Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 6–7

Invited

Self Assembled Quantum Dots and Device Prospects

P.M.Petroff, W.Schoenfeld, T.Lundstrom and N.Horiguchi
Materials Department, University of California, Santa Barbara.CA.93106

Self assembled quantum dots have been a topic of intense research for the last 5 years and much progress has been made in understanding their electronic properties and controlling their growth properties using either MOCVD or MBE deposition techniques. Because of their 3D carrier and exciton confinement properties, they provide a useful means of understanding the physics of many body interactions and possibly will lead to some new and unforeseen physical properties which may be useful for device applications. In addition, the recently demonstrated possibility of tuning the QDs electronic levels make them more useful for device applications.

However, the device engineer will have to deal with two important characteristics of the self assembled QDs: a) the unavoidable size distribution associated with the statistical nature of epitaxy and b) the positioning and control over the QDs density and size which are important when interactions between QDs are coming into play.

Since the QDs are obtained by deposition of a coherently strained epitaxial layer, their shape and dimensions indeed depend on the changes in the total energy (strain energy plus surface energy) of the thin film which will be minimized both during the formation of islands but also during the deposition of the wider band gap capping layer which because of strain also changes radically the shape of the QDs while it is being capped (See Figure 1).

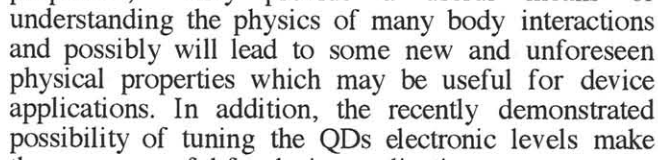

Fig. 1:Schematic of the formation of a quantum dot by epitaxial deposition of a coherently strained layer .A) Coherently strained layer. B) Island formation. C) Partial coverage of the island with partial dissolution of island through strained driven diffusion (arrows). D) Completely covered island with an interdiffused shell

This process has been described and recently used to tune the electronic states of a quantum dot (1).

Size uniformity has been much more difficult to achieve and to measure but theory and experiments suggest that size uniformity could be improved through deposition of ordered QDs lattices.

A number of device applications have recently been actively investigated. The QDs lasers which were fabricated using closely stacked layers of InGaAs QDs or InAlAs QDs show promising characteristics (2, 3). However we note that in most cases the QDs are connected through a thick wetting layer (1-2nm thick).

This makes these QDs lasers more like quantum well lasers with heavily corrugated interfaces. To establish the superior performances of the QD laser one should compare it to an equivalent device in which the active region comprises an equal number of wetting layer quantum wells.

Other devices which make use of the size distribution of the QDs structures are large density memory in which each memory element is a QD of the array. Several schemes have been proposed (4, 5) in which the information is written optically in the QD and it is read through a change in the conductivity of a 2 dimensional electron gas located close to the layer of QDs. This approach appears very promising. Reading this type of memory requires a voltage bias which may destroy a part of the stored information.

One suggested approach (6) was to use the inhomogeneously broadened ensemble of QDs to work in the optical wavelength domain for writing and reading the QDs array. The devices could then be read using a photocurrent bleaching technique (7) .

In this presentation, we discuss a different approach for a QDs memory device in which the information is stored optically in a QD pair. The electron and hole pairs generated optically are localized in the QD and its associated stress induced QD (SIQD) in an adjacent quantum well (QW) by transfer through the X valley in the AlAs (See Fig.1).

The charge separation is detected by looking at the Photoluminescence (PL) from an ensemble of InAs QDs and their associated SIQDs. As seen in Fig. 3, the SIQDs luminescence at 700nm is shifting to lower wavelength with increasing pump power. The reasons for this shift are associated with the size distribution of the SIQDs and the formation of a dipole layer (Fig. 2) due to the charge separation.

We will present PL data from an identical structure which has been included into a MISFET device. The proposed electron-hole separation into adjacent QDs pairs is consistent with the PL output of this device under bias. We will present additional data based on photocapacitance measurements which support the electron hole pair separation.

We will present also temperature dependent PL data that show the e-h pair localization at temperatures up to 100K.

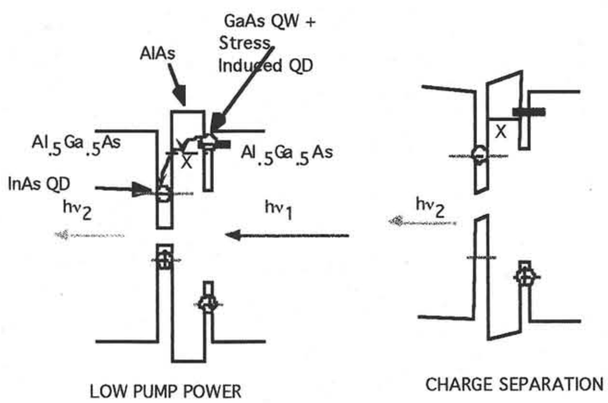

Fig. 2: Band diagram schematic showing the charge separation in a QD and its associated stress induced QD. The electron and hole generated by pumping selectively ($h\nu_1$) the stress induced QDs are redistributed as shown . The read cycle requires a voltage pulse that will transfer the holes from the SIQD to the corresponding QD. The photon generated ($h\nu_2$) is then detected.

Another type of QDs based device which appears promising is the quantum dot infrared photodetector (8).These devices are very similar in their principle to the quantum well infrared photodetector (QWIP). However the QDIP should display an improved signal to noise ratio over the QWIP because of the reduced carrier interactions with phonons in the QDs.

We will present our results on a QDIP device (9) which show polarization dependent photoconductivity with a good signal to noise ratio. Several photoconductivity peaks with polarization dependent amplitude are observed in the 5-12 microns range.

The transitions responsible are attributed to in plane and normal excitation modes of the electrons confined in the QDs. We are proposing and discussing an upconversion infrared device based on coupled QDs

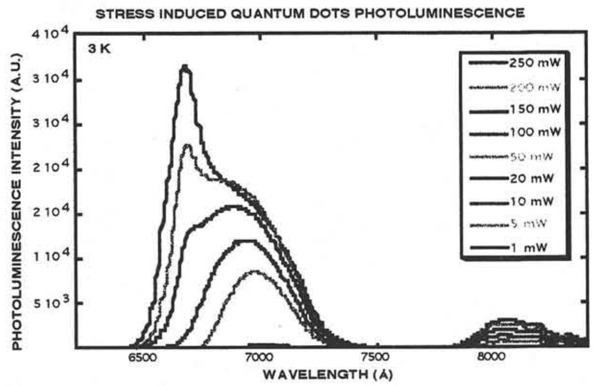

Fig. 3: Photoluminescence spectra of an ensemble of SIQDs as a function of optical pumping power. The broad line associated with the SIQDs is seen at low pump power at ≈ 700nm.

Acknowledgments: The authors wish to thank QUEST an NSF-STC center and DARPA for their financial help with this work

References:

1)J.Garcia ,T.Mankad, P.O.Holtz, P.Wellman, and P.M.Petroff Appl. Phys. Lett. 72, 24, 3172 , (1998).
2)F.Hatami, N.N.Ledentsov, M.Grundmann, J.Bohrer, F.Heinrichsdorff, M.Beer, and D.Bimberg, S.S.Ruvimov, P.Werner, U.Gosele, J.Heidenreich, S.V.Ivanov, B.Ya.Meltser, P.S.Kopev and Zh.I.Alferov . Appl. Phys. Lett. 67, 656, (1995).
3)S.Fafard, K.Hinzer, S.Raymond, J.M.Gaffrey, S.Charbonneau, Science 274, 1350 (1996).
4)G.Yusa and H.Sakaki. Appl. Phys. Lett. 70, 345 (1997)
5)J.J.Finley, M Skalitzm M.Arzberger ,A.Zrenner, G.Bohm and G.Abstreiter, Appl. Phys. Lett (submitted (1998).
6)S.Muto. Jap. J.Appl. Phys. 34, L210 (1995)
7) S.Imamura, S.Sugiyama, Y.Nakata, S.Muto and N.Yokoyama. Jpn.J.Appl. Phys. 34, L1445 (1995).
8)S.Sauvage, B.Boucaud, F.H Julien, J.M.Gerard, V.Thierry-Mieg. Appl. Phys. Lett. 71, 2785 (1997)
9)S.Maimon, E,Finkman, G.Bahir, E.Schalam, J.Garcia and P.M.Petroff Appl.Phys Lett. (in press 1998).