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PROFESSOR DING

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UNIVERSITY OF ARKANSAS
120 OZARK HALL
FAYETTEVILLE AR 72701

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During the funding period, the group lead by Prof. Yujie J. Ding at Lehigh University (and formerly at U Ark) has investigated one class of the most important nonostructures; quantum-well dots.

This class of the nanostructures serves as the first steps for eventually developing THz emitters and detectors that can be operated at room temperatures.

For our effort on quantum-well dots, we have designed and grown InGaAs/GaAs quantum wells strained by InAs quantum dots. In order to compare the quantum-well dots with quantum dots, we have also grown InAs quantum dots on the top of GaAs layers. We have used photoluminescence spectrum as an effective technique to characterize these structures - We have found tat quantum-well dots have much narrower FL linewidths for all the pump intensities. Indeed, the linewidth for the quantum-well dots can be narrower by the amount as large as 25 meV. In addition, the intensity for the wavelength-integrated PL for the quantum-well dots is enhanced by a factor of about 2 or more.

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Final Report on

Optoelectronic Devices Based on Novel Semiconductor Structures
(Subcontract of F49620-01-1-0471)

Submitted to
University of Arkansas
Fayetteville, AR 72701

Program Manager: Dr. Gernot S. Pomrenke (AFOSR)
Project Period: March 1, 2002 – December 31, 2002

Principal Investigator:
Prof. Yujie J. Ding
Department of Electrical and Computer Engineering
Lehigh University
19 Memorial Drive West
Bethlehem, PA 18015
Email: yud2@lehigh.edu
Telephone: (610) 758-4582
Fax: (610) 758-6279

Project Summary

During the funding period, the group lead by Prof. Yujie J. Ding at Lehigh University has investigated one class of the most important nanostructures: quantum-well dots.

This class of the nanostructures serves as the first steps for eventually developing THz emitters and detectors that can be operated at room temperatures.

For our effort on quantum-well dots, we have designed and grown InGaAs/GaAs quantum wells strained by InAs quantum dots. In order to compare the quantum-well dots with quantum dots, we have also grown InAs quantum dots on the top of GaAs layers. We have used photoluminescence spectrum as an effective technique to characterize these structures. We have found that quantum-well dots have much narrower PL linewidths for all the pump intensities. Indeed, the linewidth for the quantum-well dots can be narrower by the amount as large as 25 meV. In addition, the intensity for the wavelength-integrated PL for the quantum-well dots is enhanced by a factor of about 2 or more.

Detailed Description of Our Results

Self-assembled quantum dots (QD's) originated from lattice mismatch are easily formed but suffering from severe size fluctuation. Recently, strain-induced quantum-well dots (QWD's) have been observed in InGaAs and InGaP quantum wells (QW's) by using InP QD's as a 2-D stressor [1-3]. Since the thickness of the QW's can be controlled within a subatomic layer, the size fluctuation of the strain-induced QWD's can be greatly reduced. Moreover, the interface and surface recombination rates can be significantly reduced. Since the QWD's are next to QW's, the carrier capture rate can be improved. In our present work, the photoluminescence (PL) of $In_{0.26}Ga_{0.74}As/GaAs$ QWD's by using InAs QD's as stressors is investigated and compared with that of InAs QD's without the QW layer. The comparison shows the PL peak of the $In_{0.26}Ga_{0.74}As/GaAs$ QWD's has a narrower linewidth and higher intensity than the self-assembled InAs QD's. Furthermore, the spatial homogeneities reflected by the PL peak wavelength and linewidth are also significantly improved for the $In_{0.26}Ga_{0.74}As/GaAs$ QWD's.

The QWD samples are grown on GaAs (001) substrates by Prof. Greg Salamo's group at University of Arkansas, in a Riber 32 MBE system at the temperature of 500°C and growth rates of 0.23, 0.28 and 0.1 ML/s for GaAs, InGaAs and InAs, respectively. The QWD structure consists of a 300 nm-thick GaAs buffer layer, 26 ML-thick $In_{0.26}Ga_{0.74}As$ well, 18 ML-thick GaAs barrier, 2.5 ML-thick InAs and a 20 nm-thick GaAs cap layer. Due to the large lattice mismatch between InAs and GaAs, the 2.5 ML-thick InAs layer actually breaks into self-assembled QD's with an average diameter and height of ~10 nm and ~5 nm, respectively. Each InAs QD applies a 2-D potential to the QW layer beneath it, see Fig. 1. Therefore, the strain-induced QWD's are formed. In order to compare the experimental results between QWD's and

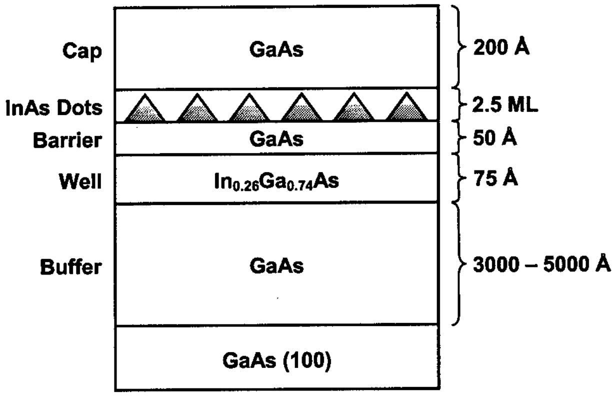

Fig. 1. Structure of quantum-well dots.

self-assembled QD's, two additional samples are grown, one of which only has the self-assemble InAs QD's and another one just has $In_{0.26}Ga_{0.74}As$/GaAs quantum well.

A Ti:sapphire laser with the wavelength of 800 nm is used in all the PL measurements as a pump source. Fig. 2 shows the typical PL spectra of QWD's and self-assembled QD's. One can

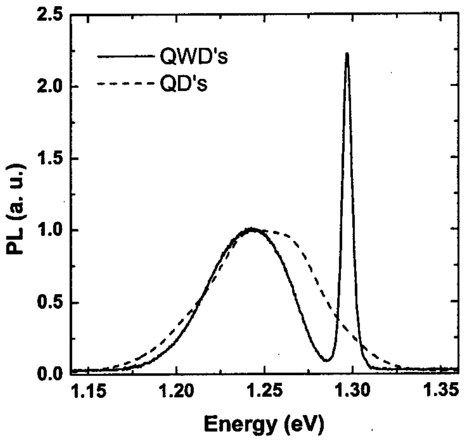

Fig. 2. PL sepctra of InAs QD's and $In_{0.26}Ga_{0.74}As$/GaAs QWD's are measured at 10 K with pump intensity of 435 W/cm^2. Two PL spectra are normalized in order to compare the linewidths.

see that the PL peak linewidth for QWD's is significantly narrower than that for the InAs QD's. Fig. 3 summarizes the PL peak linewidth as a function of the pump intensity for the QWD's and InAs QD's. One can see that the linewidth difference of 25 meV in Fig. 3 between the InAs

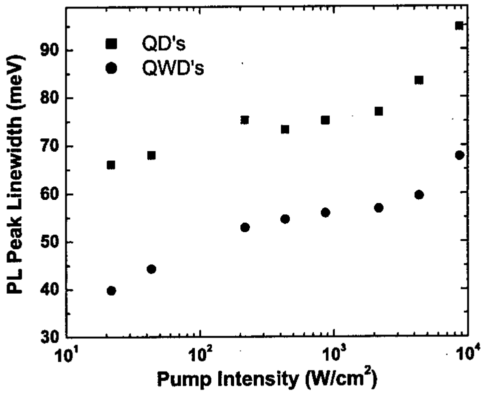

Fig. 3. PL peak linewidth as a function of pump intensity for InAs QD's and $In_{0.26}Ga_{0.74}As$/GaAs QWD's measured at 4.3 K.

QD's and QWD's is almost a constant in the entire pump intensity range. The measurements at different positions within the samples at a pump intensity of 4.35×10^3 W/cm^2 show that the average PL linewidth in the QWD sample is narrower than that for the InAs QD's by about 37 meV. This represents a significant amount of the difference, indeed. Furthermore, the PL peak wavelength and linewidth fluctuations from one position to next position within the lateral plane of the samples in the self-assembled InAs QD sample can be as high as 25 meV and 45 meV, respectively. On the other hand, in the QWD sample, the corresponding fluctuations are both significantly reduced to about 10 meV. This indicates that the QWD's are much more uniform within the lateral plane of the samples. In fact, since the height for each QD is much smaller than the diameter, the PL peak energy and linewidth are strongly dependent on the location within the sample. On the other hand, for the QWD's the QW width has the fluctuation of a subatomic-layer thickness. Therefore, the fluctuations for the PL peak energy and linewidth are greatly reduced for the QWD's.

Fig. 4 shows the comparison among the dependences of the wavelength-integrated PL intensities on the pump intensity for the self-assembled QD's and strain-induced QWD's. One can see that the PL intensity of the QWD's is also enhanced relative to the InAs QD's. For

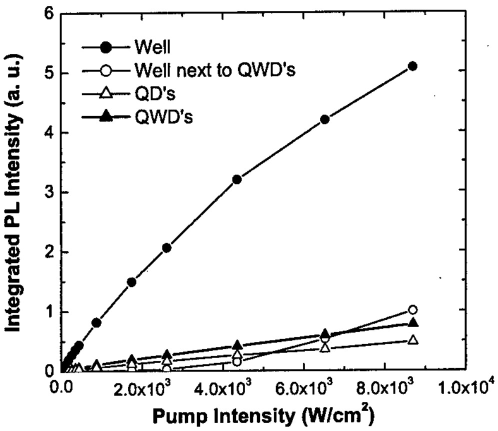

Fig. 4. Integrated PL intensity as a function of pump intensity measured at 4.3 K.

example, the integrated PL intensity measured in the QWD's at 4.35×10^3 W/cm^2 is 1.85 times higher than that for the InAs QD's. The PL enhancement in the QWD's can be partially attributed to the fact that the QW is more efficient to capture the photogenerated carriers than the QD's [4]. In fact, in the QWD structure, the carriers captured by the $In_{0.26}Ga_{0.74}As$/GaAs QW readily fall into the QWD's to enhance the PL intensity from the QWD's. As a result, the PL from the quantum well is reduced as shown in Fig. 4. In addition, the interface and surface recombination is also reduced in the QWD's.

During the funding period, we have submitted one paper to Appl. Phys. Lett. and will present one paper at CLEO'03.

1. H. Lipsanen, M. Sopanen, and J. Ahopelto, "Luminescence from excited states in strain-induced $In_xGa_{1-x}As$ quantum dots," Phys. Rev. **B51**, 13868-13871 (1995).
2. M. Sopanen, H. Lipsanen, and J. Ahopelto, "Strain-induced quantum dots by self-organized stressors," Appl. Phys. Lett. **66**, 2364-2366 (1995).
3. M. Sopanen, M. Taskinen, H. Lipsanen, and J. Ahopelto, "Red luminescence from strain-induced GaInP quantum dots," Appl. Phys. Lett. **69**, 3393-3395 (1996).

4. G. Walter, N. Holonyak, Jr., J. H. Ryou, and R. D. Dupuis "Room-temperature continuous photopumped laser operation of coupled InP quantum dot and InGaP quantum well in InP-InGaP-In(AlGa)P-InAlP heterostructures," Appl. Phys. Lett. **79**, 1956–1958 (2001).

DOD

FINANCIAL STATUS REPORT

(Short Form)

(Follow instructions on back)

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2. Federal Grant or Other Identifying Number Assigned By Federal Agency: F49620-01-1-0471

OMB Approval No. 0348-0039

Page 1 of 1 pages

3. Recipient Organization (Name and complete address, including ZIP code)

UNIVERSITY OF ARKANSAS
305 ADMINISTRATION BUILDING
FAYETTEVILLE, AR 72701

4. Employer Identification Number: 71-6003252

5. Recipient Account Number or Identifying Number: 0402-17023-21-0000

6. Final Report XXX Yes ___ No

7. Basis ___ Cash XX Accrual

8. Funding/Grant Period (See Instructions) From: (Month, Day, Year) 08/01/01 To: (Month, Day, Year) 12/31/02

9. Period Covered by this Report From: (Month, Day, Year) 08/01/01 To: (Month, Day, Year) 12/31/02

10. Transactions:	I Previously Reported	II This Period	III Cumulative
a. Total outlays	$0.00	$48,920.00	$48,920.00
b. Recipient share of outlays	0.00	0.00	0.00
c. Federal share of outlays	0.00	48,920.00	48,920.00
d. Total unliquidated obligations			0.00
e. Recipient share of unliquidated obligations			0.00
f. Federal share of unliquidated obligations			0.00
g. Total federal share (sum of lines c and f)			48,920.00
h. Total federal funds authorized for this funding period			48,920.00
i. Unobligated balance of federal funds (line h minus line g)			0.00

11. Indirect Expense

a. Type of Rate (Place and "X" in the appropriate box) __Provisional xx Predetermined __ Final __ Fixed

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40.2%	$33,357.00	$13,410.00	$0.00

12. Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.

13. Certification: I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purpose set forth in the award documents.

Typed or Printed Name and Title: Larrie Stolfi, Controller

Telephone (Area code, number and extension): 479-575-4853

Signature of Authorized Certifying Official: Larrie Stolfi

Date Report Submitted: 05/15/03