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

J-H. Kim, G.T. Noe, J. Kono (Rice U., ECE/Physics); A.A. Belyanin (TAMU, Physics); S.A. McGill (NHMFL)

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], and also obtained a series of SF bursts, corresponding to the cooperative recombination of electron-hole pairs from different Landau levels [2]. Our data clearly demonstrates Coulomb enhancement of gain near the quasi-Fermi edge, resulting in a red-shifting streak of SF at zero magnetic field and sequential SF from different Landau levels in a quantizing magnetic field [3].

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 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)–(e) show streak camera images of emission as a function of photon energy and time delay at different magnetic fields between 0 and 17.5 T. With increasing magnetic field, the number of peaks decreases and the energy separation between adjacent peaks increases due to strong Landau quantization. In addition, at a given magnetic field, the delay time is longer for lower Landau levels because the relative timing of the bursts coming from different Landau levels is correlated. Electron-hole (e-h) pairs in the highest energy state near the quasi-Fermi edge recombine first, and then those in lower energy states emit bursts sequentially. These phenomena are possible because the recombination gain for the e-h states below the quasi-Fermi edge is enhanced due to Coulomb interactions among carriers in a non-equilibrium photo-excited e-h plasma system; the highest gain leads to the fastest decay. Figure 1(f) summarizes the peak positions of the SF bursts as a function of photon energy and time.

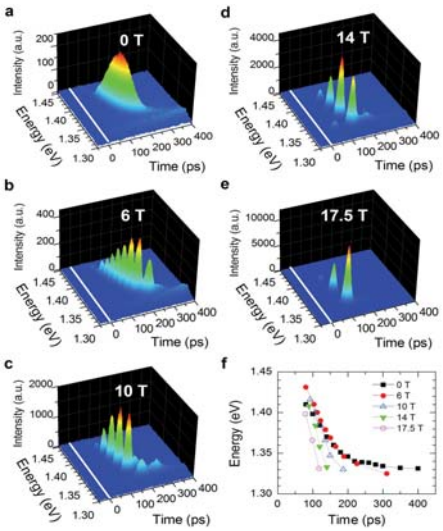

Fig. 1 Magnetic-field evolution of the observed coherent emission as a function of photon energy and time delay. Time-resolved photoluminescence data at (a) 0T, (b) 6 T, (c) 10 T, (d) 14 T, and (e) 17.5 T with 2 uJ of excitation pulse energy. (f) Peak shift of emission as a function of time at different magnetic fields.

Conclusions

The SF bursts from different Landau levels are correlated in time (sequential SF bursts). It can be explained through a Coulombic enhancement of gain near the quasi-Fermi energy (Fermi-edge singularity).

Acknowledgements

This research was sponsored by the National Science Foundation through grant No. DMR-1006663, Cooperative Agreement No. DMR-1157490, the State of Florida, and the U.S. Department of Energy.

References

[1] G.T. Noe *et al*., *Nature Phys.* **8**, 219 (2012).
[2] J-H. Kim *et al.*, *Phys. Rev. B* **87**, 045304 (2013).
[3] J-H. Kim *et al*., *Sic. Rep.* **3**, 3283 (2013).