

# attoCFM I: Spectroscopy on Quantum Dots

Confocal microscopes enable fluorescence measurements of thin sections in thick samples. In conventional fluorescence microscopy, out-of-focus fluorescence tends to overwhelm details in the actual image plane. In confocal microscopy, a tiny light spot is focused and scanned in a defined image plane of the sample to excite fluorescence. The use of a blocking pinhole in the conjugate plane eliminates the degrading out-of-focus information.

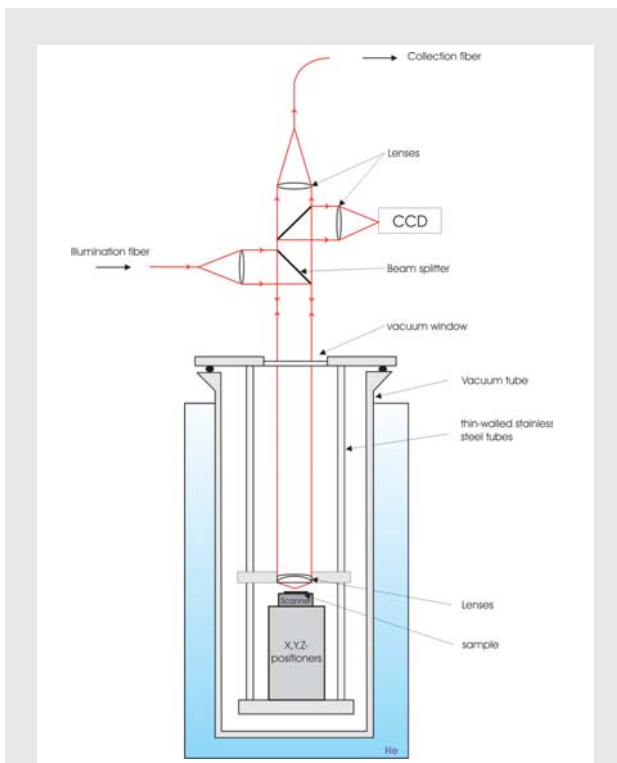
The application shown here is high resolution spectroscopy on a single quantum dot at 4 K in high magnetic fields. The precise measurements of a single quantum ring reported in *Nature* prove that quantum rings indeed behave as artificial atoms (*Nature* 405, 926 2000). The measurements of single quantum rings provide the definite proof of the „atom like“ behavior of the quantum structures. In addition, the *Nature* paper reports detection of the emission energy of excitons to which various numbers of electrons have been added. These emission energies appear to be quantized.

Khaled Karrai of the Center for NanoScience at Ludwig-Maximilians University, Munich, and Richard J. Warburton of Heriot-Watt University, Edinburgh, show that semiconductor quantum dots act like artificial atoms because they display sharp, discrete spectral lines when the confined electrons and holes that are analogous to the quantum energy levels of atoms recombine. The team examined the behavior of dots with singly, doubly or triply charged excitons and discovered that they conformed to that of artificial hydrogen, helium and lithium atoms. Further work examines the polarization of the photons which may be used to control the spin of the electrons in the dots, enabling applications in spintronics.

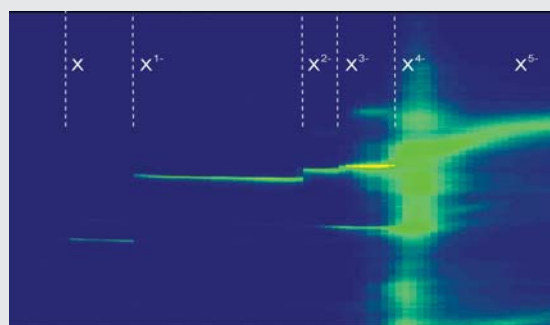
The collaboration of scientists use one prototype of the attoCFMI microscope, that operates at temperatures between 1.6 and 300 K and is machined entirely from titanium to resist magnetically induced perturbations. Karrai noted that the instrument is so stable that it enables the investigation of a single quantum dot for months at a time without drifting out of focus.

**Related article:**

“Optical emission from a charge-tunable quantum ring” by R. J. Warburton, C. Schäflein, D. Haft, F. Bickel, A. Lorke, K. Karrai, J.M. Garcia, W. Schoenfeld, *Nature* 405, 926 (2000).



**Fig. 1:** A laser beam is coupled into an illumination fiber and focused on the sample. The reflected light from the sample is then collected by the collection fiber, which is also the blocking pinhole aperture for the confocal setup. The signal detection is then achieved by a photon counting system or CCD-camera.



**Fig. 2:** A color-scale plot of the photoluminescence (PL) versus gate voltage showing the discrete spectral lines of a quantum dot.

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