

Reengineering quantum dot optics with nanomechanical strain

Developing and exploiting precision metrology for quantum and nanotechnology requires nanoscale modeling of ultrasmall devices, their dynamical operation, and their response to probes. Atomic-scale simulations of the electronic and optical properties of complex nanosystems are being carried out. These systems include nanocrystals, self-assembled dots, nanodot arrays and solids, and nanohybrids. Nanoscale simulations of optical fields near nanosystems are being used to design nanoprobes and nanocavities for precision nano-optics metrology and to model the transport of excitations in quantum devices.

The work is providing the foundation needed to engineer nanolasers, detectors, biomarkers and sensors, and quantum devices. Dynamical control of excitons in quantum dots (QDs) is highly desirable for such applications with QDs as active optical sources and detectors. Applied strain provides a new paradigm for controlling QD optics and for acting as a transducer to couple dot response to mechanical motion and pressure. Applications include QDs as sources in nanolasers; as sources in optomechanical cavities used, for example, for wavelength routing; pressure and motion sensing for ultrasensitive mass detection, electronic skin, mechanical memory and computing; nanomechanical energy harvesting; and as transducers for cooling nanomechanical structures to the quantum limit. We have developed atomistic models to describe these highly strained structures and carried out simulations for 10 million atom structures.

The applied strain makes dramatic changes in the exchange splitting between exciton bright states that modify the exciton fine structure induced by QD asymmetry and atomistic effects, induce crossing between bright states, and rotate the polarized response of bright states through large angles, as shown in the figure. Such control can be exploited in applications of QDs as entangled photon sources, where the elimination of asymmetric exchange splitting is essential, or cavity-coupled QDs, where tuning the exchange-induced dark and bright states is needed. Manipulation of exciton energies and polarizations via the strain provides a signature for sensing motion or applied pressure.

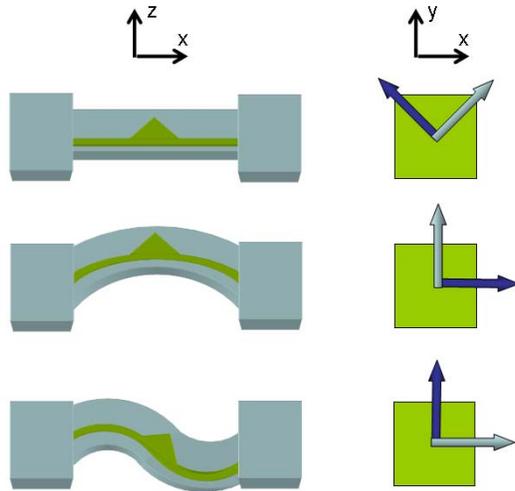


Figure 2.3: Pyramidal InAs quantum dots in a flat nanomechanical beam, a beam providing biaxial deformation and a beam under shear. The rotation of the polarization of the ground exciton (purple) and exchange-split exciton induced by the indicated mechanical strain is demonstrated.

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