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Remarkable Enhancement of Optical Kerr Signal by increasing Quality Factor in a GaAs/AlAs Multilayer Cavity

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1. Introduction

The semiconductor photonic microcavity is desirable structures in order to enhance the nonlinear switching signals, since the strong electric field enhancement occurs due to the strong photon confinement in the cavity. We have demonstrated the strong optical Kerr signals of a GaAs/AlAs multilayer cavity structures by inserting a resonant InAs quantum dots (QDs) as the half-wavelength ($\lambda/2$) cavity layer [1,2]. Recently, the numerical simulation using self-consistent transfer matrix method showed that the optical Kerr signal intensity of the GaAs/AlAs multilayer cavity structure is remarkably enhanced in proportional to the Q^4 [3], where Q is a quality factor depending on the numbers of distributed Bragg reflector (DBR) layers. It is quite important to confirm this extremely enhanced Q dependent signal for the future applications of nonlinear optical switches based on the GaAs/AlAs multilayer cavity structures. We have previously measured the optical Kerr signals using a 100 fs ultrafast laser pulse. However, the transmission decrease of the laser pulse should be considered since the spectral width of the pulse was much wider than the cavity mode [4]. In order to confirm the remarkable enhancement of the optical Kerr signal quantitatively, the spectral width and wavelength of the laser pulse should be well tuned to the narrow cavity mode.

In this report, the spectral width and wavelength of the laser pulse was tuned to the cavity modes and the Q dependent optical Kerr signal of GaAs/AlAs multilayer cavity structures was investigated by time-resolved optical measurements.

2. Samples and Experimental setups

The samples were grown by the molecular beam epitaxy on GaAs(001) substrates. They consist of $\lambda/2$ GaAs layer (222 nm) in n (= 26 and 30) periods of GaAs (111 nm)/AlAs (130 nm) DBR multilayers. The GaAs substrates were removed by mechanical polishing and selective wet etching in order to eliminate nonlinear signals originating in the thick substrate. The cavity modes of the n = 26 and 30 cavities appeared at 1543.0 and 1541.2 nm, and spectral width were 2.64 and 1.65 nm, respectively. Hence, Q ($=\lambda/\Delta\lambda$) was obtained as 583 and 934 for the n = 26 and 30 cavities, respectively. We used a light source with a pulse width of ~100 fs and a repetition rate of 100 kHz generated from an optical amplifier system (Coherent RegA) for the time-resolved optical measurements. The center wavelength of the laser pulse was tuned to the each cavity mode and the pulse width and wavelength of the incident laser pulses were controlled by a slit and pair of gratings and cylindrical lenses, as shown in Fig. 1(a). The wavelength restricted laser pulse was divided into pump and probe pulse by a beam splitter, and the relative delay of the probe pulse (Δt) was varied using a mechanical delay stage. Fig. 1(b) shows the cross-Nicol configuration used for our optical Kerr signal measurements. The pump beam polarization ([110]) was set at 45° with respect to the probe beam polarization ([010]), and the probe beam intensity of

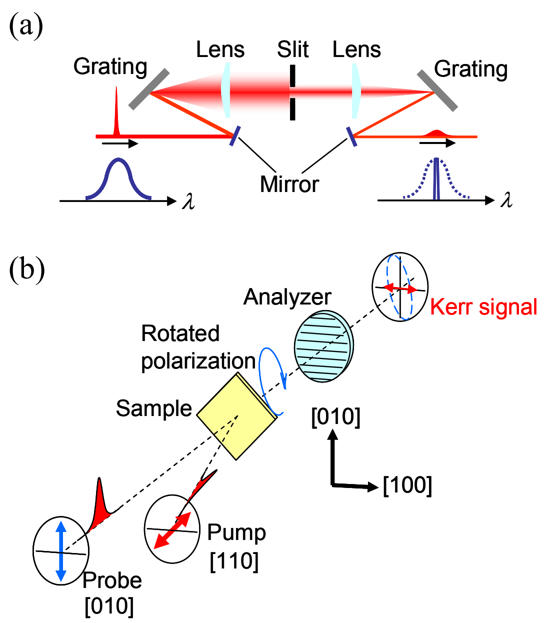

Fig. 1(a) Optical setup of pulse wavelength restricted system. (b) The cross-Nicol configuration used for our optical Kerr signal measurements.

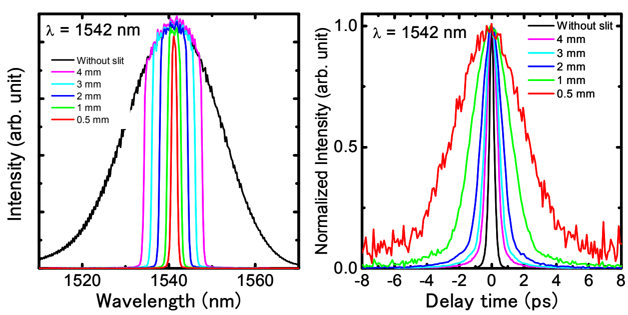

Fig. 2(a) The restricted laser pulse spectra for the different slit width. (b) The corresponded auto-correlation signals.

the [100] polarization passing through an analyzing polarizer was detected as the optical Kerr signal.

Figures 2(a) and (b) show the restricted laser pulse spectra for the different slit widths at laser wavelength and the corresponded auto-correlation signals. As the spectrum-width of the laser pulse becomes narrower, the time-width of the laser pulse becomes larger. The spectral width of laser pulse was restricted to 1.6 nm when using the 0.5 mm slit width. This corresponds to the 4.1 ps time-width of the restricted laser pulse.

3. The Q dependent optical Kerr signals

Since the spectral width of the cavity mode in the n = 30 cavity is 1.65 nm, the Q dependence of the optical Kerr signal was measured by restricted laser pulse using 0.5 mm slit width. Figure 3 (a) shows the optical Kerr signals for the n = 26 and 30 cavities at incident pump power 300 and 5 μW, respectively. The time-width of the optical Kerr signal was 4.7 ps, which indicates that the response time was limited to the restricted pulse width of 4.1 ps. Although Q of the n = 30 cavity is only 1.6 times larger than that of n = 26 cavity, the optical Kerr signal intensity was about 10 times larger than that of n = 26 cavity. Figure 3 (b) shows the peak intensity of optical Kerr signal plotted by the Q in a log-scale. We have revealed that the optical Kerr signal increases in proportional to ~Q^4, which is also consistent with our simulation result [3].

The optical Kerr signal intensity is expressed as $I_{Kerr} \propto sin^2(\Delta\phi/2)$, where $\Delta\phi \propto \Delta n l_{eff}$ is the phase shift due to the large changes of the refractive index Δn, and l_{eff} is the effective optical length of the cavity [1]. When the Δn occurs owing to the third-order optical nonlinearity, Δn is proportional to the I_{Pump}, where I_{Pump} is the pump excitation intensity. In the case of the cavity, Δn is proportional to the Q since the I_{Pump} is increased in the cavity in proportional to the Q due to the internal-field enchantment effect [5]. Moreover, l_{eff} is also proportional to the Q since photon life time is in proportional to the Q. Therefore, if the third-order optical nonlinearity is only considered, the optical Kerr signal should be in proportional to Q^4, due to the internal-field enchantment effect and the photon life time of the cavity.

3. Conclusions

In this report, the spectral widths of the laser pulses were well tuned to the cavity modes and the Q dependent optical Kerr signal was investigated using GaAs/AlAs multilayer cavity structure. We have revealed that the optical Kerr signal was remarkably enhanced by Q and increases in proportional to ~Q^4 in the GaAs/AlAs multilayer cavity. This is consistent with our previous simulation result of optical Kerr signal intensity which increased in proportional to Q^4.

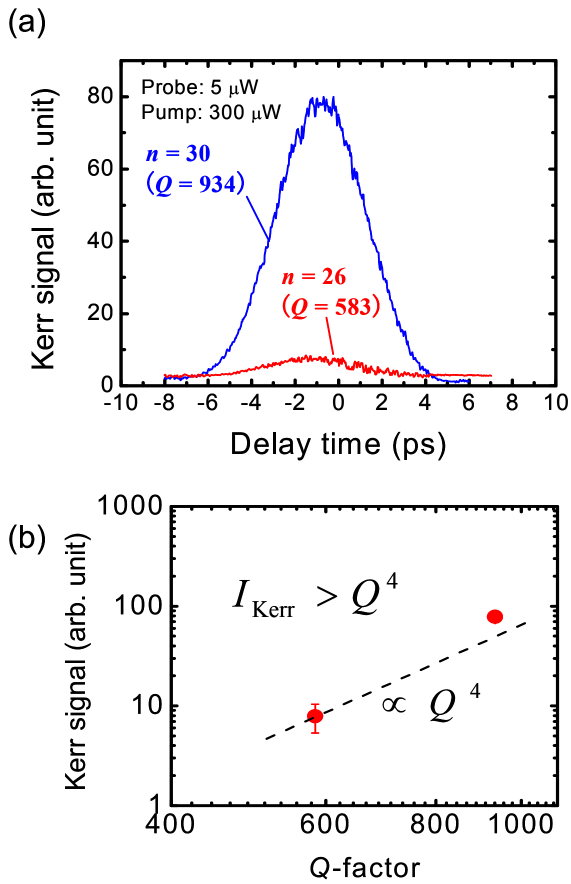

Fig. 3(a) The optical Kerr signals for the n = 26 and 30 cavities. (b) The peak intensity of optical Kerr signal plotted by Q in a log-scale. Dotted line shows the slope proportional to the Q^4.

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