Photocurrent Spectroscopy of a Resonant Cavity Enhanced Photodetector

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INTRODUCTION

Semiconductors have various applications in devices based on their electronic and optoelectronic properties. With the need for better devices, a class of optoelectronic devices has been developed that rely on resonant cavity effects to enhance device efficiency. These devices require critical matching of the cavity resonance and the material absorption edge. At the resonant wavelengths, incident light experiencing multiple reflections at the two mirrors build up the optical field. Among these are resonant cavity enhanced (RCE) photodetectors capable of improved wavelength selectivity (Kishino et al., 1991; Salvador et al., 1994). One of the most widely used semiconductor material in devices today is the III-V semiconductor Gallium Arsenide (GaAs). Bulk GaAs and GaAs-based modulated semiconductor structures such as quantum wells, with band gap absorption around 1.5 eV are both commonly used as infrared photodetectors. Moreover, GaAs quantum well heterostructures have enhanced absorption over their bulk counterparts due to excitonic effects. In this paper, we study the features of a resonant cavity enhanced (RCE) GaAs MQW photodetector by means of photocurrent (PC) spectroscopy.

METHODOLOGY

Fig. 1 shows the schematic diagram of the RCE p-i-n photodetector. The GaAs/AlGaAs multiple quantum wells (MQW's) were grown by molecular beam epitaxy (MBE) on Si substrate and are situated in the intrinsic region of the p-i-n device. The resonant cavity is formed with the MQW's forming part of the cavity created by the two dielectric mirrors.

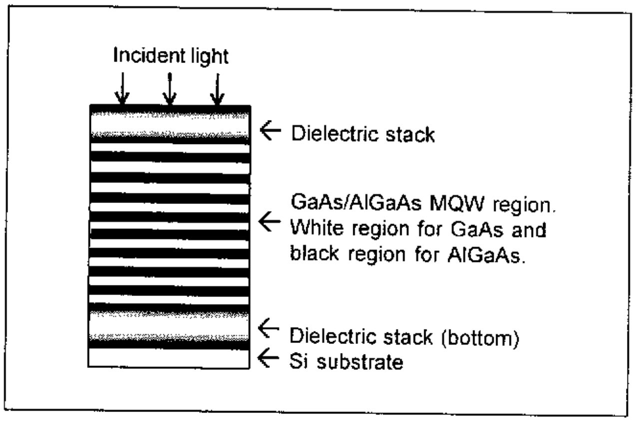

Fig. 1. Schematic diagram of an RCE photodetector. The effective cavity length is the distance between the two dielectric stack mirrors.

Needle probes mounted on translation stages were used as contacts to the device. Photocurrent was measured at room temperature with the device illuminated with a tungsten-halogen lamp dispersed by a SPEX 500M (F=0.5m) monochromator. Fitted with a 600 gr/mm grating (blazed at 1.5 microns), the monochromator system has an effective resolution of 10Å with slit widths at 300 microns. The incident light was chopped at ~210 Hz and the resulting photovoltage detected using an SR510 Lock-in amplifier. The schematic of the PC set-up is shown in Fig. 2.

The experimental transition energy of the ground exciton transition (1HH-1C) is calculated using effective-mass approximation and finite-square model (Salvador et al., 1998) with the absorption energy of the exciton peak *h*n given by the equation:

$$h\nu = E_{g\,(bulk)} + E_{1hh} + E_{1c} - E_{xb}$$

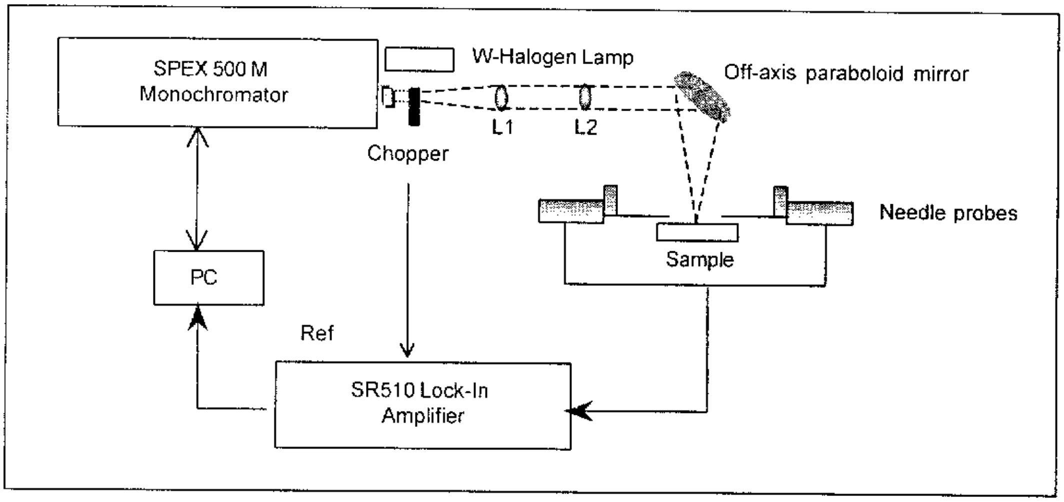

Fig. 2. Schematic diagram of the set-up used for photocurrent measurements

where $E_{g(bulk)}$ is the GaAs bulk band gap, E_{1e} and E_{1hh} is the energy from confinement for the electron and the hole and E_{xb} is the exciton binding energy.

To investigate the cavity effects and wavelength selectivity of the device, a layer of SiO_2 was deposited on the top mirror using a Plasma Enhanced Chemical Vapor Deposition (PECVD) system at the Condensed Matter Physics Laboratory. After deposition, the current–voltage characteristic of the sample was checked and it was made sure that no damage was done during the deposition process. PC spectroscopy was again performed and compared with the PC spectrum of the device before deposition.

RESULTS AND DISCUSSION

In the device under study, the absorption region consists of GaAs multiple quantum wells (MQW). The absorption edge or the exciton resonance is determined by the composition and thickness of the MQW and is calculated to be $E_g = 1.462$ eV (w=90 Å). Because the MQW's were deposited on Si substrates, the strain of the lattice mismatch between the GaAs and Si layers may have caused the observed change in the position of the band edge absorption.

Fig. 3 shows the photocurrent spectra of the RCE photodetector before and after deposition of the SiO_2 layer. The peak at ~8568 Å is attributed to the heavy-hole excitonic peak and is the band edge absorption while the other observable peaks are identified to be Fabry-Pérot modes. This is supported by the unchanged position of the band edge absorption even after the deposition of the SiO_2 layer contrary to the shift in the positions of the oscillations below the absorption edge. The deposited SiO_2 layer changed the reflectivity of the top surface by acting as an external mirror (Hefferman & Hegarty, 1995). This external mirror

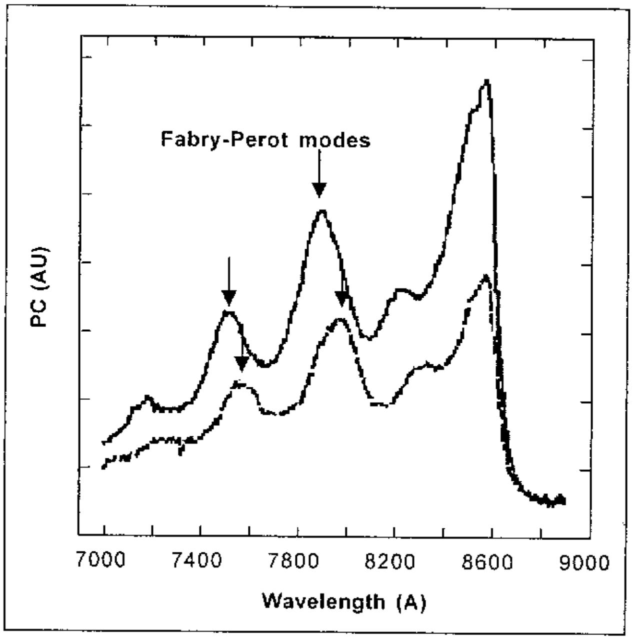

Fig. 3. Comparison of the photocurrent spectra of photodetector before (solid lines) and after deposition of the SiO_2 layer (dashed lines).

effectively changes the cavity length as light exiting the former top mirror is again reflected back into the intrinsic region of the device. These changes alter the standing wave pattern in the device cavity leading to the shift in the Fabry-Pérot modes.

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