

LETTER | NOVEMBER 15 1990

Phototransmission study of strained-layer $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ single quantum well structures

Shu Yuan; Shumin Wang; Shixiong Qian; Yufen Li; T. G. Andersson; Z-G. Chen



J. Appl. Phys. 68, 5388–5390 (1990)

<https://doi.org/10.1063/1.347019>



Articles You May Be Interested In

Electrical and optical properties of $\text{Cd}_x\text{Zn}_{1-x}\text{Te}$ single crystals for applications as terahertz electro-optic sensors

J. Appl. Phys. (August 2004)

A mechanism for low-power all-optical switching in multiple-quantum-well structures

Appl. Phys. Lett. (December 1996)

Detection of THz radiation with devices made from wafers with HgTe and InSb quantum wells

AIP Conf. Proc. (December 2011)



Nanotechnology & Materials Science



Optics & Photonics



Impedance Analysis



Scanning Probe Microscopy



Sensors



Failure Analysis & Semiconductors



Unlock the Full Spectrum.
From DC to 8.5 GHz.

Your Application. Measured.

Find out more



Phototransmission study of strained-layer $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ single quantum well structures

Shu Yuan, Shumin Wang, Shixiong Qian, and Yufen Li
Department of Physics, Fudan University, Shanghai, People's Republic of China

T. G. Andersson
Department of Physics, Chalmers University of Technology, S-41296 Göteborg, Sweden

Z-G. Chen
Institute of Semiconductor, Academia Sinica, Beijing, People's Republic of China

(Received 4 August 1989; accepted for publication 30 July 1990)

We report the phototransmission measurement of strained-layer $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ single quantum well structures at room temperature. The spectra obtained show distinct features of excitons in the single quantum wells. Fitting of the phototransmission spectrum indicates that the excitonic transition energy modulation is the main mechanism. The phototransmission can be used as a supplement to photoreflectance due to its sensitivity and convenience.

Optical properties of quantum wells and superlattices have been extensively investigated with various techniques. Photoreflectance¹⁻⁴ (PR) has been used to study the real part of dielectric function and other properties of quantum wells. We report in this communication the phototransmission (PT) measurements (e.g., photomodulated absorption spectroscopy⁵) on two strained-layer $\text{InGaAs}/\text{GaAs}$ single quantum well (SQW) samples at room temperature. The data are fitted by using the modulation of a dielectric function due to excitonic transitions⁴ rather than the third-derivative functional form (TDDFF).⁵

The samples were grown by molecular-beam epitaxy (MBE) in a Varian MBE-360 system. A (001) oriented substrate of semi-insulating GaAs was used on which a 500-Å GaAs buffer layer had been grown. An $\text{In}_x\text{Ga}_{1-x}\text{As}$ quantum well layer was then grown to a thickness of 50 Å and was covered with a GaAs cap layer of 500 Å. The samples were not intentionally doped. The In contents of the well of the samples are 0.1 and 0.2, respectively. The details of the growth and the calibration procedures were described in Ref. 6.

It is very difficult to measure the excitonic absorption of the single quantum well structures with such a small well thickness by ordinary absorption spectroscopy because the product of the absorption coefficient (α) and the thickness of the quantum well (w) is smaller than 0.01 at the peak of the exciton resonance. To overcome this difficulty, we used the modulated pump technique and detected the change of the transmittance of the probe beam after passing through the sample under modulated pumping. The modulation transmission spectra obtained from this sensitive method clearly show the quantum well nature.

The experimental setup is shown in Fig. 1. A 2-mW He-Ne laser beam chopped at 200 Hz was used as the pump beam which was completely absorbed by the sample because its photon energy (1.96 eV) is much larger than that of the absorption edge of GaAs at room temperature. A 150-W tungsten-halogen lamp together with a monochromator was used to produce a monochromatic probe beam which normally incident on the same spot of the pump beam on the sample. The GaAs substrate is transparent for the probe

beam at photon energies of interest (below the GaAs energy gap). A silicon photocell was located just behind the sample, therefore the samples were not specially treated. The modulated signal detected by the photocell was analyzed by a lock-in analyzer whose output was proportional to the modulated change of the transmitted intensity (ΔI). The dc level of the detected signal was also recorded as the transmitted intensity (I). Thus, $\Delta I/I$ (i.e., $\Delta T/T$) was obtained.

The phototransmission mechanism is similar to that of the photoreflectance. The applied field reduces the built-in electric field inside the sample⁷ and thus modifies the dielectric function (ϵ) in the SQW layer, so the transmittance is modulated.

In the PT experiment, the intensity of the transmitted probe beam is $I = I_0 \exp(-\alpha w)$, where I_0 is the incident intensity, w is the layer thickness, $\alpha = \epsilon_2 \omega / (\eta c)$, where η is

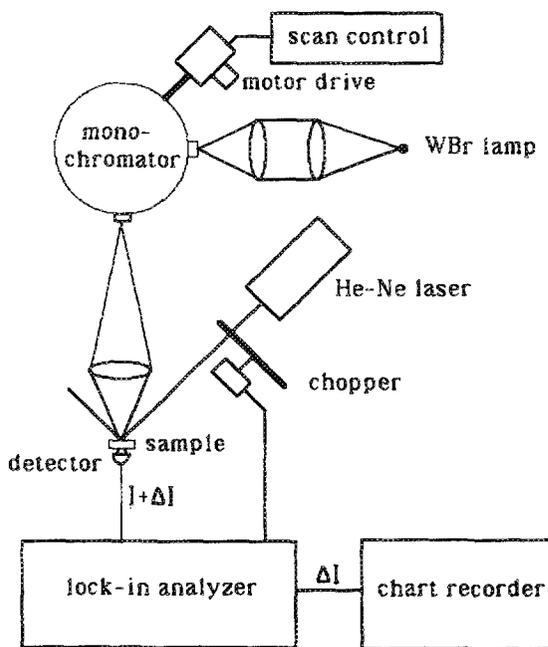


FIG. 1. The experimental setup for phototransmission.

the refractive index, ω is the light frequency, and c is the light velocity in vacuum.

With the change of the electric field inside the sample (ΔF), T alters to $T + \Delta T$. One gets:

$$\Delta T/T = (\omega\omega/\eta c)\Delta\epsilon_2. \quad (1)$$

ϵ_2 is related to excitonic transition energy ($E_{n,m}$), the oscillation strength ($f_{n,m}$), and linewidth ($\Gamma_{n,m}$) of the excitons, where n and m denote the n th conduction-band level and m th valance band level of a exciton. At room temperature, ϵ exhibits a Gaussian absorption profile⁸ and ϵ_2 takes the following form:

$$\epsilon_2 = (1/2\pi^{-1/2})\sum_{n,m} (-f_{n,m}/\Gamma_{n,m})\exp(-x_{n,m}^2) \quad (2)$$

where $x_{n,m} = (E - E_{n,m}/2\Gamma_{n,m})$, E is the photon energy ($E = \hbar\omega$).

So,

$$\Delta\epsilon_2 = [(\partial\epsilon_2/\partial E_{n,m})/(\partial E_{n,m}/\partial F) + (\partial\epsilon_2/\partial f_{n,m})(\partial f_{n,m}/\partial F) + (\partial\epsilon_2/\partial \Gamma_{n,m})(\partial \Gamma_{n,m}/\partial F)]\Delta F. \quad (3)$$

Setting

$$U_{n,m} = \partial E_{n,m}/\partial F, \quad V_{n,m} = \partial \Gamma_{n,m}/\partial F,$$

and

$$W_{n,m} = \partial f_{n,m}/\partial F,$$

one obtains

$$\Delta T/T = A\sum_{n,m} E/\Gamma_{n,m} [U_{n,m}f_{n,m}x_{n,m}/\Gamma_{n,m} - V_{n,m}f_{n,m}(1 - 2x_{n,m}^2)\Gamma_{n,m} + W_{n,m}] \times \exp(-x_{n,m}^2), \quad (4)$$

where $A = \omega\Delta F/(2\pi^{1/2}\hbar\eta c)$ is a constant.

According to the above equations, the PT line shapes depend upon the terms contain $U_{n,m}$, $V_{n,m}$, and $W_{n,m}$, the magnitudes of which reflect the relative contributions of the modulation of the energy gap, linewidth, and the oscillation strength of the excitonic transition. Using Eq. (4), we calcu-

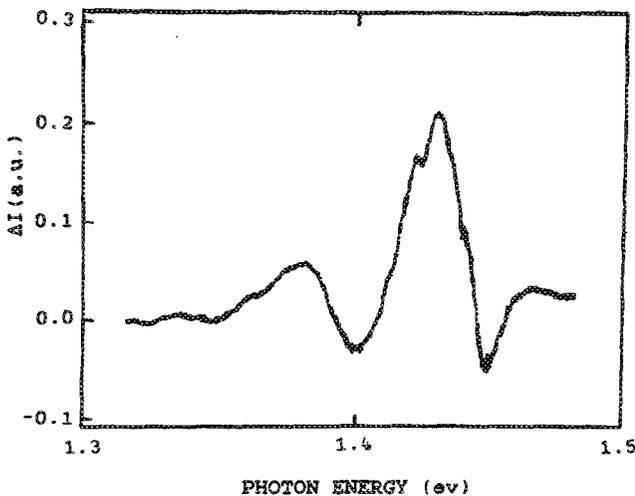


FIG. 2. The dependence of ΔI on photon energy of the $\text{In}_{0.1}\text{Ga}_{0.9}\text{As}/\text{GaAs}$ SQW sample.

lated the $\Delta T/T$ spectrum and fit the experimental PT spectrum by taking $U_{n,m}$, $V_{n,m}$, and $W_{n,m}$ as fitting parameters. Since ϵ_2 takes a simple form as compared to ϵ_1 , the fitting of PT data is easier than that of PR data.

Shown in Figs. 2 and 3 are the experimental PT spectra of 50-Å thick strained-layer $\text{In}_{0.1}\text{Ga}_{0.9}\text{As}/\text{GaAs}$ and $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}/\text{GaAs}$ SQWs at room temperature.

The PT spectra clearly demonstrate the features of the excitons in the well at room temperature, while no evidence of the exciton structure of the single well was found from the ordinary absorption spectra at room temperature and at 77 K.

In Fig. 2, there are two features. The first one is composed of a peak and a valley around 1.43 eV and the second around 1.38 eV. In Fig. 3, there are three features. The first one is also around 1.43 eV, but the rest shift to lower energy side. This is because the strain reduces the energy gap of the $\text{In}_x\text{Ga}_{1-x}\text{As}$ strain layer.⁹

For the GaAs bulk sample, only the feature around 1.43 eV remained in the spectrum. Therefore, the feature around 1.43 eV refers to the transition in the GaAs layer and the rest

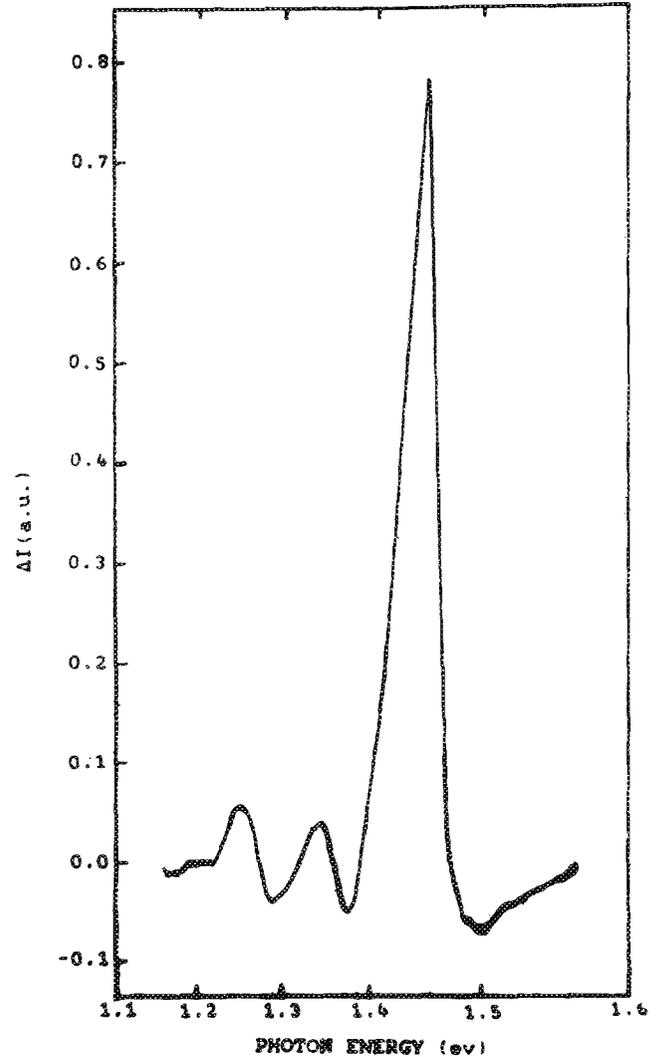


FIG. 3. The dependence of ΔI on photon energy of the $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}/\text{GaAs}$ SQW sample.

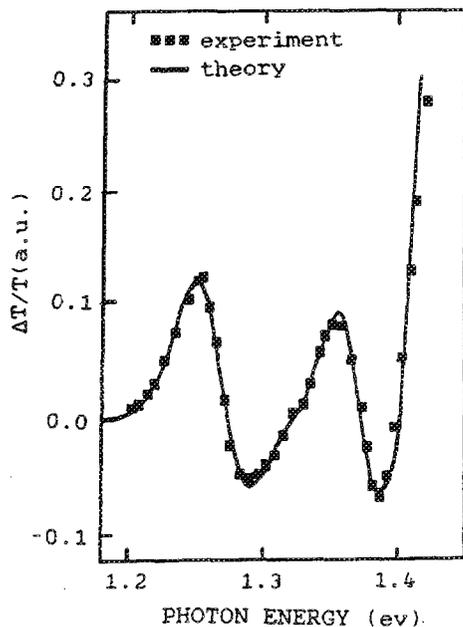


FIG. 4. The fit of the phototransmission spectrum for the $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}/\text{GaAs}$ SQW sample.

refer to the excitonic transitions in the InGaAs wells.

Shown in Fig. 4 is a least-squares fit of the PT spectrum of the strained-layer $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}/\text{GaAs}$ SQW at room temperature.

Since in this research we are mainly concerned with the optical properties of the SQWs and $\Delta T/T$ is large due to low transmittance near the absorption edge of GaAs, the fit was performed for the spectrum in the lower photon energy re-

gion. This procedure yielded good agreement with the observed line shape. Since $U_{n,m}$ is much larger than $V_{n,m}$ and $W_{n,m}$, the excitonic transition energy modulation is the main mechanism of the PT spectra. Shanabrook *et al.*² have drawn the same conclusion from the PR experiments. Therefore, PR and PT reflect the changes of the real and imaginary parts of the dielectric constant with the electric field, respectively. From the fit, the excitonic transition energies were also obtained, $E = 1.265$ eV and $E = 1.368$ eV.

In addition, there was no obvious change of the PT signal with the change of the pump power from 2 to 0.3 mW.

In summary, we have reported the phototransmission measurements of two SQW samples which clearly show the exciton structures of the SQWs. The mechanism for PT was discussed and the data were fitted very well. The high signal-to-noise ratio and relative convenience have showed that this technique can be used to study single quantum well and other microstructures.

¹O. J. Glembocki, B. V. Shanabrook, N. Bottka, W. T. Beard, and J. Comas, *Appl. Phys. Lett.* **46**, 970 (1985).

²B. V. Shanabrook, O. J. Glembocki, and W. T. Beard, *Phys. Rev. B* **35**, 2540 (1987).

³S. H. Pan, H. Shen, Z. Hang, F. H. Pollak, W. Zhuang, Q. Xu, and D. Morris, *Phys. Rev. B* **38**, 3375 (1988).

⁴W. M. Theis, G. D. Sanders, C. E. Leak, K. K. Bajaj, and H. Morkoc, *Phys. Rev. B* **37**, 3042 (1988).

⁵C. Van Hoof, D. J. Arent, K. Deneffe, J. De Boeck, and G. Borghs, *J. Appl. Phys.* **64**, 4233 (1988).

⁶T. G. Andersson, Z. G. Chen, V. D. Kulakovskii, A. Uddin, and J. T. Vallin, *Appl. Phys. Lett.* **51**, 752 (1987).

⁷D. E. Aspnes, *Solid State Commun.* **8**, 267 (1976).

⁸O. J. Glembocki, B. V. Shanabrook, and S. Rudin, *Bull. Am. Phys. Soc.* **32**, 470 (1987).

⁹T. T. Leu, F. A. Thiel, H. Scheiber, J. J. Kobim, B. I. Miller, and J. Backmann, *J. Electron. Mater.* **8**, 663 (1979).