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Ultrafast Coherent Control of Excitons in Quantum Nano-Structures

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1. Introduction

The study of ultrafast coherent carrier dynamics in quantum nano-structures is very important for the realization of novel devices such as ultrafast all optical devices, terahertz electromagnetic wave generators and quantum information devices. In this work, we have investigated the coherent dynamics of excitons and exciton-polaritons in quantum nanostructures using the coherent control technique[1] .

2. Qunatum nano-structure samples

Two quantum nano-structures of 1) InGaAs/GaAs multiple-quantum-well-Bragg structure[2] with interwell distance of half the wavelength of light and 2) crescent shaped GaAs/AlGaAs multi quantum wire structures[3] are used for the coherent control experiment of exciton-polaritons and excitons, respectively.

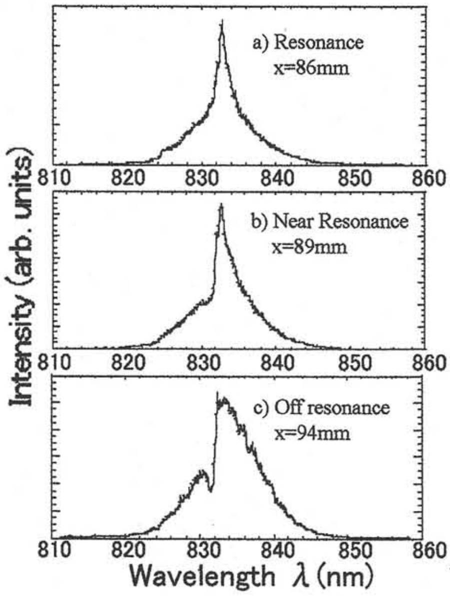

Fig.1 Reflection spectra of the probe-beam from the multi-quantum-well-Bragg samples for the various sample positions (x). Top – On resonance, Middle – Close to resonance, Bottom – Far off resonance.

Sample 1) consists of twenty 8nm thick QW's, and is intentionally wedge shaped, enabling us to tune the distance between the quantum wells by moving the position (x) of the excitation spot. Reflection spectra of probe-beam from the multi-quantum-well-Bragg samples for the various sample positions are shown in Fig. 1. At resonant condition (top figure), where the interwell separation is half the wavelength, the reflection spectrum of this sample shows super-radiant polariton characteristics with a Lorentzian shape. Sample 2) consists of fifteen periods of GaAs/AlGaAs quantum wires fabricated on a V-grooved GaAs substrate.

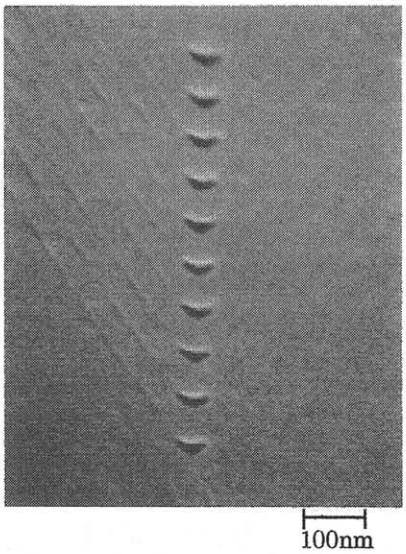

Fig. 2 The cross-sectional SEM picture of the quantum wire. Very small crescent-shaped GaAs/AlGaAs quantum wires (11nm thick, 46nm full width) are formed at the bottom of V-groove.

SEM pictures of quantum wires samples are shown in Fig.2. The precise size of quantum-wires are measured by TEM picture and the central thickness and the lateral full width of the quantum wires were, 11nm and 46nm, respectively. We observe a sharp 1e-1hh exciton peak (at

799nm) with a linewidth of about 5-6meV in the macro PLE and very sharp 1e-1hh exciton lines with linewidth of less than 0.1meV in the micro PL measurement.

3. Experimental Results

We coherently create and destroy the excitons or exciton-polaritons using phase-locked double-pulses of light generated in an actively-stabilised Michelson interferometer[1]. We monitor the pump induced reflectivity change using a weak probe, which in the results presented below, arrives several ps after the second of the pump pulses. The delay between the pump pulses is either changed on an attosecond scale, i.e. within a fraction of an optical wavelength by using a piezoelectric actuator or on a femtosecond scale using a conventional translation stage. The pump and probe beams are focus on the sample with long focal lens (f=300mm) for the excitation of the ensembles of the low-dimensional excitons within the focal diameter of about 300μm. The experiments are performed at 5K. Figure 3 shows the coherent control results for multiple-quantum-well-Bragg sample, with the three different conditions.

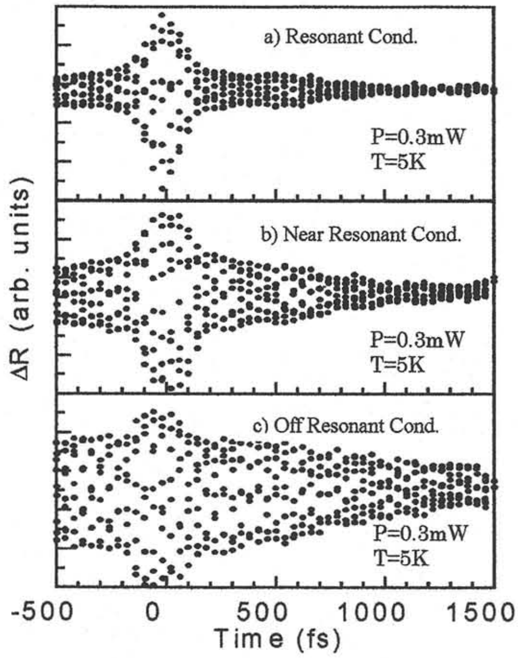

Fig. 3. Coherent control of exciton-polaritons in Multi-Quantum-Well-Bragg samples. Experimental pump induced reflectivity change ΔR versus the time interval of the double-pulses are plotted for the various sample position. Top – On resonance, Middle – Close to resonance, Bottom – Far off resonance.

The results obtained on resonance show two-stage decay with initial fast decay (200fs) and slower decay (0.8-1ps). We attribute the initial fast decay to the decay of the super-radiant mode. The slower decay is due to sub-radiant modes that are also excited. The excitation of sub-radiant modes is theoretically forbidden for an ideal structure, but becomes allowed when disorder is taken into account. From the results obtained near the resonance condition, the super-radiant mode is clearly reduced in strength and the sub-radiant modes are now brighter than compared to the resonance condition. Figure 4 shows the coherent control results for the quantum wire samples. Using the high sensitive detection technique, the coherent control for crescent shaped quantum wires were demonstrated. The result of the resonant excitation for the 1e-1hh excitons shows very fast decay. This might be caused by the contribution of the inhomogeneous broadening.

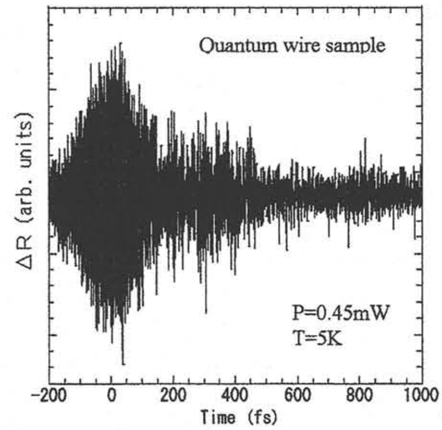

Fig. 4. Coherent control of excitons in crescent-shaped quantum wires. Experimental pump induced reflectivity change ΔR are plotted versus the time interval of phase-locked double-pulses.

4. Conclusions

We have studied ultrafast coherent carrier dynamics of exciton-polraritons in multi-quantum-well-Bragg structures and excitons in GaAs crescent quantum-wires using coherent control technique. In the multi-quantum-well-Bragg structures, super-radiant exciton-polariton characteristics with two-stage decay are clearly observed. In the crescent shaped quantum-wires, very fast dephasing characteristics are observed, which might be caused by the contribution of the inhomogeneous broadening.

References

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