Studying the optical properties of self-assembled quantum dots

An application using Oxford Instruments Superconductivity's MicrostatHiRes, high resolution microstat cryostat

Han Htoon, Dmitri Kulik, Hongbin Yu and CK Shih at the University of Texas at Austin have developed a spectroscopic imaging technique capable not only of isolating the spectral features of a single Quantum Dot (QD) but also of locating the exact position of a QD under a micron scale aperture. Their simple and effective technique has now been used to explore both temperature induced carrier transfer and the formation and disintegration of multiple particle states in self assembled quantum dots.

Semiconductor quantum dots (QDs) are tiny crystals that confine electrons and holes in all three dimensions, quantising the energy levels of the electrons and holes. When these confined electron and holes recombine, QDs emit sharp atomic like spectra. This unique property is not only scientifically interesting but also very important for many technological applications such as semiconductor lasers and solid state quantum computers.

Among the different types of QDs, self-assembled quantum dots grown by molecular beam epitaxy are most promising for technological applications. A tremendous amount of research effort is, therefore, being devoted to studying the optical properties of self assembled quantum dots.

For spectroscopic studies of QDs, the most challenging task is to limit the number of QDs in the probing volume and isolate emission lines of a single QD from the ensemble. When the density of QDs is sufficiently low, a metal mask with micron scale apertures can reduce the number of QDs in the probing region. However, for a high density QD ensemble, even a 1 µm aperture can only reduce the number of probed QDs to approximately a hundred. The resultant spectra collected through the aperture still consist of a group of atomically sharp spectral lines, and further isolation of the spectral features of a single QD from that jungle of peaks is essential.

The imaging scheme developed in Texas exploits the fact that the position of the diffraction limited image of a point light source can be determined on a nanometer scale far below the diffraction limit. It uses a conventional low temperature micro photoluminescence (MicroPL) imaging system together with an Oxford Instruments Superconductivity MicrostatHe or MicrostatHiRes microscope cryostat (Figure 1).

The MicrostatHiRes has a high mechanical stability and the temperature at the sample can be changed from 4 to 50 K without needing to realign the optics. A Ti:Sapphire

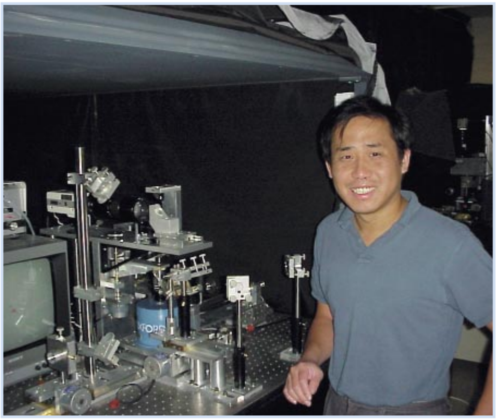

Figure 1: Han Htoon with the micro PL system including a MicrostatHiRes

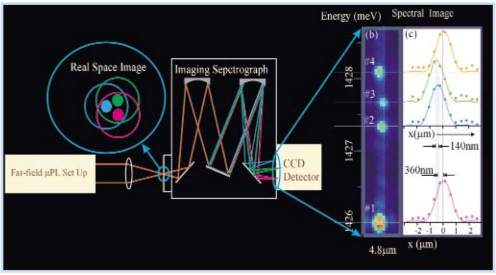

Figure 2: Isolation of the spectral features of a single QD using spectroscopic imagingtechnique. Spectral images collected using a MicrostatHe at a temperature of 4.3 K.

Contact:

Han Htoon, Department of Physics, University of Texas, Austin, TX 78712, USA

laser beam is projected onto the sample surface at an angle of incidence of 30°. The images of QDs, collected through a 2 µm aperture, will overlap each other in real space. However, since each QD usually emits at different wavelengths, their PL peak images can be dispersed along the axis perpendicular to the spectral axis (without distorting their spatial positions) by using an imaging spectrograph. A liquid nitrogen cooled CCD detector mounted at the exit plane of the spectrograph can collect spectral images containing both spatial and spectral information. Spatial misalignment of the PL peaks in the magnified spectral image shown in Figure 2(b) (peaks #1-#4) clearly demonstrate this. The exact spatial origin of these peaks can be determined by fitting their intensity distribution along the lines parallel to the x-axis with a point-spread function, as shown in Figure 2(c). In this way, the position of the spectrally isolated PL peak is determined very effectively, with a precision of ±0.1 pixel (±40nm).

Further two-dimensional (2D) mapping of QDs is achieved by scanning the real space image of the aperture across the slit of the imaging spectrograph in 200 nm steps and recording a spectral image (like that in Figure 2) at each scanned position. The 2D map is then reconstructed from these spectra. Fitting the intensity in both the x and y directions positions the centres of the QDs within the aperture. In Figure 3, for example, the centers and sizes of the ellipses in the yellow circle correspond respectively to the positions of the QDs and the uncertainties in position resulting from the fitting process.

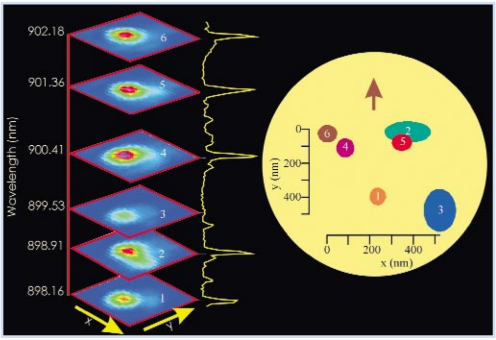

Figure 3: Two-dimensional mapping of QDs under a 2 µm aperture using a MicrostatHe at a temperature of 4.3 K. The 2D map was constructed from 20 spectral images similar to Figure 2(b). The 2D map took a total of around 15 minutes to collect.

Oxford Instruments Superconductivity

UK
Tubney Woods, Abingdon
Oxfordshire OX13 5QX
Tel: +44 (0)1865 393 311
Fax: +44 (0)1865 393 333

Germany
Otto-von Guericke Ring 10
D-65205 Wiesbaden
Tel: +49 6122 937 171
Fax: +49 6122 937 175

Italy
Via Leone Tolstoi 86
20098 San Giuliano
Milanese
Milan
Tel: +39 02 98 2531
Fax: +39 02 98 24407

Japan
Haseman Building
2-11-6 Tomioka, Koto-ku
Tokyo 135-0047
Tel: +81 03 5245 3261
Fax: +81 03 5245 4472

Spain
Avda Mata Piñonera, 2
28700 San Sebastian de los Reyes
Madrid
Tel: +34 91 659 0740
Fax: +34 91 654 6794

U.S.A.
130A Baker Ave. Ext.
Concord, MA 01742-2121
Tel: +1 978 369 9933
Fax: +1 978 369 6616

E-mail:
superconductivity@oxinst.co.uk

Visit our web site at
www.oxford-instruments.com

Reference No: OI 600/0502

UK sites of Oxford Instruments Superconductivity Limited, operate a Quality Management System approved to the requirements of BS EN ISO 9001.

Certificate No Q4118