Time-Resolved Evidence for Superfluorescent Radiation from Quantum Wells in Strong Magnetic Fields

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Introduction

Superfluorescence (SF) is the coherent emission of radiation from a macroscopic ensemble of two-level dipoles. It is an unusual example of self-organization where macroscopic coherence spontaneously develops through many-body interactions among individual dipoles. SF has been observed in atomic and molecular gases, but not in condensed matter systems, where ultrafast scattering typically destroys such coherence. We observed SF in an $In_{0.2}Ga_{0.8}As/GaAs$ quantum well in magnetic fields up to 17.5 T using pump-probe and time-resolved photoluminescence (TRPL) measurements [1]. Here, we present a series of SF bursts, discrete both in time and energy, corresponding to the cooperative recombination of electron-hole pairs from different Landau levels [2].

Experimental

Experiments were performed in the Fast Optics Facility of the National High Magnetic Field Laboratory in Tallahassee, FL, using the 17.5 Tesla superconducting magnet in Cell 3 (SCM3). We used a high-intensity chirped pulse amplifier to optically pump the sample, creating a high density of electron-hole pairs. For pump-probe measurements, we used a tunable optical parametric amplifier to probe the population of each state as a function of time using an optical delay line. For TRPL measurements, we collected the emission using two multimode fibers, one placed directly behind the excitation spot and the other at the edge of the sample after redirecting the in-plane emission with a right-angle micro-prism. We then used a streak camera with a spectrometer to measure the spectrally resolved TRPL.

Results and Discussion

Figures 1(a)–(d) show time-resolved PL spectra with high power excitation using the amplified Ti:sapphire laser, taken with a streak camera at magnetic fields between 0 and 17.5 T. Each (N,N) recombination is observed as a peak both in energy and time, characteristic of a burst of SF. The number of peaks increases with decreasing B, and at each B the (0,0) burst occurs last. Additionally, at a given magnetic field, the delay time is slower for smaller Landau level because electron-hole pairs in higher states burst first, and those in lower states burst in a sequential manner. We observe strong energy and mass renormalization due to a large electron-hole pair density, as compared to linear magnetoabsorption transitions. At zero field, the exciton binding energy vanishes, indicating that the electron-hole pair density is larger than the Mott density.

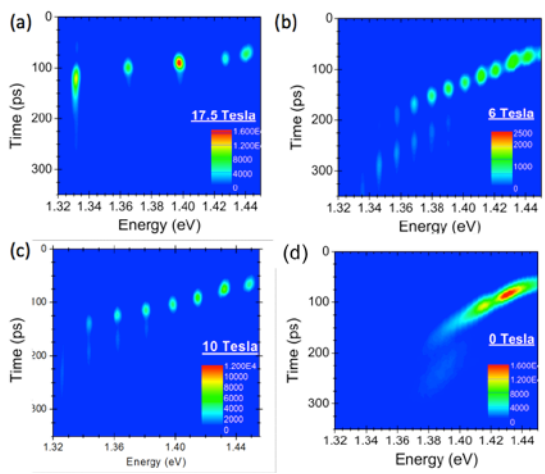

Figure 1. TRPL at 17.5 T, 10 T, 6 T, and 0 T. As the magnetic field is decreased, the intensity of SF bursts decreases, and the delay between excitation pulse and the SF burst increases. A continuous line of emission is seen at 0 T.

Conclusions

The lowest-energy SF burst occurs only after most upper states become empty, suggesting that excitonic stability is related to the "hidden symmetry" of 2D magnetoexcitons expected in the magnetic quantum limit.

Acknowledgements

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References

[1] G. T. Noe *et al.*, *Nature Physics* **8**, 219 (2012).
[2] J.-H. Kim *et al.*, *Phys. Rev. B*, **87**, 045304 (2013).