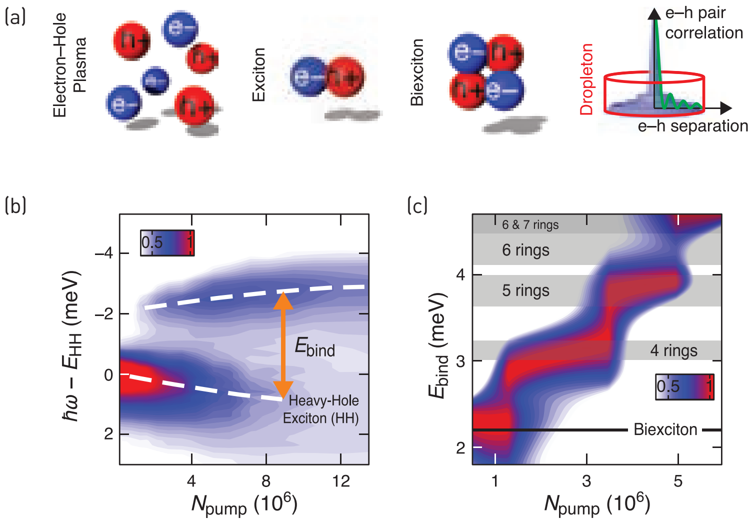
QUANTUM OPTICS

Quantum-Optical Spectroscopy Reveals Dropletons in Quantum Wells



(a) Hierarchy of quasiparticles in gallium-arsenide quantum wells. The dropleton is represented by its two-particle electron-hole correlation function. The red shell indicates the dropleton-plasma boundary. (b) Probe absorption for a range of pump photon number. (c) Differential probe absorption between quantum-optical states chosen to isolate the effect of three-and-greater–photon correlations. Gray bars show theoretical dropleton binding energies.[4]

Quantum-optical spectroscopy is a new tool well suited for studying quasiparticles.[1] In semiconductors, these include excitons and biexcitons, as well as higher-order electron-hole clusters. It is virtually impossible to separate the individual resonances of nearly degenerate quasiparticles when limited to traditional optical spectroscopic techniques. However, quantum-optical spectroscopy takes advantage of the prediction that multi-photon correlations in the optical field will excite equivalent electron-hole correlations, i.e., clusters in the semiconductor. Understanding quasiparticles and their interactions has led to increasingly accurate microscopic models of semiconductor systems, benefitting both fundamental science and semiconductor technology.[2]

We realize quantum-optical spectroscopy by measuring transient-absorption spectra of gallium arsenide quantum wells at 6 K with high precision while scanning a wide range of pump-pulse amplitudes with a mode-locked Ti:sapphire laser. This way, we generate the needed set of system responses over a large region in the phase space of coherent states. Recently, we developed a method that robustly projects the quantum-optical response of a many-body system from a set of measured coherent-state responses.[3] The exciton resonance shows the well-known blue shift that corresponds to a gradual decrease of the exciton binding energy. Simultaneously, however, we note a totally unexpected increase in the binding energy of the lower-energy state.

When the absorption is projected into the quantum-optical response resulting from excitation by three-and-greater–photon correlations, new quantized levels emerge with increasing pump photon number. To explain the progression in binding energy, we analyzed an extensive set of many-body configurations and found that the quantized steps can only be explained by a liquid-like state consisting of four-to-seven electron-hole pairs within a microscopic correlation bubble. The quantized energetics, liquid characteristics and small size are unique to a new quasiparticle that we call a dropleton.[4] Our dropleton discovery demonstrates the capabilities of quantum-optical spectroscopy; this methodology has already been applied to identify a new quantum memory effect in quantum dot microring emission.[5] OPN

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