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GaAs/AlAs Triple-Coupled Cavity with InAs Quantum Dots for an Ultrafast Wavelength Conversion Device via the Four-Wave-Mixing

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Abstract

Novel ultrafast wavelength conversion devices based on a GaAs/AlAs triple-coupled multilayer cavity are proposed. A clear wavelength-converted signal was demonstrated by four-wave mixing using three cavity modes realized in the triple-coupled cavity. We found that precise control of the cavity modes is important to obtain stronger frequency conversion signals. Significant improvements in the wavelength conversion are also expected by introducing good nonlinear materials in the half-wavelength (λ/2) cavity.

1. Introduction

The novel wavelength conversion devices based on the four-wave-mixing (FWM) are attractive for ultrahigh-speed optical processing. A coupled optical microcavity system with nanostructured materials having the large third-order nonlinearity is a good candidate for the planar-type device with the high conversion efficiency. Recently, We have proposed a GaAs/AlAs tirple-coupled multilayer cavity structure as novel ultrafast wavelength conversion devices. Three cavity modes with optical frequencies ω_1, ω_2, and ω_3 are realized in the triple-coupled cavity structure that consists of three cavity layers with the same thickness. The frequency separations between two adjacent modes are the same as each other, that is, $\omega_1 - \omega_2 = \omega_2 - \omega_3$. The four-wave mixing(FWM) signal with $2\omega_2 - \omega_1$ should be efficiently generated in the triple-coupled cavity because the frequency is coincident with the other mode frequency of ω_3. Recently, we clearly observed the wavelength-converted FWM signal from the triple-coupled cavity structure by the incident pulses covered only the two modes of ω_1 and ω_2 [1]. However, the signal showed smaller intensity compared with the degenerate FWM signals of the two cavity modes with frequencies of ω_1 and ω_2. We found that $2\omega_2 - \omega_1$ was not exactly coincident with ω_3 and that the slight variation of the cavity mode frequency was caused by the layer-to-layer thickness variation due to slight and gradual changes of Ga and Al fluxes during molecular beam epitaxy (MBE) [2]. In other words, precise control of the cavity modes is important to obtain stronger frequency conversion signals. Significant improvements in the wavelength conversion are also expected by introducing good nonlinear materials in the half-wavelength (λ/2) cavity. One of the candidate materials is ensemble of InAs quantum dots (QDs) having resonance energy near the cavity mode wavelengths [3,4]. In this work, we grew the GaAs/AlAs triple-coupled multilayer cavity structure with self-assembled InAs QDs by MBE, and demonstrated that $\omega_1 - \omega_2 = \omega_2 - \omega_3$ by the precise contlol of effective optical thicknesses of three cavity layers.

2. GaAs/AlAs triple-coupled cavity with InAs quantum dots

The GaAs/AlAs triple-coupled multilayer cavity structure with InAs quantum dots shown in Fig. 1 was grown on a 2-inch GaAs (001) substrate by MBE. Two 10.5-period GaAs/AlAs (111 nm/130 nm) DBRs were used for the series connection of three λ/2 cavity layers based on AlAs, and 10.5 period DBRs were formed at both sides. The single InAs QD layer (3.4 ML) was inserted only in the topside AlAs λ/2 cavity. The QDs were embedded in strain-relaxed $In_{0.35}Ga_{0.65}As$ layer (5 nm) to extend the resonance wavelength over 1.5 μm and they were sandwiched between two strain-relaxed $In_{0.35}Al_{0.65}As$ layers (10 nm). The substrate was rotated at 30 rpm during MBE except for the growth of two AlAs layers (109 nm) composing the topside λ/2 cavity.

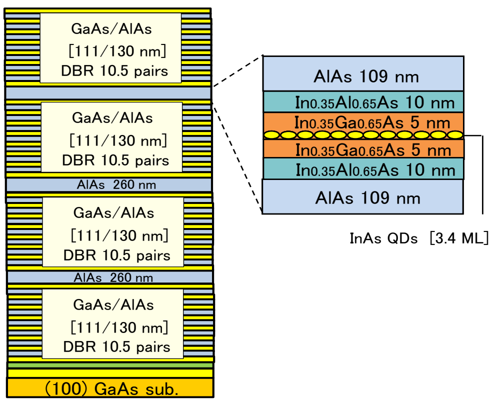

Fig. 1 Structure of the GaAs/AlAs triple-coupled multilayer cavity with InAs quantum dots.

3. Reflection spectra

Lateral thickness variation by the growth without the substrate rotation causes a slight variation of three cavity mode frequencies ($\omega_1, \omega_2, \omega_3$) in the 2-inch wafer. Figure 2 shows calculated results of the frequency separations (ω_1 - ω_2, ω_2 - ω_3) depending on the thickness of the AlAs layers in the top side cavity. Although the frequency separations were the same value at three layer thicknesses, we found that the electric field intensities of all the three modes were enhanced at the same cavity layers only at the layer thickness of 109 nm, which was desirable to enhance FWM signals.

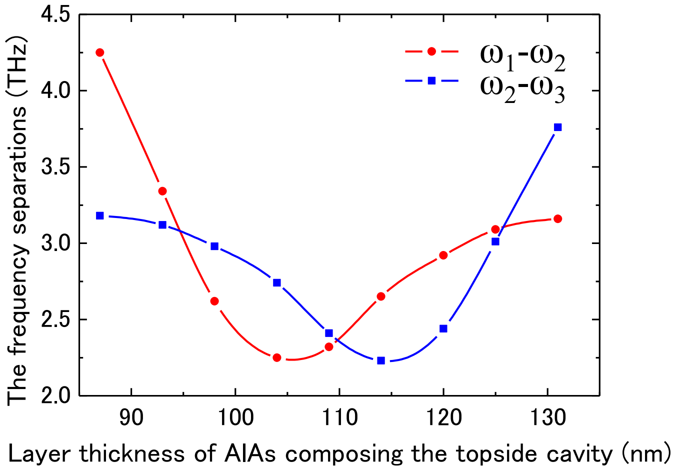

Fig. 2 Distribution of the frequency separations by growth without rotation.

Figure 3 shows optical reflection spectra measured at various wafer positions. Three reflection dips around 1.5 μm correspond to the cavity modes whose intensities depended on the measurement position. The frequency separations were changed at wafer positions and showed the same value at the position (x = - 10 mm). Three reflection dips due to the cavity modes were observed at 1466 nm, 1483 nm and, 1501 nm. The frequency separations between two adjacent modes were 18 nm respectively. These results correspond to calculated results indicate that tirple-coupled multilayer cavity structure with InAs QDs where effective optical thicknesses of three cavity layers were the same as each other was successfully fabricated.

4. Conclusions

We grew the GaAs/AlAs triple-coupled multilayer cavity with InAs quantum dots. Lateral thickness variation by the growth without the substrate rotation caused a slight variation of three cavity mode frequencies ($\omega_1, \omega_2, \omega_3$) in the 2-inch wafer. The frequency separations were changed at wafer positions and showed the same value position. These results indicate that the GaAs/AlAs triple-coupled multilayer cavity with InAs quantum dots was successfully fabricated and expected to enhance the wavelength-converted FWM signal.

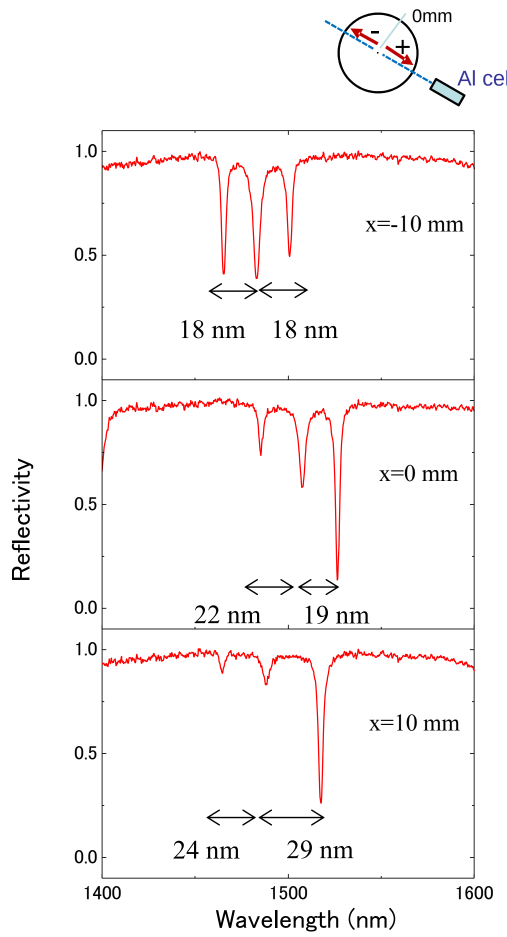

Fig. 3 Reflection spectra measured at various positions of the epitaxial wafer.

References

[1] T. Kitada, Y. Yasunaga, Y. Nakagawa, K. Morita, and T. Isu, Appl. Phys. Lett. **103** (2013) 101109

[2] T. Kitada, Y. Yasunaga, Y. Nakagawa, K. Morita, and T. Isu, Jpn. J. Appl. Phys. **53** (2014) 04EG03.

[3] K. Morita, T. Takahashi, T. Kitada, and T. Isu, Appl. Phys. Express **2** (2009) 082001.

[4] Y. Yasunaga, H. Ueyama, K. Morita, T. Kitada, and T. Isu, Jpn. J. Appl. Phys. **52** (2013) 04CG09.