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Characterization of InAs/GaAs QD Structures by HREM and PL Spectroscopy

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High resolution electron microscopy (HREM) and photoluminescence (PL) spectroscopy were used to investigate InAs Quantum dots (QD's) grown on GaAs (100) substrates by molecular beam epitaxy (MBE) at 450°C. It was seen that the InAs dotted layers are associated with more contrast in the structures. This contrast was related to strain relaxation and island formation in the QD structures. PL measurements of these samples were also evaluated. It was seen that the InAs QD layers are optically active with a PL line between 50-83 meV located around a peak PL emission between 1.055-1.232 eV.

The growth techniques for strained-layer structures have been continuously improved. Consequently, low-dimensional semiconductors, e.g. superlattices, quantum wells and quantum dots, have been produced for high-speed electrical and optical devices. Quantum dots have attracted more attention because of their application in semiconductor technology. The structural, transport and optical properties of QD's have recently been the subject of many investigations [1-4]. Interfacial defects, the shapes of QD's and the growth conditions have been found to have a large effect on the device performance.

In order to investigate the effect of interface structure on the electrical and optical properties of self-assembled quantum dots, InAs dots were grown on GaAs (100) substrates by MBE at 450°C. Transmission electron microscopy (TEM) and PL have been used to characterize two InAs/GaAs QD samples in this study. Ten and twenty 1.8 monolayer-thick InAs layers were deposited on GaAs (samples NU1537 and NU1529, respectively).The InAs layers are separated from each other by 1.7 and 5.1 nm thick GaAs barriers in NU1537 and NU1529. The structure is completed with a 25 nm GaAs cap. Philips EM 430 and Hitachi HF 2000 electron microscopes were used to investigate the microstructures of NU1537 and NU1529. Cross-sectional TEM specimens from NU1529 and NU1537 were prepared mechanically followed by Ar ion thinning at 5 kV and 0.5 mA/gun at an angle of 10-20°. The PL measurements were performed at T=5 K. The optical excitation was provided by the 514.5 nm line of an Ar^+ laser. The luminescence was dispersed by a 3/4 m monochromator and detected by a cooled Ge diode.

[110] cross-sectional TEM dark-field and bright-field images of NU1537 are seen in Figure 1 (a-b).

Figure 1. Dark-field and bright-field images of cross-sectional NU1537, (a) the sample is edge on, showing 10 InAs dotted layers in **g**=400, (b) misfit dislocations in **g**=220.

Figure 1-a depicts 10 InAs layers clearly in **g** = 400. It was observed that the InAs layers associate with misfit dislocations due to the mismatch between the dot layer and

substrate (Figure 1-b, taken in **g**=220). More contrast around the dot layers was related to island formation in the structures. HREM image in Figure 2 shows the layers with contrast in the [110] zone axis. The sample NU1529 exhibited the dotted layers and island formation more clearly. Figure 3 shows a pair of dark-field and bright-field images of NU1529 taken in **g**=400. The 20 InAs dotted layers associating with contrast are seen in the micrographs. It was observed that there is not any dislocations at the interfaces of NU1529. The islands and 1.8 monolayer-thick InAs layers are obviously seen in HREM images in Figure 4.

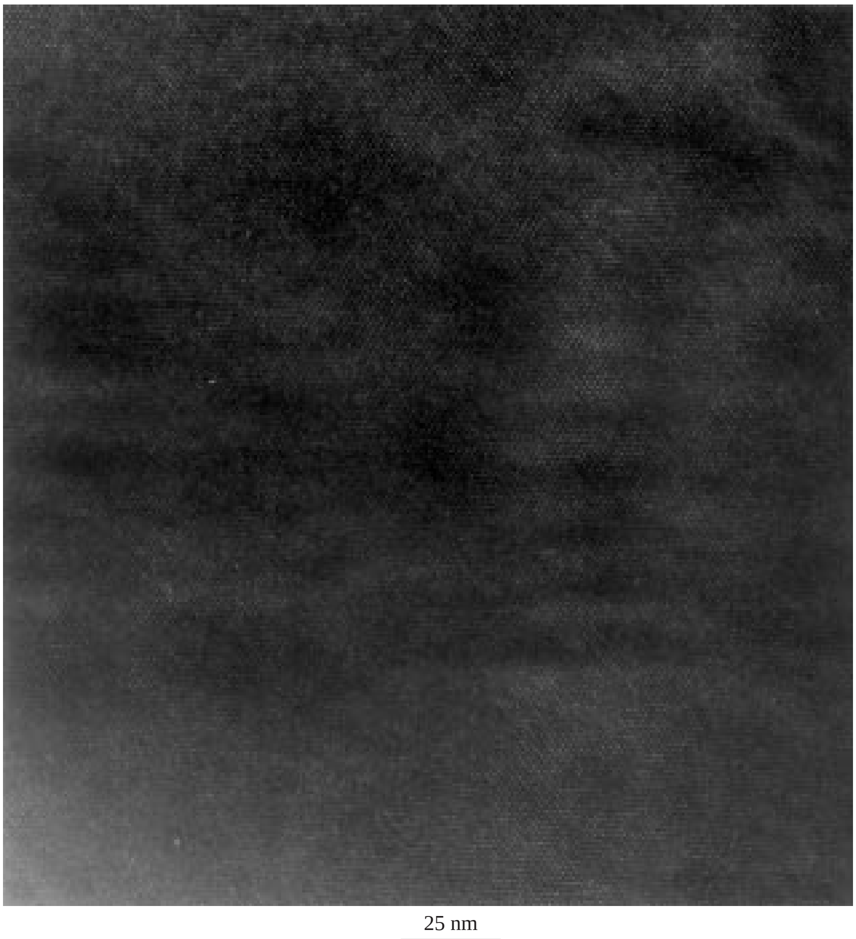


Figure 2. HREM image of NU1537 demonstrating the InAs layers with contrast in the [110] zone axis.

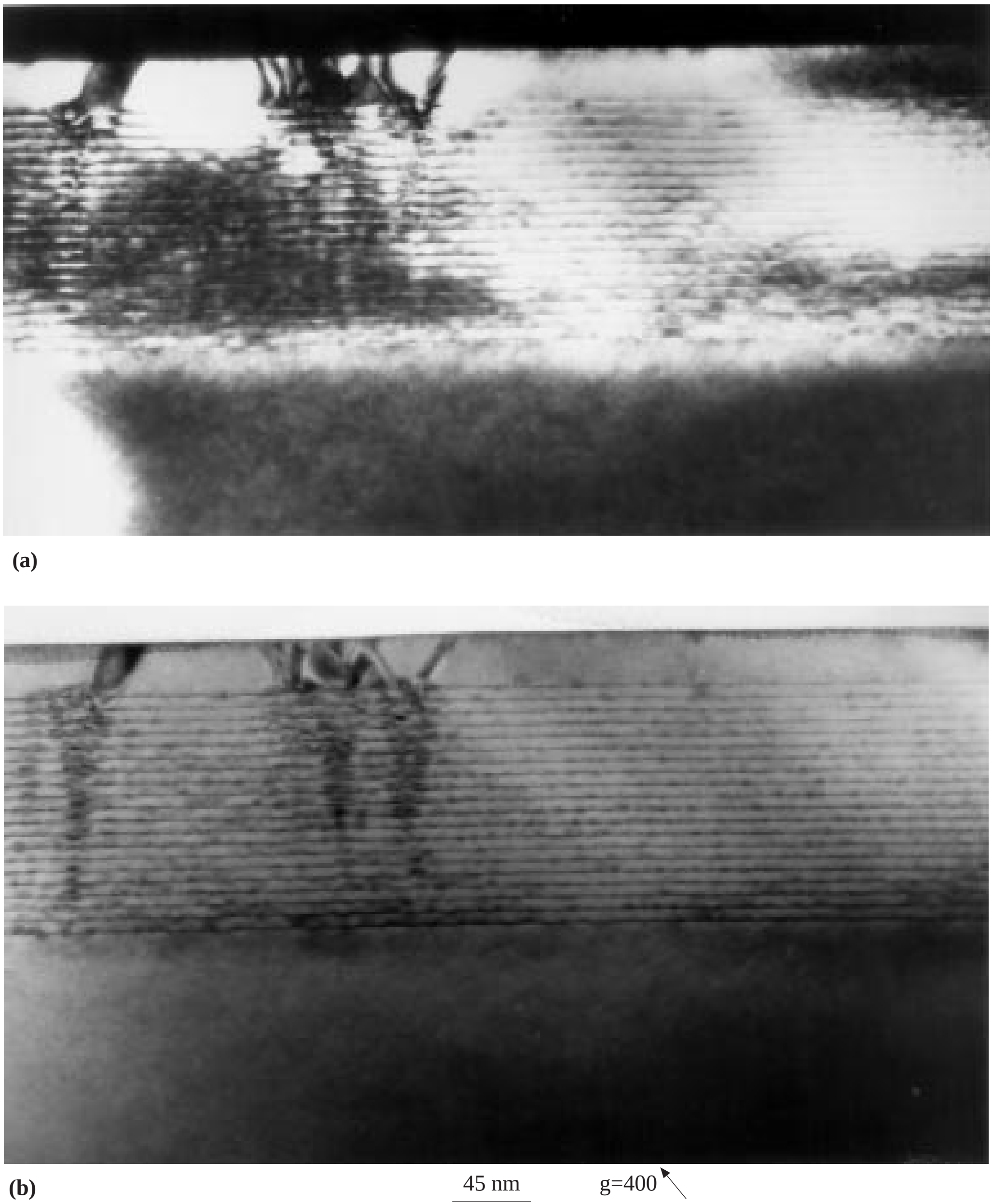


Figure 3. Dark-field and bright-field images of cross-sectional NU1529, showing 20 InAs dotted layers and island formation.

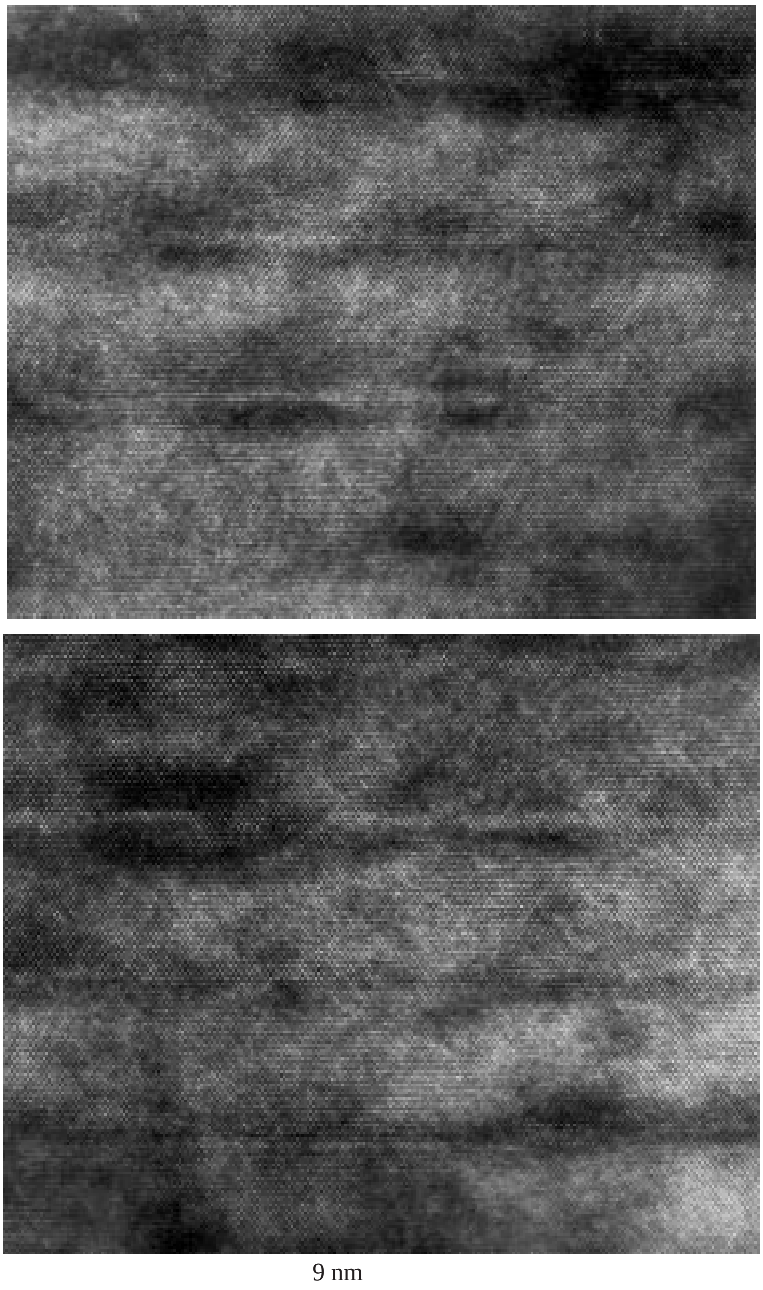
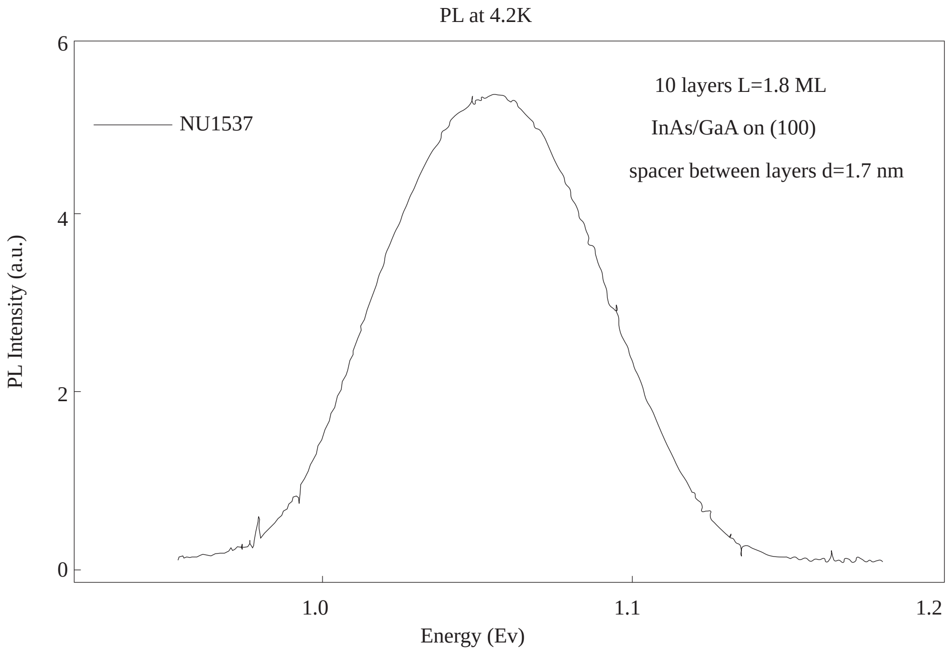
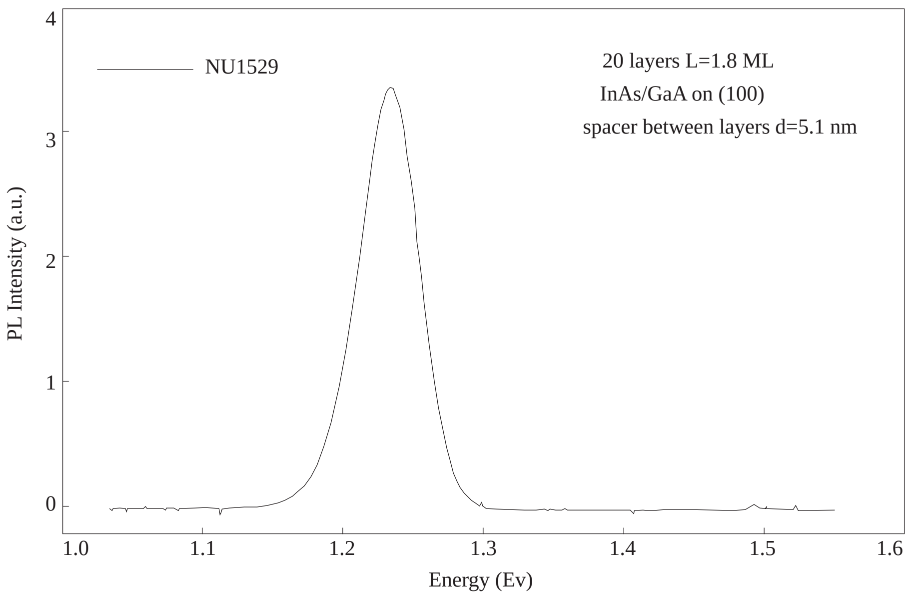


Figure 4. HREM images of NU1529 taken along the [110] zone axis. The islands and InAs layers are obviously seen in the images.



(a)



(b)

Figure 5. PL spectra of NU1537 and NU1529 QD superlattices.

It was discovered that the InAs QD layers of NU1529 and NU1537 are optically active with a PL line of 50 and 83 meV located around a peak PL emission of 1.232 and 1.055 eV, respectively. The thickness, size and shape of islands structural defects are effective on the PL measurements[1,4]. The low-temperature PL spectra of two QD superlattices are seen in Figure 5. The PL data of sample NU1537 show that the dots appear electronically coupled to each other as witnessed by the large red-shift of the energy emission. The small separation between the dots in different layers leads to a morphological and electronic coupling along the growth direction. In turn, this gives rise to the formation of mini-bands similarly to what happens in quantum well (QW) superlattices. The PL spectrum of sample NU1529 shows a low degree of coupling between dots grown in different layers. In fact, the PL peak position and linewidth are very similar to those of a sample in which the separation between dots is as large as 30 nm. The optical data are confirmed by the TEM analysis where the dots belonging to different layers appeared vertically uncoupled from each other. In this study, QD size variations did not give rise to a structure in the PL spectra due to a smooth interface structure.

As conclusions, a regular dot layer structure was observed in the QD superlattices by TEM. It was seen that the strain relaxation in one of the QD superlattices occurred by the misfit dislocations. More contrast around the InAs dotted layers was detected and related to island formation in the structures. PL measurements showed that the InAs QD layers are optically active with a PL line between 50-83 meV located around a peak PL emission between 1.055-1.232 eV.

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References

[1] Grundmann M. Heitz R. Ledentsov N. Stier O. Bimberg D. Ustinov V.M. Kop'ev P. S. Alferov Zh. I. Ruvimov S. S. Werner P. Gösele U. and Heydenreich J. Superlattices and Microstructures, Vol. 19 No. 2 (1996) 82-95.

[2] Hawrylak P. and Wojs A. Semicond. Sci. Technol. 11 (1996) 1516-1520.

[3] Lee H. J. Ryu H. and Nahm S. Journal of Crystal Growth, 182 (1997) 292-298.

[4] Atici Y. Hovsepian A. Cherns D. Polimeni A. Henini M. and Eaves L. 14th International Congress on Electron Microscopy ICEM-14, August 31- September 4 (1998) Cancun, Mexico.