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Tunable Slow Light of 1.3 μm Region in Quantum Dots at Room Temperature

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1. Introduction

Controlling the group velocity of light (slow and fast light) has been attracting much attention since this technique has many potential applications including optical routing, dispersion compensation, optical gate control, and photon storage [1]. Several groups have reported on slow- and fast light using optical nonlinearity and spectral filtering in various optical media [2-5]. Most applications require compact slow and fast light devices with a tunable delay and a wide spectral response. In this paper, we report a slow light in the 1.3 μm region in quantum dots (QDs) observed at room temperature. The maximum slowdown factor is 2.5 for a 500 μm-long device. This slowdown can be controlled by tuning the pump beam, which has not yet been reported in previous studies. Our result is an important step towards the implementation of slow and fast light devices applicable to actual conventional sub-systems as well as future quantum information devices.

2. Experimental

The QD samples were grown by MOVPE. Ten InAs QD layers were buried in waveguide structures. The samples were etched to form single-mode waveguides that were 500 and 1000 μm long. The interfaces of the waveguides were anti-reflection coated to prevent the multi-reflection effects.

The slow light effects were evaluated with the counter--propagating pump-probe method [5]. Figure 1 shows a schematic of the setup. A cw pump with a strong intensity and a modulated (1 GHz) probe beam were input into the waveguides. The transmitted probe was detected with a network analyzer. The transmitted power and the phase relative to the input were recorded. The phase delay corresponded to the slow light. All measurements were performed at room temperature.

3. Results and discussion

Figure 2 shows the photoluminescence (PL) spectrum of a QD sample measured at room temperature with a 980 nm excitation source. The PL peak is around 1320 nm and its width is about 50 nm. This PL width is determined by the size distribution of many QDs. The PL peaks for many QDs are different from each other because of the size distribution, and this leads to the broad PL spectra seen in Fig. 1. The broad PL spectrum may not be favorable for certain applications such as LEDs and lasers. However, this broad PL is good for slow light devices with a wide spectral response.

Figure 3 shows the measured slow light results. The pump wavelength was 1305 nm and the waveguide length was 500 μm. Detuning is defined as the frequency difference between the pump and probe frequencies. Zero detuning is the resonant condition. Around zero detuning, the transmission increases with a bandwidth of few GHz. Moreover, a positive phase delay can be clearly seen. These results were yielded by the coherent population oscillation

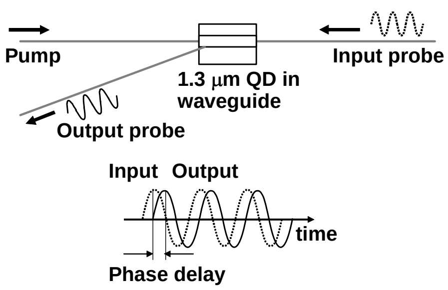

Fig.1 Slow light measurement setup. The pump beam is from cw DFB lasers. The 1 GHz-modulated probe beam is from a tunable laser source.

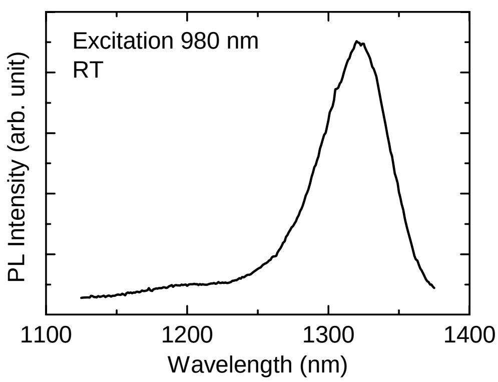

Fig.2 PL spectrum of a QD sample. The excitation condition is in the linear region.

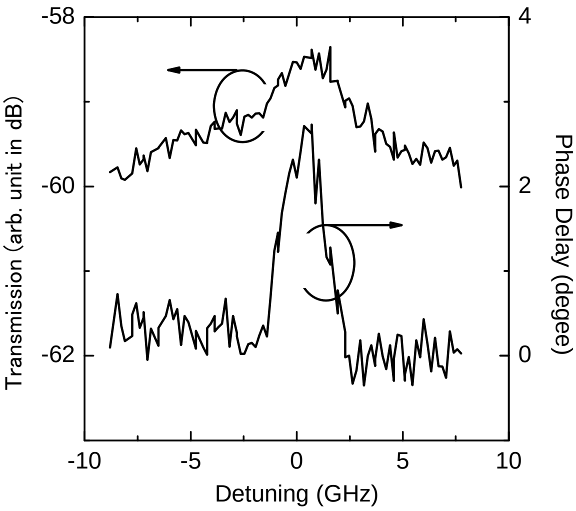

Fig.3 Measured transmission and phase delay. Detuning is the frequency difference between the pump and probe frequencies.

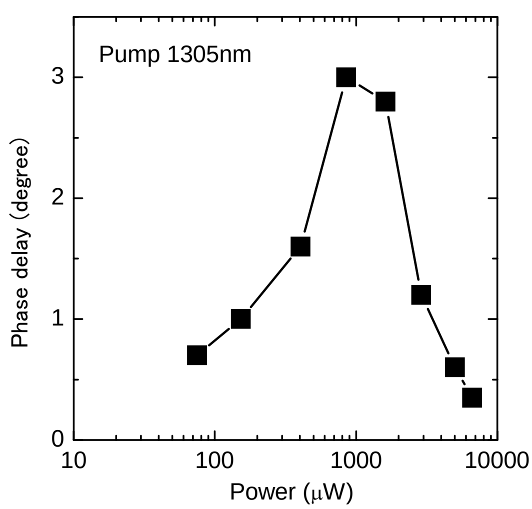

Fig.4 Pump power dependence of phase delay. The maximum delay is about 3 degrees. This corresponds to a slowdown factor of 2.5.

(CPO). The strong pump beam creates electrons and holes in QDs. These carriers reduce the absorption of the probe resulting in increased transmission. The pump beam also induces carrier oscillation effects whose frequency is determined by the detuning frequency. The oscillation creates a grating that diffracts the probe beam. These effects change the transmission and refractive index for the probe beam and cause the phase delay in Fig. 3.

Figure 4 plots phase delay as a function of pump power. The phase delay increases up to 1000 μW and then decreases above this power. This result is a characteristic of CPO. In a weak excitation region, changes in absorption and refractive index around the pump wavelength become larger with pump power. This leads to an increased phase delay region. However, these changes reach saturation, and additional pump power causes spectral broadening in the optical spectra. The broadening induces a region that decreases with pump power.

In Fig. 4 the maximum phase delay is about 3 degrees. This corresponds to the fact that the propagation time in the waveguide was 2.5 times longer. The result clearly shows that the slow light effects can be controlled by tuning the pump power. This result has not yet reported in the previous studies. The result suggests that it might be possible to use QDs to design devices for controlling optical group velocity with a tunable delay function.

4. Conclusions

We have observed tunable slow light in QDs at room temperature. The slowdown (phase delay) can be controlled by the tuning of the pump source. The wavelength is in the 1.3 μm region, which is a telecommunication wavelength. Our results constitute an important milestone on the road to creating slow and fast light devices that will find various useful applications.

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