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Tailoring Quantum Oscillations of Excitonic Schrodinger's Cats as Qubits

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Abstract : We report [https://arxiv.org/abs/2107.13518] experimental detection and control of Schrodinger's Cat like macroscopically large, quantum coherent state of a two-component Bose-Einstein condensate of spatially indirect electron-hole pairs or excitons using a resonant tunneling diode of III-V Semiconductors. This provides access to millions of excitons as qubits to allow efficient, fault-tolerant quantum computation. In this work, we measure phase-coherent periodic oscillations in photo-generated capacitance as a function of an applied voltage bias and light intensity over a macroscopically large area. Periodic presence and absence of splitting of excitonic peaks in the optical spectra measured by photocapacitance point towards tunneling induced variations in capacitive coupling between the quantum well and quantum dots. Observation of negative 'quantum capacitance' due to a screening of charge carriers by the quantum well indicates Coulomb correlations of interacting excitons in the plane of the sample. We also establish that coherent resonant tunneling in this well-dot heterostructure restricts the available momentum space of the charge carriers within this quantum well. Consequently, the electric polarization vector of the associated indirect excitons collective orients along the direction of applied bias and these excitons undergo Bose-Einstein condensation below ~100 K. Generation of interference beats in photocapacitance oscillation even with incoherent white light further confirm the presence of stable, long-range spatial correlation among these indirect excitons. We finally demonstrate collective Rabi oscillations of these macroscopically large, 'multipartite', two-level, coupled and uncoupled quantum states of excitonic condensate as qubits. Therefore, our study not only brings the physics and technology of Bose-Einstein condensation within the reaches of semiconductor chips but also opens up experimental investigations of the fundamentals of quantum physics using similar techniques. Operational temperatures of such two-component excitonic BEC can be raised further with a more densely packed, ordered array of QDs and/or using materials having larger excitonic binding energies. However, fabrications of single crystals of 0D-2D heterostructures using 2D materials (e.g. transition metal di-chalcogenides, oxides, perovskites etc.) having higher excitonic binding energies are still an open challenge for semiconductor optoelectronics. As of now, these 0D-2D heterostructures can already be scaled up for mass production of miniaturized, portable quantum optoelectronic devices using the existing III-V and/or Nitride based semiconductor fabrication technologies.

Keywords : exciton, Bose-Einstein condensation, quantum computation, heterostructures, semiconductor Physics, quantum fluids, Schrodinger's Cat
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