Our research is in the broad field of light-matter interaction, with an emphasis in optical and electronic properties of materials and quantum optical measurements. The primary thrusts of our research are the collective phenomena of electron and exciton fluids in mesoscopic systems, as well as optical control of electron and nuclear spins in semiconductors at the nanoscale. This has been stimulated by my previous research experience in the field of light-matter interaction in condensed matter, particularly the many-body effects and optical orientation in semiconductors.

In particular, we are interested in (i) understanding the many-body interactions and quantum collective phenomena and (ii) developing optical manipulation and coherent control of electron and nuclear spins effects in low-dimensional nanostructures such as quantum wells, wires and dots. These mesoscopic material systems whose sizes, on the order of nanometers, are intermediate between those of atoms and bulk solids. The quantum size effects dramatically reshape the many-body interactions; therefore, these systems are ideal test beds for understanding both (a) quantum collective phenomena (eg. quantum Hall effects and Bose-Einstein condensation) and (b) isolated quanta with long coherence time (eg. electron and nuclear spins in quantum dots).

Research in the area of excitonic condensates focuses on the transient properties of coherence, spin, and spatial transport of non-equilibrium excitonic states. In the search for condensates of excitons and their kindred quasiparticles, we have observed ordered states or properties analogous to those in Bose-Einstein condensates and superfluids in two candidates: (a) spatially indirect excitons in coupled quantum wells, and (b) exciton-polaritons in planar microcavity structures. We are continuing to study exciton condensation and coherent optical processes in these two systems as well as their hybrids and variants. The core thrust is to merge quantum optical measurements and ultrafast spectroscopy techniques for studies of exciton fluids in quantum confined structures. We have also been integrating metal electrodes and superconducting niobium thin films with semiconductor quantum well structures to generate structured electric and magnetic fields in order to control the exciton interactions and transport.

Other research themes include (1) coherent manipulation of spin states in single and coupled ions/impurities in solids, and (2) transient non-equilibrium behaviors of light-matter hybrid quasiparticles in low-dimensional systems as described below.

Solid-state Spins for Potential Quantum Computation Applications

Coherent manipulation of electronic and nuclear magnetic moments associated with their spins is an immense field enabled by technologies to engineer electromagnetic radiation in the radiofrequency, microwave, and optical laser regimes with precise coherence properties and timing. My interest in this area lies in using optically detected magnetic resonance and ultrafast spectroscopies for studies of single and coupled ions/impurities in solid-state matrices.

Out-of-equilibrium Many-body Interactions in 2D Excitonic Condensates and Lattices

The complex interplay among electrons, holes, and photons as well as the non-equilibrium nature of energy transport and polarization relaxation in solids are of critical importance for research in excitonic condensation in low-dimensional semiconductors. Out quest for exciton condensation has stimulated me to further examine laser theory, phase transitions in low-dimensional systems, as well as correlations, excitations, and fluctuations in quantum liquids. Ongoing research activities include investigations of new low-dimensional exciton systems and comparison with out-of-equilibrium theoretical treatments.