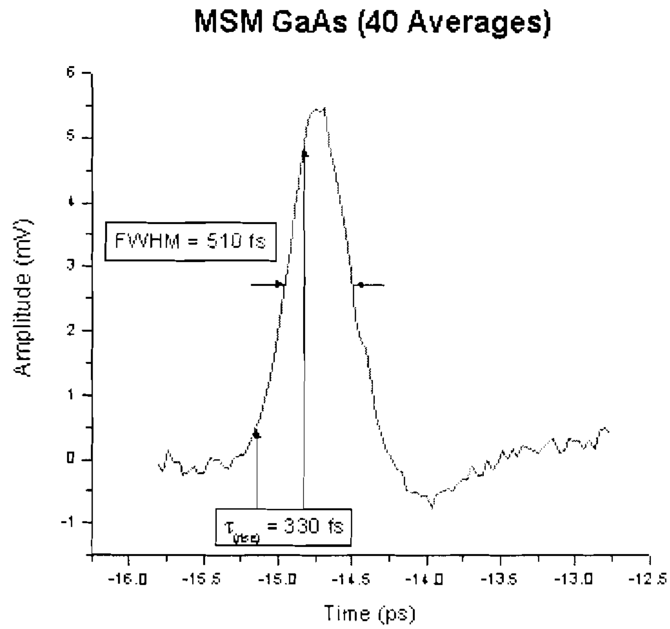
Figure 4.1- Image of one of the MSM on GaAs samples. Finger width is about 300 nm, finger spacing is about 200 nm.



MSM structures have been fabricated with finger spacing and width as small as 100 nm on low-temperature grown GaAs. The particular samples of MSM GaAs samples used in this study were of ~300 nm finger width and ~200 nm spacing.

The following is a graph generated from the data gathered from the EO sampling of the MSM GaAs sample depicted in the previous image.

Figure 4.2- A graph of the electrical transient measured. FWHM is approximately 510 fs.



Rise time is typically defined as amount of time measured from 10% of full amplitude to 90% of the full amplitude of a pulse. Full-width at half-maximum (FWHM) is the width of a pulse at 50% of the amplitude. From the data obtained, we can determine the rise time to be approximately 330 fs and the FWHM to be about 510 fs. Not only was this the fastest signal encountered during the course of this study, it was the cleanest signal as well. The data was a result of 40 averages and is relatively devoid of excess noise. The signal shown in Fig. 4.2 not only confirms that MSM diodes are one of the fastest optoelectronic devices known, but also demonstrates that the carrier generation by light (pulse rise time) and relaxation (pulse fall time) happen at time scales well below 1 ps.

5. Conclusion

High speed photoconductive switches can be characterized with subpicosecond resolution on electro-optic sampling systems. Over the last eight weeks I have been learning about EO sampling while testing various GaAs with MSM structures. Samples with pulse widths as short as 510 fs were measured with the use of an EO sampling system based on a 100 fs Ti:sapphire laser with a repetition rate of 76 MHz.

References

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