Functional Imaging Using InGaAs/GaAs Photorefractive Multiple Quantum Wells

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Abstract. We propose the use of an InGaAs/GaAs photorefractive quantum well (PRQW) as an adaptive beam combiner for holographic optical coherence imaging applications. Holograms have been observed by using a diode laser and an interferometer. A weaker quantum confined exciton leads to the saturation of electroabsorption and hence diffraction, under a high external electric field, in the InGaAs PRQW. A careful choice of external electric field modulation seems to reduce this effect. We examine several characteristics that govern the use of an InGaAs PRQW in a functional imaging system.

INTRODUCTION

Holographic optical coherence imaging (OCI) can record full-frame depth-resolved without computed tomography, allowing real-time video display [1]. Holographic OCI based on AlGaAs/GaAs PRQWs has been demonstrated for imaging through tissue in a degenerate four-wave mixing configuration [1,2]. Although AlGaAs PRQWs can also operate in a non-degenerate FWM configuration [3], it is difficult to use them for functional imaging. The photon energy of the writing beams, being necessarily above the band-edge of AlGaAs, is in a range where light suffers strong scattering in biological tissue. InGaAs based multiple quantum wells have been shown to possess good photorefractive properties at 1064 nm [4]. It is therefore of interest to study the use of an InGaAs/GaAs PRQW in a coherence imaging system. This will enable one to write holograms at a longer wavelength than AlGaAs thereby reducing the scatter from tissue.

FUNCTIONAL IMAGING SETUP

Our functional imaging system consists of a low-coherence length light source (a broadband, ~50 nm, Light Emitting Diode) that writes the hologram using an imaging Michelson interferometer configuration. One of the two beams writing the hologram is from the sample and the other is the reference. The hologram is read by a laser diode at 1064 nm. Wavelength tunability is achieved by temperature tuning the laser diode enabling one to sweep the excitonic wavelength of the PRQW. The PRQW acts as the optical filter by passing the ballistic image-bearing light while rejecting the incoherent scattered background. A square aperture after the PRQW rejects the zero-orders. The image is then recorded from the diffracted first order using a CCD camera. Since the PRQW is just an optical filter, there is no reconstruction involved and one can acquire full-frame depth resolved images by changing the path length of the reference beam.

EXPERIMENTS AND DISCUSSION

The phenomenon of saturation in the FWM signal has been observed in InGaAs/GaAs PRQWs though the mechanism still remains unclear as the FWM saturates without the associated saturation of the electro-absorption [4]. Varying the duty cycle of the applied electric field could help in increasing the electric field cutoff at which the FWM saturates. This has important consequences to improving the

CP772, *Physics of Semiconductors: 27th International Conference on the Physics of Semiconductors,*
edited by José Menéndez and Chris G. Van de Walle

sensitivity of our imaging system. To test this hypothesis the photocurrent was monitored across a 1.047 MΩ resistor. Unipolar square wave electric fields of 8 and 10 kV/cm were applied to an InGaAs/GaAs PRQW (similar to the one in ref. 2) at a modulation of 105 Hz. The laser diode was tuned to the excitonic absorption of the PRQW and an intensity of 2.23 mW/cm^2 was incident on the sample. Figure 1 shows the load voltage as a function of duty cycle. One can see a 20% increase in the photocurrent at 50% duty cycle when the electric field is increased from 8 to 10 kV/cm. The duty cycle was kept below 50% for the 10 kV/cm applied field to prevent possible surface damage to the sample.

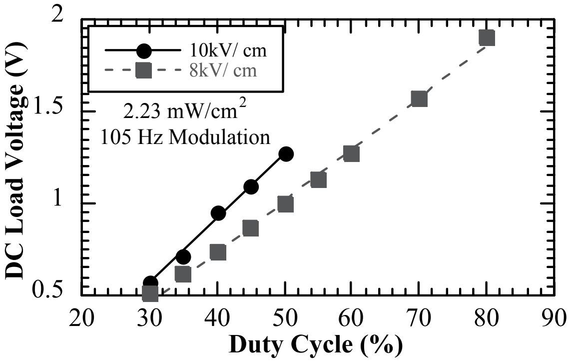

FIGURE 1. Load voltage as a function of duty cycle across a 1.047 MΩ resistor. The light intensity across the sample is 2.23 mW/cm^2.

Looking at Fig. 2, which shows the peak differential transmission (defined as the ratio of the change in transmission due to the electro-absorption under an applied electric field to the zero-field transmission) as a function of duty cycle, one sees that at 50% duty cycle there is nearly a 50% increase in the differential transmission when the field is increased from 8 to 10 kV/cm. Further the electro-absorption seems to start saturating at higher duty cycle values for 8 kV/cm and even decreases for duty cycles larger than 60%. Detailed time-resolved experiments will help us to understand the effect of hot-carriers on this saturation. Non-degenerate FWM experiments with a mirror in the place of the sample were done by writing gratings with a laser diode that was temperature tuned through 1064 nm at a fringe spacing of 71 µm. The FWM signal was read off the signal beam using a photodiode and lockin amplifier. An external unipolar square wave electric field of 10 kV/cm and frequency 1 kHz was applied in the plane of the PRQW. The total light intensity on the sample was 12.5 mW/cm^2 with a signal to reference ratio of 3.5. The FWM efficiency (defined as the ratio of the diffracted beam to the transmitted beam) is shown in Fig. 3 as a function of laser diode temperature. Laser diode noise is seen as the dip near 29°C in the spectra. One can clearly see that there is an optimum duty cycle, ~ 40%, for a measurable FWM signal. Also correcting for laser fluctuations, the spectra for 40% and 50% duty cycles are on top of each other. This is evidence that by reducing the duty cycle, and thereby the joule heating, one can optimize the performance of the InGaAs PRQW without sacrificing on FWM efficiency. Further experiments are planned to improve beam shaping and stability to improve the FWM efficiency.

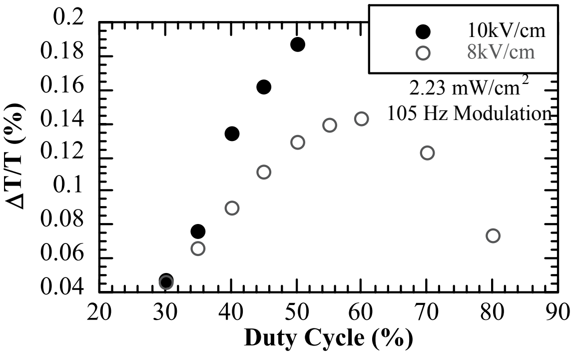

FIGURE 2. Differential transmission vs. duty cycle for applied fields of 8 and 10 kV/cm.

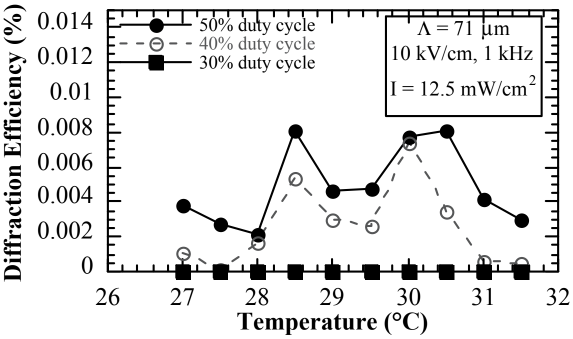

FIGURE 3. FWM efficiency as a function of laser diode temperature. The exciton is around 29 °C.

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