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

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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.

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.

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.

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.

References

[1] Amit Bhunia, Mohit Kumar Singh, Maryam Al Huwayz, Mohamed Henini, and Shouvik Datta, '0D-2D Heterostructure for making very Large Quantum Registers using 'itinerant' Bose-Einstein Condensate of Excitons'. Materials Today Electronics, 4, 100039 (2023).

[2] A lucid summary of this study can be found in Phys.Org at https://phys.org/news/2023-07-tailoring-quantum-oscillations-bose-einstein-condensate.html.