High Resolution and High Collection Efficiency of Single Quantum Dots.

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We apply the subsurface Numerical Aperture Increasing Lens (NAIL) technique to microscopy and spectroscopy of single InGaAs quantum dots (QDs) grown by Stranski-Krastanow self-assembly on GaAs substrates [1]. In self-assembled QD samples, a typically >100nm capping layer of the substrate material is grown over the QDs to protect them from any potential environment induced damage. Optically, the capping layer introduces a planar boundary between the object space and the far-field microscope. The dielectric interface acts as a barrier limiting both the resolving and light gathering power of the microscope. Incorporation of the index matched plano-convex NAIL mitigates the difficulties introduced by the planar boundary improving both the resolution and collection efficiency of our optical microscopy system. In contrast to conventional Solid Immersion Lens (SIL) techniques, the NAIL configuration (with the plano-convex lens attached to the substrate side of the sample) moves the interface between sample and SIL away from the focal plane of the confocal microscope thus minimizing interface imperfections on image quality.

Treating the QD as an ideal point source and applying the Houston Criterion, we are able to measure an optical resolution for our NAIL-assisted confocal microscope of 350 nm with an emission wavelength of 960nm. The ~λ/3 resolution of our system allows us to perform both PL and PLE measurements on single QDs. Potentially, more exciting than the enhanced optical resolution, is the improvement in our ability to collect QD light emission afforded by a NAIL. With our 1.61mm radius GaAs NAIL, we have measured a 6-fold increase in the collection efficiency of our system. We are now trying to take advantage of the collection efficiency increase in applications where high signal-to-noise ratio is beneficial. Specifically, we are building a Hanbury-Brown Twiss (HBT) photon counting apparatus to do both auto-correlation and cross-correlation measurements on lines in the QD spectra.

[1] Z. Liu, B. B. Goldberg, S. B. Ippolito, A. N. Vamivakas, M. S. Ünlü, and R. Mirin, "*High resolution, high collection efficiency in numerical aperture increasing lens microscopy of individual quantum dots*," Appl Phys Lett, *accepted for publication*