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STRAIN-CONFINED WIRES AND DOTS AT A GaAs/$Al_xGa_{1-x}As$ INTERFACE

Yitong Gu, Yong Zhang and M.D.Sturge
Department of Physics, Dartmouth College, Hanover, NH 03755-3528
U.S.A.

K. Kash*
Physics Department, Case Western Reserve University,
Cleveland, OH 44106,
U.S.A.

B.P. Van der Gaag, A.S. Gozdz, L.T.Florez and J.P.Harbison
Bellcore, 331 Newman Springs Road, Red Bank,NJ 07701-7040, U.S.A.

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We have observed lateral exciton confinement at the GaAs/$Al_xGa_{1-x}As$ interface. The confinement is achieved in both the growth and lateral directions by the strain potential under an amorphous carbon stressor. The potential well varies from 15 meV to 40 meV for different stressor sizes. We have also made transient measurements on this structure, which show efficient exciton transfer from the bulk GaAs to the confined region.

1. Introduction

The past decade has witnessed tremendous progress in low dimensional semiconductor systems such as quantum wires and quantum dots, thanks to our ability to control the growth of such mesoscopic structures with atomic accuracy. However, up to now, one-dimensional and zero-dimensional exciton confinement has usually been achieved by patterning quantum wells[1] . A shortcoming of this approach is that well width fluctuations, and the relatively poor quality of "inverted" interfaces in which GaAs is grown on AlGaAs, limit the uniformity of the quantum wire or quantum dot. Recently, in the course of a study of strain confined quantum wires and quantum dots in quantum wells[2], we found an extra peak in the photoluminescence (PL), which appears to be associated with excitons confined by strain at the interface between the GaAs buffer and AlGaAs layer. More details on these results are given in Ref.[3]. We have confirmed this assignment by observing excitons confined by strain in a sample that contains a heterojunction but no quantum well. This raises the interesting possibility of using strain confinement to fabricate one-dimensional and zero-dimensional structures at high quality single interfaces.

This paper reports the observation of strain-induced carrier confinement at the GaAs/AlGaAs interface. In section 2, we briefly describe the samples and the experiment. Steady-state and transient results are presented and discussed in section 3. A summary is given in section 4.

2. Sample Preparation and Experimental Set-up

The samples were grown by molecular-beam epitaxy as follows. Sample 1: 500 nm GaAs buffer layer, a 200 nm barrier layer consisting of 160 nm of $Al_{0.3}Ga_{0.7}As$ followed by a 20-layer superlattice of 1.4 nm of GaAs and 0.6 nm AlAs to smooth and clean up the interface, a 12 nm GaAs quantum well, a 20 nm barrier of $Al_{0.3}Ga_{0.7}As$, and a 30 nm GaAs cap layer. Sample 2: 500 nm GaAs buffer, 3μm $Al_{0.2}Ga_{0.8}As$, a 25-layer superlattice of 2 nm of GaAs and 2 nm of $Al_{0.4}Ga_{0.6}As$, 20 nm $Al_{0.2}Ga_{0.8}As$, 500 nm GaAs, 20 nm $Al_{0.2}Ga_{0.8}As$. The material was not intentionally doped and was p-type, probably compensated, at the 10^{14} cm^{-3} (net) level. A uniformly strained amorphous carbon layer was deposited on each sample, which was then patterned by electron-beam lithography and etched to form 50-μm square arrays of stressor wires and dots of different sizes[4]. Upon etching the stressors relax, deforming the semiconductor beneath, thus producing a dilated center and a compressed edge. The dilation reduces the bandgap and forms a potential well for excitons in the lateral direction. In a quantum well, vertical confinement is provided by the band offsets, but at a GaAs/AlGaAs interface it is the variation of strain in the growth direction which confines excitons to the interface region. The strain decay length along the growth direction is of the order of half the stressor width [5], so the interface should be as close to the stressor as possible to achieve strong confinement. In these samples, we are interested in the interface nearest the stressors. The details of the strain tensor and its bandgap modulation in both directions can be found elsewhere [5][6].

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* work done while at Bellcore

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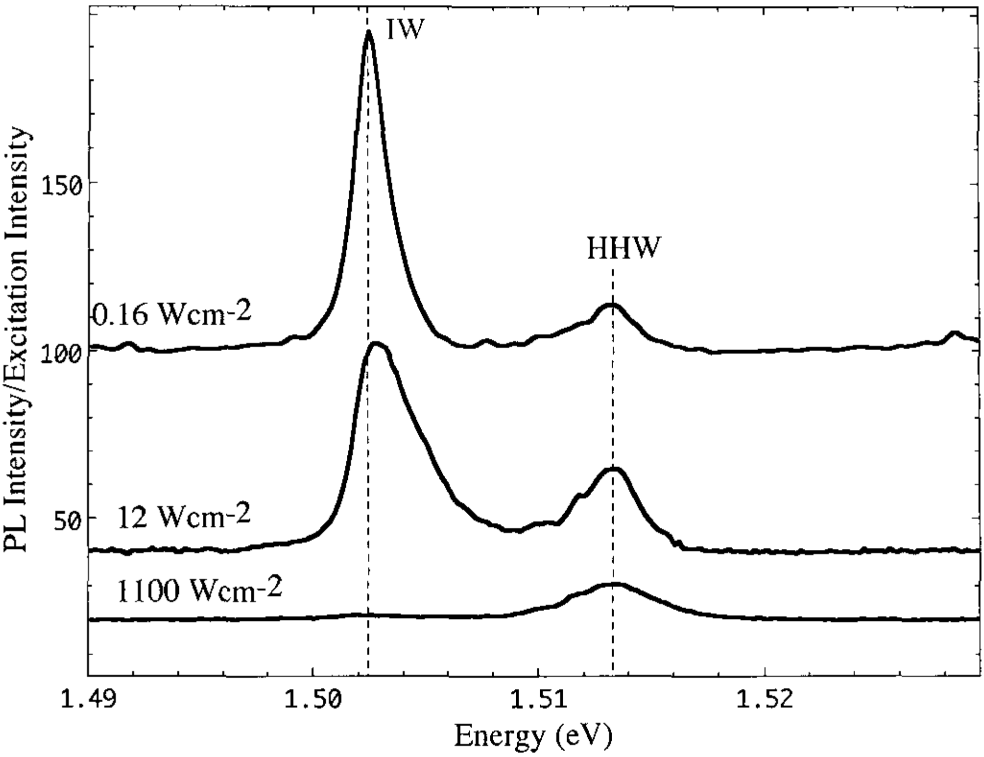

Fig.1 Photoluminescence (PL) spectra of 400 nm wire in sample 1, at 4.2K, at various excitation intensities.

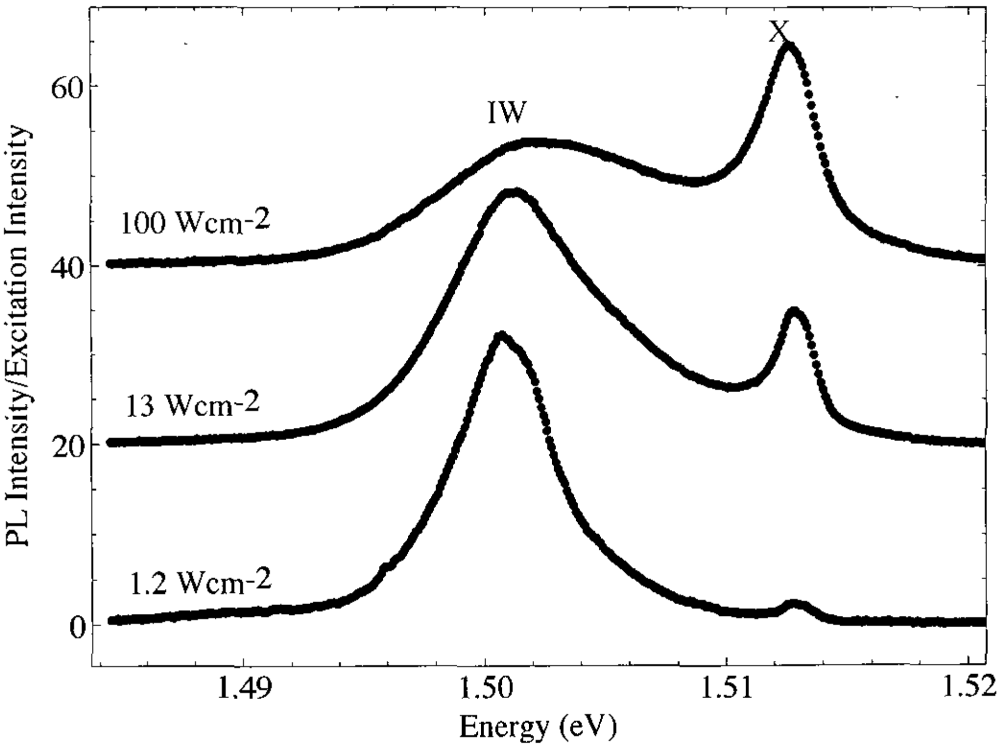

Fig.2 PL spectra of 200 nm wire in sample 2, at 4.2K, at various excitation intensities. "IW": interface wire exciton. "X": bulk GaAs exciton.

Steady-state photoluminescence (PL)was excited with a HeNe laser (632.8 nm), while for transient measurements we used a mode-locked Ar$^+$ laser (514.5nm) with a time-resolved single photon counting system, resolution 44ps/channel.

3. Experimental Results and Discussion

A. CW Measurements

The laser beam was focused to a spot ~15 µm diameter within a square array of stressor wires. Fig.1 shows emission from a 400-nm-wire (800 nm spacing) array on sample 1 at 4.2K, for three different excitation intensities. Geometrically, 60% of the excitation is created in the interwire region , where the strain has little effect. However, because exciton diffusion and trapping into the strained regions occur, the PL is dominated by two peaks: "HHW", from excitons in the strain confined region of the quantum well, and "IW" , which we assign to excitons under the stressor at the interface. We will refer to this as the "Interface Wire" line. Analogous lines, with similar saturation behavior, are observed for all the wires and dots in sample 1 containing the quantum well. While the excitation spectrum of the "HHW" peak shows peaks at the exciton energies of the unpatterned quantum well, that of the interface wire line shows no such peaks and is dominated by the bulk GaAs exciton . In sample 2 "HHW" is, of course, absent, and the interface wire line is the only strong PL line at low excitation intensity (< 1Wcm^{-2}).

Fig. 2 shows the excitation intensity dependence of an interface wire line in sample 2. With increasing intensity, the low energy confined states saturate and higher states become populated, extending the interface wire line on the high energy side. As in sample 1, the integrated PL intensity is proportional to excitation intensity in the range shown, but saturates at ~10^3 Wcm^{-2}. Under selective excitation this hot PL of the wires in sample 2 shows extensive fine structure, which will be discussed elsewhere. The PL of the bulk GaAs "X", increases superlinearly and dominates above 100Wcm^{-2}.

The redshift due to confinement increases with stressor width. In sample 2, it is 14 meV for 200 nm and 40 meV for 400 nm wires, measured from the bulk GaAs exciton. This result demonstrates that the interface wire line comes from the region right beneath the stressors.

Fig. 3 shows the temperature dependence of the intensity of the interface wire line. At high temperature the intensity for different wire widths quenches with an activation energy roughly equal to the redshift mentioned above. However there is also a quenching process with an activation energy ~5meV, which is probably related to localization of the exciton by fluctuations in the wire width: as the temperature is raised the exciton can migrate along the wire to nonradiative centers. Transfer from the bulk GaAs is

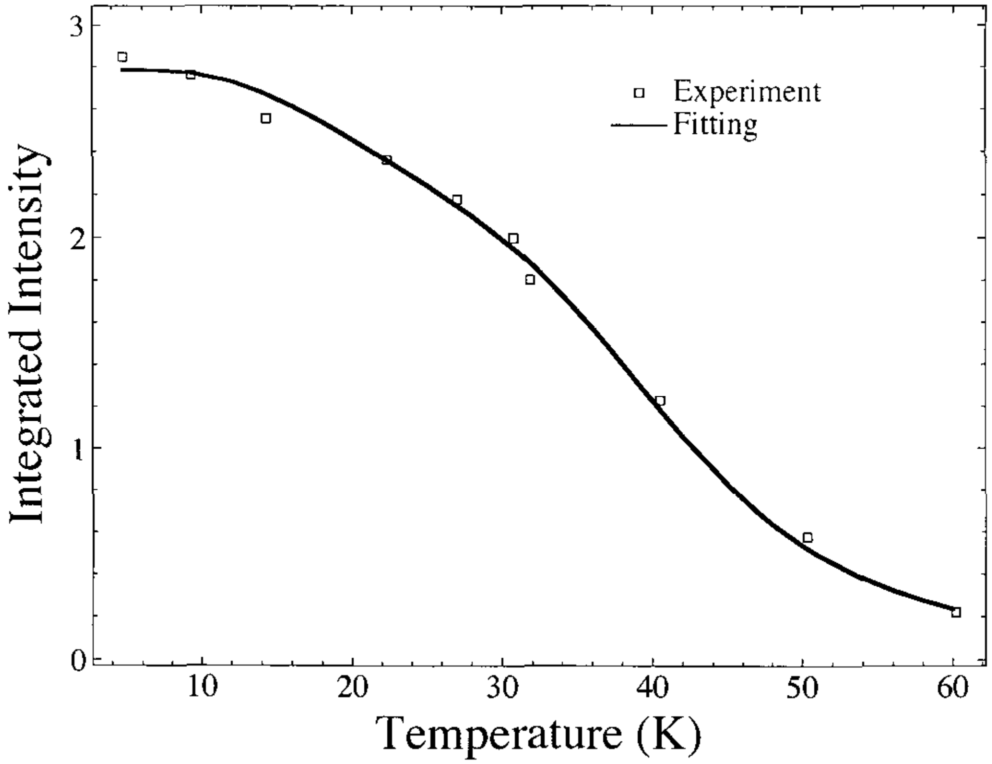

Fig.3 Integrated low-excitation PL intensity I(T) of 300 nm wire from sample 2 as a function of temperature. The line is a fit to

$$I(T) = I(0)/[1 + Ae^{-E_1/kT} + Be^{-E_2/kT}]$$

with E_1 = 5 meV, E_2 = 27 meV, A = 2.3, B=1.9x10^3 .

strong at all temperatures and is not thermally activated, unlike the case of wires and dots in quantum wells, where there is a barrier of a few meV to transfer [2,3].

B. Transient Measurements

Transient excitation measurements were made on the 200 nm wires of sample 2, and since the AlGaAs layer and the strained region of GaAs under the stressor are too thin to contribute appreciably to the absorption, excitation is predominantly into the 500 nm GaAs layer. The laser pulse creates excitons in the GaAs both beneath the stressor and between the wires. The CW data indicate that the strain gradient causes most of these excitons to transfer rapidly to the confined region. This interpretation is confirmed by our transient data.

Fig.4 shows the time decay of the bulk exciton at 1.513 eV and of the confined exciton in the 200 nm wire at 1.500 eV at 4.2 K after a 5x10^{-8}J/cm^2 excitation pulse. The repetition rate was 80 MHz, giving an average excitation intensity of 4 Wcm^{-2}. The system response (0.25 ns FWHM) is also shown. The wire shows a single exponential decay rate of 1.0±0.1 ns^{-1}, consistent with the known radiative rates at 1.2K of the donor and acceptor bound excitons in GaAs of 1.33±0.26 ns^{-1} and 1.0 ± 0.1 ns^{-1} respectively [7], and a rise-time of about 0.5 ns which is discussed below. The bulk exciton rise-time is determined by the system response, and its decay can be fitted to a biexponential with 74% decay at a rate of 2.27±0.26 ns^{-1} and 26% at 0.95±0.11 ns^{-1}. We assign the slower decay to excitons which are too far from the wire to transfer to it, and the faster decay to the effect of transfer of excitons to the wire.

This assignment is confirmed by analysis of the early part of the interface wire decay curve. We assume a delta function laser pulse, fast hot carrier relaxation, and rapid diffusion of the transferring excitons, and divide the excitons into two groups, those that transfer and those that do not. We use a simple three-level kinetic model with a single transfer rate w to describe the former group. The result for the intensity of the interface wire line is

$$I(t) \propto \exp(-ut) - \exp(-ut-wt)$$

where u is the radiative decay rate (assumed the same for all the excitons). We have neglected the small contribution of direct excitation into the confined region. I(t) is a maximum at time $t_m = w^{-1}\ln(1+w/u)$. The transferring excitons have a decay rate (u+w), while the non-transferring ones have a decay rate u, so both u and w can be obtained from the biexponential fit to the bulk exciton

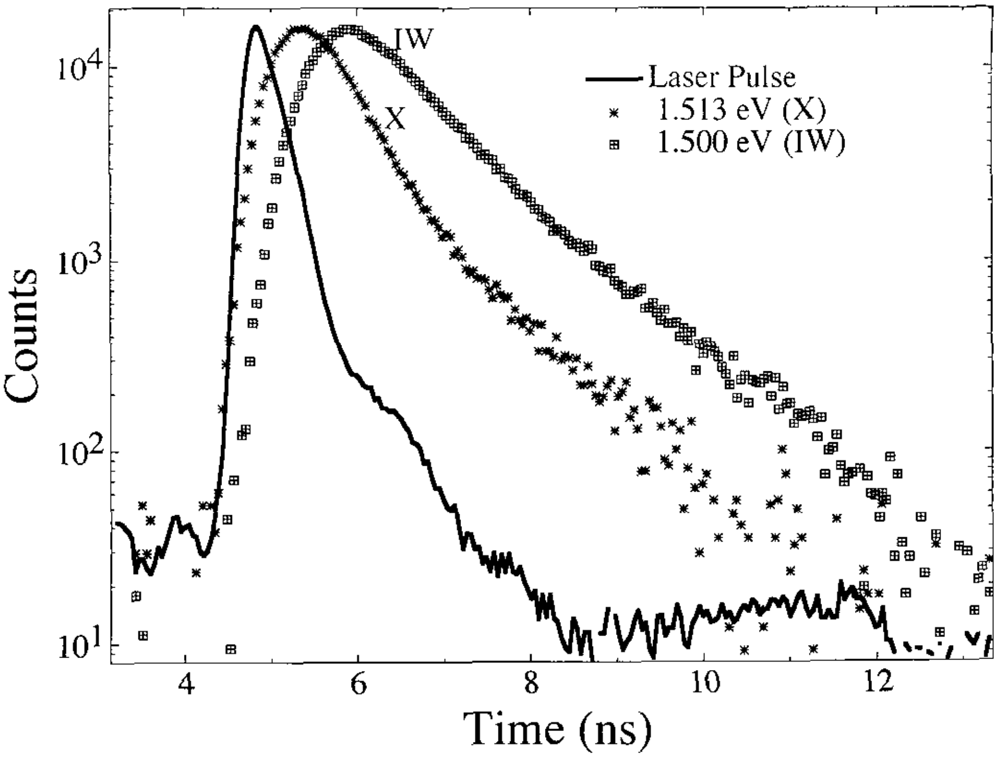

Fig.4 Transient PL from 200 nm wire in sample 2 at 4.3K. "IW": interface wire exciton , measured at 1.500 eV. "X" : bulk GaAs exciton, measured at 1.513 eV. "Laser pulse": system response.

decay. Taking the values $u = 0.95\ \mathrm{ns}^{-1}$, $w = 1.3\ \mathrm{ns}^{-1}$ from that fit, we find $t_m = 0.66$ ns. This value of t_m agrees well with the observed delay of 0.62 ns, considering the over-simplification of our model.

At higher excitation intensity the decay time gets slightly shorter, and the decay curve of the interface wire line, measured at the peak of the PL, flattens out at the top, as the lower confined exciton states are repopulated from the higher ones. The high energy side of the interface wire line shows a shorter decay time, confirming that the excitons in the wire are not in thermal equilibrium under these conditions.

4. Conclusion

We have observed a stressor-size-dependent redshift of strain-confined excitons in a strain patterned GaAs/AlGaAs heterostructure. We find efficient transfer of excitons from the bulk GaAs to the states confined by strain to the interface under the stressor. This type of structure opens new possibilities for the fabrication of high quality low dimensional systems, by eliminating the inverted interface of the quantum well.

Acknowledgments

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