Quantum Oscillations of Excitonic Schrodinger's Cats as Qubits Using Quantum Dot Based Resonant Tunneling Diodes

Shouvik Datta[1], S. V. U. Vedhanth[1], Amit Bhunia[1], Mohit Kumar Singh[1], Maryam Al Huwayz[2], Mohamed Henini[2]
[1] IISER-Pune, [2] University of Nottingham

Introduction: Experimental detection and control of macroscopically large, quantum coherent states within semiconductor heterostructures can open up new paradigms in quantum optoelectronics including quantum computation. We studied excitons or electron-hole pairs as the chosen platform [1,2]. This is because Bose-Einstein condensation (BEC) of excitons can provide access to a large number of identical, two-level quantum states as excitonic qubits.

Methods: A molecular beam epitaxy grown double-barrier, resonant tunneling diode of a p-GaAs/AlAs/InAs/AlAs/n-GaAs heterostructure with InAs quantum dots was studied. Photocapacitance was measured to probe the observed oscillations of collective electrical polarization of these dipolar excitons over a macroscopically large area as a function of both applied biases and photo excitation intensities within 10-100 K.

Results: Coherent resonant tunneling in this quantum coupled 0D-2D heterostructure directly indicated the presence of excitonic BEC. We further reported density driven onset of long-range order below a threshold temperature, Rabi oscillations and execution of Hadamard gates to substantiate these claims.

Conclusions: Observation of photocapacitance oscillations were attributed to 'itinerant' undulations of macroscopically large, Schrodinger's cat like, two-component, quantum ground state of a BEC consisting of millions or more "identical" excitons interacting through coherent resonant tunneling. Therefore, instead of trying to entangle quantum states of few "individual" qubits in the usual brick-by-brick fashion, here we proposed an alternative top-down approach for building large, N-qubit quantum registers. Operational temperatures can be increased with more densely packed, ordered arrays of quantum dots and/or with single crystals of 0D-2D heterostructures of nitrides, oxides etc. having higher excitonic binding energies.