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Femtosecond Response of Diffraction Efficiency in GaAs/AlGaAs Photorefractive Multiple Quantum Well

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1. Introduction

Photorefractive quantum well (PRQW) devices are attractive for the application to optical modulators and switches for their high sensitivities, small saturation intensities, and short response times. Recently, femtosecond diffraction from quasi-static excitonic gratings in PRQW was studied, in order to use PRQW in the optical system for pulse shaping and femtosecond information processing [1-3]. In those applications, both diffraction bandwidth and response time are of great importance. The operating bandwidth of a typical GaAs/AlGaAs photorefractive multiple quantum well (MQW) device at room teperature is as small as 4 nm. For using the QW devices in dynamic spectral holography system with a 100 fs-class ultrashort pulse, the bandwidth must cover approximately 10 nm at 800 nm. Also, to design the PRQW devices for ultrafast laser operation, understanding of ultrafast temporal evolution of diffraction efficiency is prerequisite. In this work, we report time-resolved diffraction efficiency in PRQW in the femtosecond region.

2. PRQW device structure and experiments

The PRQW device structure used in this study is shown in Fig.1 [3]. The growth was performed by molecular beam epitaxy. A 500-nm buffer layer of GaAs was grown on a semi-insulating GaAs (001). After the buffer layer growth, 500-nm $Al_{0.5}Ga_{0.5}As$ and 20-nm AlAs were grown as selective etching layers to remove the GaAs substrate. Then 200-nm $Al_{0.2}Ga_{0.8}As$ and GaAs/$Al_{0.3}Ga_{0.7}As$ MQW were deposited on it, which was followed by 100-nm $Al_{0.2}Ga_{0.8}As$ and 5-nm GaAs. The top GaAs layer is for protecting the device from oxidaton. GaAs well width was 7 nm, $Al_{0.3}Ga_{0.7}As$ barrier width was 6 nm and the repetition was 100 periods. After the growth, the sample was proton implanted with a dose of 10^{12} cm^{-2} at 160 keV and 5×10^{11} cm^{-2} at 80 keV to create deep-level defects and render the material semi-insulating and persistently photorefractive.

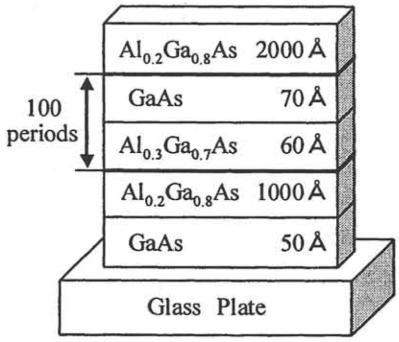

Fig.1 Structure of designed PRQW device

The implanted wafer was cleaved and was bonded onto the glass plate with the epilayer side on glass. To remove the substrate for transmission experiments, the substrate was lapped to 100 μm and etched to $Al_{0.2}Ga_{0.8}As$. An HF acid etch was used to remove the $Al_{0.2}Ga_{0.8}As$ and AlAs layer.

The transmission spectra for the PRQW device are

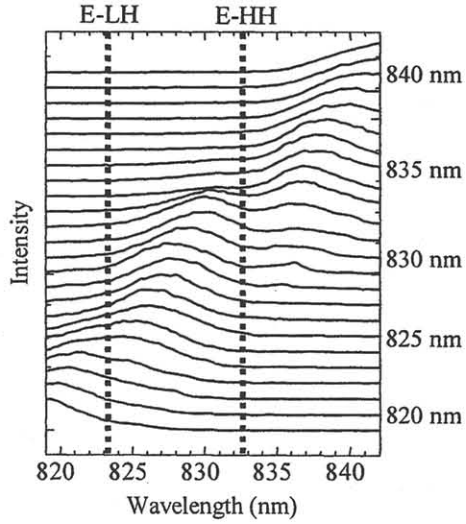

Fig.2 Transmission spectra for different central wavelengths of 100-fs pulses

plotted in Fig.2. With changing the central wavelength of incident pulses, the transmission spectra were measured at room temperature. The incident pulses with approximately Gaussian shape had a bandwidth of 8 nm and a duration of ~100 fs. Resonant absorption lines are confirmed at ~832 nm and ~823 nm, which can be attributed to exciton recombinations between the ground electron and heavy (light) -hole state, E-HH (E-LH), in the PRQW.

3. Ultrafast evolution of diffraction efficiency

We measured differential transmission spectra ($\Delta T/T$) as a function of time by using pump-probe system. The result is shown in Fig.3. Pump- and probe- excitation densities were 240 and 40 fJ/μm^2, respectively. The laser wavelength was changed from 819 nm to 842 nm, which involves the excitation resonances of E-HH and E-LH. Near the exciton resonances, especially for E-HH, the $\Delta T/T$ shows a rapid change just after the excitation. For small pump-induced absorption changes ($-\Delta\alpha$), $\Delta T/T$ is regard as $-\Delta\alpha d$, where d is thickness of the device [4]. By using this relation, diffraction efficiency spectra evaluated from Fig.3, and the results are shown in Fig.4. During the initial stage up to 500 fs, gradual decay contributed the E-HH and E-LH excitons are clearly resolved. Especially, the diffraction efficiency due to the E-HH exciton shows a dramatic energy shift, with increasing the delay time. The diffraction signals are observable in the wavelength region at least from 822 nm to 836 nm, covering >14 nm. The response speed estimated near 832 nm is approximately 200 fs.

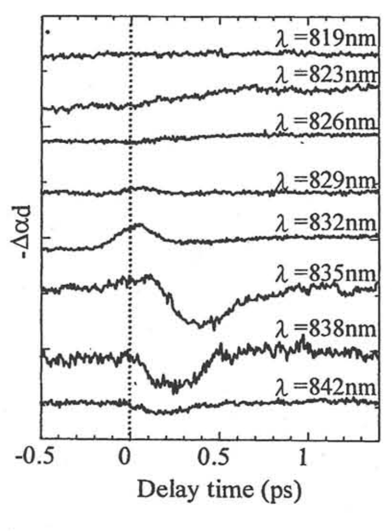

Fig.3 Differential transmission transients for various wavelengths

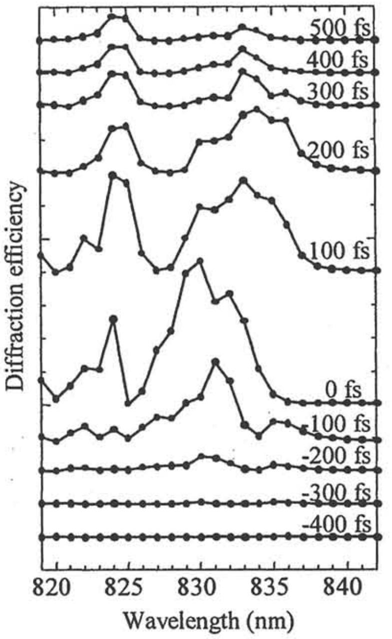

Fig.4 Temporal evolution of diffraction efficiency

4. Conclusions

We have characterized the temporal evolution of diffraction efficiency in a PRQW. Distinctive contributions of the E-HH and E-LH excitons were observed, a wide bandwidth (>14 nm) and fast response time (~200 fs) were determined. This result has demonstrated usefulness of PRQW's for diffractive optical elements in ultrafast switching and information processing with femtosecond laser pulses.

References

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