Superfluorescence from a Two-Dimensional Electron-Hole System: Magnetic Field, Temperature, and Density Dependence

Cong, K. (Rice U., Physics & ECE); Kim, J.H. (SKKU, Physics); Noe, G.T. (Rice U., Physics & ECE); McGill, S.A. (NHMFL); Wang, Y.; Belyanin, A.A. (TAMU, Physics); Kono, J. (Rice U., Physics & ECE)

Introduction

In our prior work at the National High Magnetic Field Laboratory (NHMFL), we studied light emission dynamics as well as carrier population dynamics in an undoped multiple quantum well (MQW) structure consisting of InGaAs quantum wells with GaAs barriers. At sufficiently low temperatures and sufficiently high magnetic fields, we observed superflourescence (SF) [1, 2]. SF is a many-body process in which a large number of (initially incoherent) dipoles (i.e., electron-hole pairs in our case) recombine collectively, emitting bursts of coherent radiation. It represents one of the unusual examples of self-organization processes where **macroscopic coherence spontaneously develops** through many-body interactions among the individual dipoles. Our measurements in the Fast Optics Facility of the NHMFL have provided the **first convincing evidence for SF in a solid-state environment**.

Experimental

In order to create the required conditions for SF from our InGaAs MQW sample, we must use a unique combination of an intense femtosecond laser (amplified Ti:sapphire laser) to create a high-density of electron-hole pairs and a strong perpendicular magnetic field (17.5 T superconducting magnet) to laterally confine the electrons and holes and increase the density of states through Landau quantization.

In February and March 2014, we fully mapped out the magnetic field (*B*), temperature (*T*), and power (*P*) dependence of time-integrated photoluminescence (TIPL), and constructed a 'phase' diagram of SF, showing the '*B-T-P*' region where SF can be observed in the MQW system. In November 2014, we carried out second-order correlation function $g^{(2)}(0, t)$ measurements of SF with a time-correlated single-photon counting system. We measured $g^{(2)}(0, t)$ as a function of magnetic field, temperature, and emission wavelength to investigate the photon statistics of emitted SF bursts.

Results and Discussion

Figures 1(a) and (b) show the temperature dependence of PL emission from the (00) Landau level at 17.5 T with an excitation power of 4 mW. At 95 K, the linewidth suddenly increases and intensity quickly decreases, and we identify this temperature as the critical temperature (T_c) for SF observation. Figures 1(c) and (d) show the '*B-T*' phase diagram of SF, for the (00) and (11) Landau transitions, respectively, at different excitation powers, which clearly show that SF is more easily observable at higher magnetic fields, lower temperatures, and higher excitation powers.

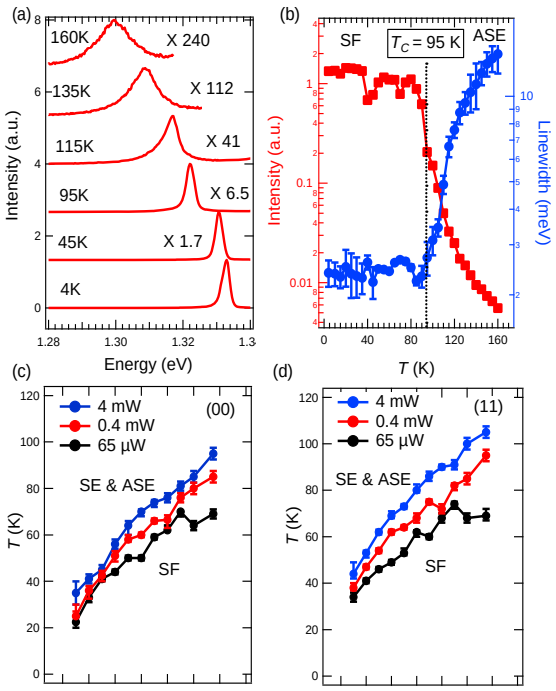

Fig.1 (a) The temperature dependence of TIPL and (b) emission analysis for (00) energy transition; (c)-(d) the '*B-T*' phase diagrams for (00) and (11) energy transitions.

Conclusions

We have constructed a 'phase' diagram, showing the '*B-T-P'* region in which SF is observable.

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References

[1] Noe, G. T., *et al.*, Nature Phys. **8**, 219 (2012). [2] Kim, J. H., *et al.*, Sci. Rep. **3**, 3283 (2013).