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Strong sum frequency generation in a GaAs/AlAs coupled multilayer cavity grown on a (113)B-oriented GaAs substrate

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1. Introduction

Efficient wavelength conversion devices using second-order optical nonlinearity of semiconductor materials are attractive for new light sources in the undeveloped frequency region. Especially, difference frequency generation (DFG) methods with high conversion efficiency enable us to develop compact terahertz emitters operating at room-temperature. A half-wavelength ($\lambda/2$) cavity structure sandwiched between two GaAs/AlAs distributed Bragg reflector (DBR) multilayers is useful for nonlinear optical devices such as all-optical Kerr gate switches [1,2] because extremely strong light field is realized in the $\lambda/2$ cavity layer. Recently, we have proposed a GaAs/AlAs coupled multilayer cavity structure, where two $\lambda/2$ cavity layers are coupled by the intermediate DBR multilayer, grown on a high-index GaAs substrate. [3] 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. We can expect strong frequency mixed signal from the two cavity-mode lights with different fundamental frequencies, since the light electric field of each cavity mode is strongly enhanced in both of the two $\lambda/2$ cavity layers. Growth of the coupled cavity structure on a non-(001) substrate is essential for the frequency mixing because the effective second-order nonlinear coefficient is zero on the conventional (001) orientation due to crystal symmetry. [4] The growth on the (113)B substrate would be beneficial for the high conversion efficiency with keeping good crystalline quality of the epitaxial layers. In fact, Kaneko et al. demonstrated blue vertical-cavity surface-emitting lasers (VCSELs) based on second-harmonic generation (SHG) grown on the (113)B GaAs substrate. [5]

In this study, the GaAs/AlAs coupled multilayer cavity structure was grown on the (113)B-oriented GaAs substrates by molecular beam epitaxy (MBE). Strong sum frequency generation (SFG) using the two cavity modes were demonstrated by the ultrashort pulse laser excitation.

2. GaAs/AlAs coupled multilayer cavity structure

The GaAs/AlAs coupled multilayer cavity structure (Fig. 1) was grown on the semi-insulating (113)B GaAs substrate by a solid-source MBE. 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. The coupled cavity sample was grown at 650ºC under an As_4 pressure of 1×10^{-5} Torr. The growth rate was 1 μm/h both for GaAs and AlAs layers.

Figure 2 shows the reflection spectrum of the (113)B coupled cavity sample. Two cavity modes were clearly observed at wavelengths of 1514 nm and 1540 nm in the center of the high reflection band. Frequency difference between the two cavity modes corresponds to 3.3 THz. The observed reflection spectrum was well reproduced by the numerical simulation based on the conventional transfer matrix method.

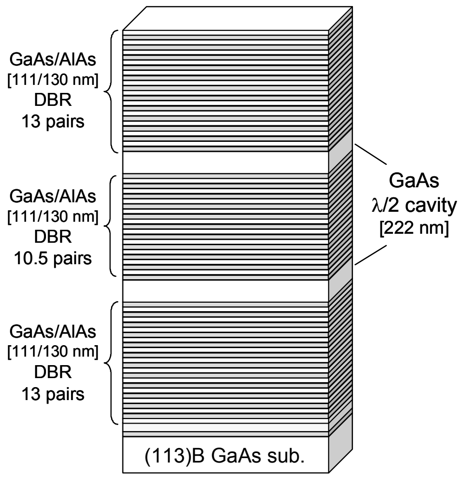

Fig. 1 Structure of the GaAs/AlAs coupled multilayer cavity grown on the (113)B GaAs substrate.

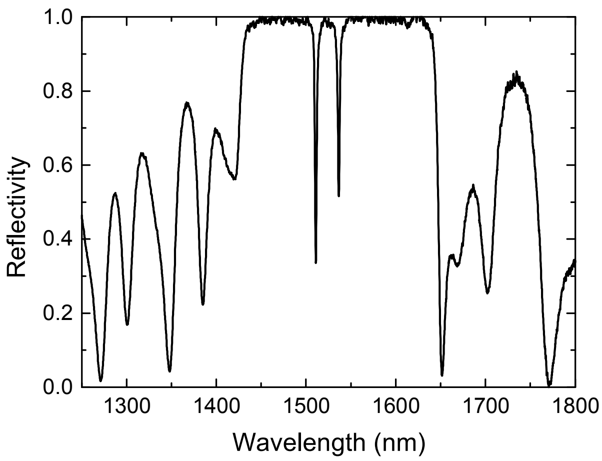

Fig. 2 Reflection spectrum of the (113)B GaAs/AlAs coupled multilayer cavity sample.

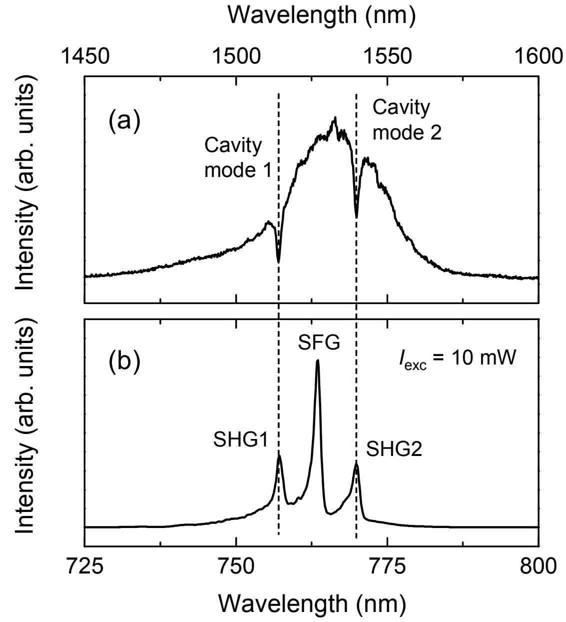

Fig. 3 Spectra of (a) reflected laser pulse and (b) SFG and SHG signals of the (113)B coupled cavity sample.

3. SFG measurements

SFG in the (113)B coupled cavity sample was characterized at room-temperature by using an ultrashort pulse laser as fundamental light source. The excitation laser beam (100 fs pulse trains with a 100 kHz repetition) was focused on the sample surface about 140 μm diameter in the normal incidence configuration. Center wavelength of the excitation laser pulse was tuned at 1533 nm, and the excitation power was varied from 5 to 20 mW. Figure 3(a) shows the spectrum of the reflected laser pulse used for the excitation. Two dips corresponding to the two cavity modes were clearly observed in the spectrum of the reflected laser pulse, indicating that the two cavity modes were simultaneously excited by the 100 fs laser pulse. The spectrum shown in Fig. 3(b) was measured in the half-wavelength range of Fig. 3(a) using the same measurement configuration (reflection configuration). Two peaks observed at 757 and 770 nm correspond to the SHG signals of the two cavity modes. In addition, the strongest peak attributed to the SFG was observed at the middle position (764 nm) between the two SHG signals. This indicates that efficient frequency mixing can be realized by using two cavity modes of the (113)B coupled cavity structure.

Figure 4 shows the excitation power dependence of peak intensities of the SHG and SFG signals. Peak intensity of the SHG signal measured for the (113)B GaAs substrate without epitaxial structure is also plotted in Fig. 4. All the SHG and SFG intensities increase in proportion to the square of the excitation power. Note that the SFG and SHG intensities of the (113)B coupled cavity sample are more than 400 times larger than peak SHG intensity of the (113)B GaAs substrate without epitaxial structure. This indicates that effective second-order nonlinearity of GaAs is strongly enhanced by the cavity effect.

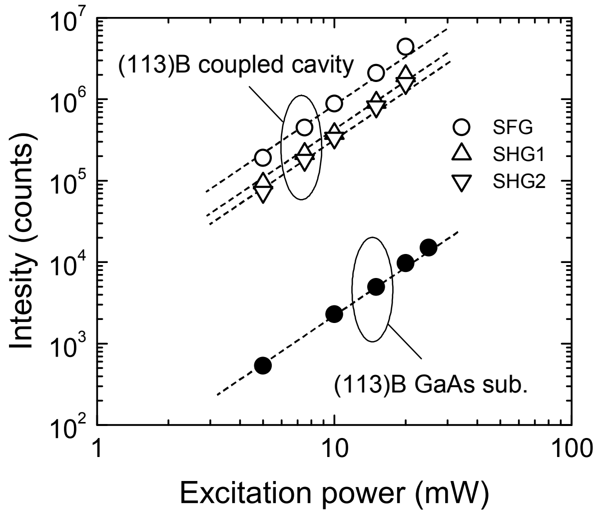

Fig. 4 Excitation power dependence of the peak intensities of the SFG and SHG signals of the (113)B coupled cavity sample. The peak SHG intensity of the (113)B GaAs substrate without epitaxial structure is also plotted.

4. Conclusions

Strong SFG in the (113)B GaAs/AlAs coupled multilayer cavity was demonstrated by ultrashort laser pulse excitation of the two cavity modes. Two GaAs λ/2 cavity layers were coupled by the intermediate DBR consisting of the 10.5-period GaAs/AlAs multilayer. Two cavity modes with frequency difference of 3.3 THz are realized in the center of the high reflection band. Strong SFG and SHG signals were observed when the two cavity modes were simultaneously excited by the 100 fs laser pulse. Peak intensities of the SFG and SHG signals are more than 400 times larger than that of the (113)B GaAs substrate without epitaxial structure because of the strong cavity effect. The GaAs/AlAs coupled multilayer cavity grown on the (113)B GaAs substrate is promising structure for the nonlinear frequency mixing devices such as terahertz emitters based on DFG of the two cavity-mode lights.

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References

[1] T. Kitada *et al.*, Appl. Phys. Express **1** (2008) 092302.
[2] K. Morita *et al.*, to be published in Phys. Status Solidi C.
[3] T. Kitada *et al.*, in preparation for publication.
[4] N. Yamada *et al.*, Jpn. J. Appl. Phys. **35** (1996) 2659.
[5] Y. Kaneko *et al.*, J. Appl. Phys. **87** (2000) 1597.