Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp61-62

Time-Resolved Measurements on Sum Frequency Generation Strongly Enhanced in (113)B GaAs/AlAs Coupled Multilayer Cavity

Fumiya Tanaka, Toshikazu Takimoto, Ken Morita, Takahiro Kitada, and Toshiro Isu

Center for Frontier Research of Engineering, Institute of Technology and Science, The University of Tokushima
2-1, Minami-Josanjima-Cho, Tokushima 770-8506, Japan
Phone: +81-88-656-7671 E-mail: f.tanaka@frc.tokushima-u.ac.jp

1. Introduction

Optical microcavities consisting of GaAs/AlAs distributed Bragg reflector (DBR) multilayers are good candidates for nonlinear optical devices such as planar-type all-optical switches [1-3] because an extremely strong light field in the cavity layer markedly enhances nonlinear optical responses of the semiconductor material used in the cavity. Recently, we have proposed GaAs/AlAs coupled multilayer cavity structures for novel terahertz emission devices utilizing difference frequency generation (DFG) of two cavity modes. [4] When two half-wavelength ($\lambda/2$) cavity layers are coupled by the intermediate DBR multilayer, two cavity modes are realized in the center of the high reflection band, and its frequency difference can be precisely defined in the terahertz region by the number of periods of the coupling DBR multilayer. Since the light electric field of each cavity mode is strongly enhanced in both two $\lambda/2$ cavity layers, strong terahertz-DFG of the two cavity-mode lights will be expected at room temperature when the coupled cavity structure is grown on a high-index GaAs substrate. The growth on the non-(001) substrate is essential for frequency mixing because the effective second-order nonlinear coefficient is zero on the conventional (001) orientation due to crystal symmetry. [5] In our recent study, strong sum frequency generation (SFG) has been demonstrated by the simultaneous excitation of two cavity modes in the GaAs/AlAs coupled multilayer cavity grown on a (113)B- oriented GaAs substrate by molecular beam epitaxy (MBE) using an ultrashort pulse laser with a wide spectrum. [6] The peak intensity of the SFG signal was more than 400 times larger than that of the second harmonic generation (SHG) signal from the (113)B GaAs substrate alone.

In this study, time-resolved measurements were performed on the SFG and SHG of two cavity modes in the (113)B GaAs/AlAs coupled multilayer cavity using two ultrashort laser pulses with a time delay. The observed delay-time dependence of the SFG and SHG signal intensity was well explained by the simulated internal light electric field inside the coupled cavity.

2. Experimental details

The GaAs/AlAs coupled multilayer cavity structure was grown on the semi-insulating (113)B GaAs substrate by a solid-source MBE. [6] Two GaAs $\lambda/2$ cavity layers (222 nm) were coupled by a 10.5-period GaAs/AlAs (111 nm/130 nm) DBR multilayer. The 13-period DBR multilayers were formed at both sides of the coupled cavity structure. 100 fs laser pulses with a 100 kHz repetition rate were used as the excitation source. The laser central wavelength was tuned at 1530 nm. Because of the wide spectral width (~ 35 nm) of the incident laser pulses, two cavity modes were clearly observed at 1511.7 and 1537.4 nm in the transmission spectrum of 100 fs laser pulses through the coupled cavity sample. Figure 1 shows experimental setup for time-resolved SFG and SHG measurements. The 100 fs laser pulses were divided into two beams and a variable time delay (Δt) was introduced in one path. The two beams were then focused on the sample surface about 140 µm in diameter in the normal incidence configuration. The power of each incident beam was 5 mW. In order to measure SFG and SHG signals caused by combining of two beams, only the signals appearing between two reflection beam paths were detected using a small slit as shown in Fig. 1. All optical measurements were performed at room temperature.

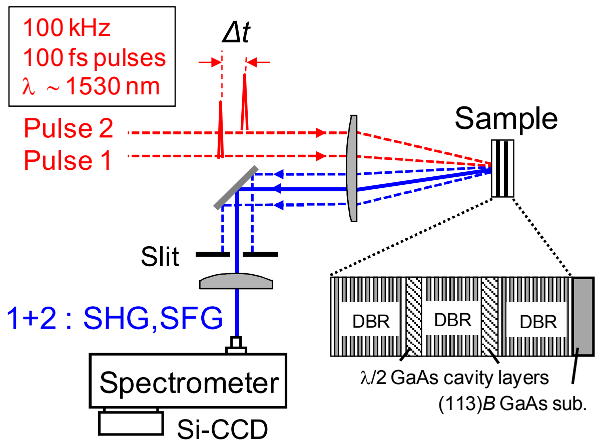

Fig. 1 Experimental setup for time-resolved measurements on SFG and SHG signals from the (113)B coupled multilayer cavity.

3. Time-resolved measurements

Figure 2 shows the spectrum measured in the half- wavelength region of the excitation laser at $\Delta t = 0$. Two peaks at 755.5 and 767.9 nm correspond to the SHG signals of two cavity modes and the strongest peak attributed to the SFG signal was observed at the midpoint (761.6 nm) of two SHG signals. The SFG and SHG signals were observed only when the sample was irradiated by two laser beams because of the small slit width shown in Fig. 1.

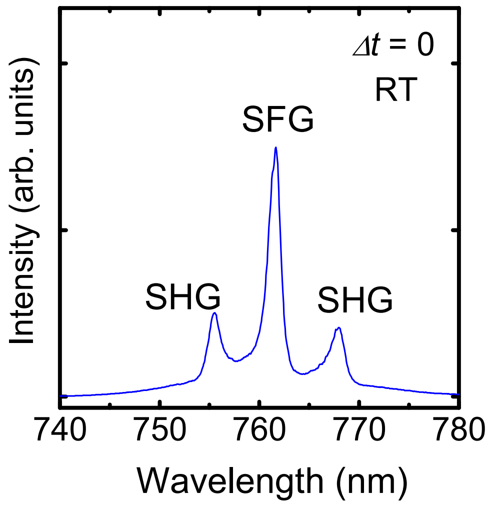

Fig. 2 Measured spectrum of the SFG and SHG signals from the (113)B coupled multilayer cavity at $\Delta t = 0$.

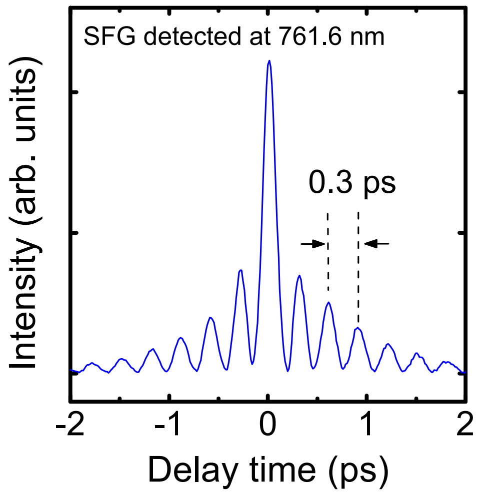

Fig. 3 Delay-time dependence of the SFG signal intensity.

Figure 3 shows delay-time dependence of the SFG signal intensity detected at 761.6 nm. The oscillating decay behavior was clearly observed in the time-resolved SFG signal intensity. The observed oscillation period (0.3 ps) corresponds to the optical frequency difference (3.3 THz) of two cavity modes. The decay time was determined to be 0.6 ps, which was consistent with the photon life time of the coupled multilayer cavity estimated by the spectral width (2.5 nm) of the cavity modes.

Figure 4 shows the delay-time dependent spectral map of SFG and SHG signals from the (113)B coupled multilayer cavity. Each peak decays with the photon lifetime (0.6 ps) of the coupled multilayer cavity. However, the clear oscillating behavior with a period of 0.3 ps was only observed for the SFG of two cavity modes. In order to understand these experimental results, the light electric field inside each cavity layer was simulated through the usual transfer matrix method when two Gaussian pulses [$E_1(t)$ and $E_2(t + \Delta t)$] were incident with a time delay (Δt) in the normal configuration. The delay-time dependent spectral map of Fourier component of $E_1(t)E_2(t + \Delta t)$ around the half-wavelength region of two-cavity modes closely resembles the experimental results of SFG and SHG signals shown in Fig. 4. This indicates that strong SFG signal from the (113)B coupled multilayer cavity originates from the interference between the enhanced light electric fields of the cavity modes inside the coupled cavity.

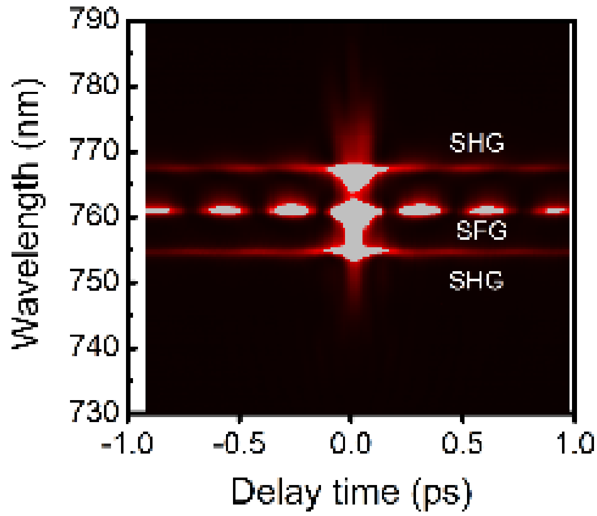

Fig. 4 Measured spectral map of the delay-time dependent SFG and SHG signals. The signal intensity is plotted in linear scale.

4. Conclusions

Time-resolved measurements on SFG and SHG strongly enhanced in the (113)B GaAs/AlAs coupled multilayer cavity were performed using two 100 fs laser pulses with a time delay. SFG and SHG signals caused by combining of two beams were detected in the reflection configuration. The strong SFG and SHG signals of the two cavity modes decay with the photon life time (0.6 ps) of the coupled multilayer cavity. The clear oscillating behavior with the period (0.3 ps) corresponding to optical frequency difference (3.3 THz) of two cavity modes was only observed for the SFG signal. The observed results were well explained by the simulated light electric field inside the coupled cavity under two Gaussian pulse excitation. Strong SFG from the (113)B coupled multilayer cavity was confirmed to originate from the interference between the enhanced internal light electric fields of the cavity modes.

References

[1] T. Kitada et al., Appl. Phys. Express **1** (2008) 092302.
[2] K. Morita et al., Appl. Phys. Express **2** (2009) 082001.
[3] T. Takahashi et al., Jpn. J. Appl. Phys. **49** (2010) 04DG02.
[4] T. Kitada et al., Appl. Phys. Lett. **95** (2009) 111106.
[5] N. Yamada et al., Jpn. J. Appl. Phys. **35** (1996) 2659.
[6] F. Tanaka et al., Jpn. J. Appl. Phys. **49** (2010) 04DG01.