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GaAs/AlAs Coupled Multilayer Cavity by Wafer-Bonding for Two-Color Emission Devices

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Abstract

We fabricated GaAs/AlAs coupled multilayer cavity structure with InAs quantum dots by wafer-bonding and demonstrated two-color emissions from the coupled cavity by optical pumping at room temperature.

1. Introduction

We have proposed novel terahertz emission devices based on efficient difference-frequency generation (DFG) of two cavity modes realized in a GaAs/AlAs coupled multilayer cavity in which two cavity layers are coupled by an intermediate distributed Bragg reflector (DBR) multilayer [1]. Terahertz DFG signal was already demonstrated by simultaneous excitation used as the fundamental light sources of the two cavity modes by irradiation of femtosecond laser pulses which had a wide spectral width of about 35 nm [2]. We also found that the nonlinear polarization control was desirable to generate strong terahertz DFG signal and that wafer-bonding was one of the best ways to fabricate the nonlinear polarization controlled structure [3]. From the view point of device applications, the fundamental lights of the two modes should be generated inside of the coupled cavity structure, which would enable terahertz emission through the DFG process without external light sources of the two fundamental modes. Actually, we fabricated the GaAs/AlAs coupled multilayer cavity including InAs quantum dots (QDs) on a (001) GaAs substrate by molecular beam epitaxy (MBE). Two-color lasing was successfully demonstrated by optical pumping under room temperature cw operation [4]. In this work, we demonstrated two-color emission from a wafer-bonded GaAs/AlAs coupled multilayer cavity by optical pumping at room temperature. InAs QDs were inserted in one of the cavities as optical gain materials of the two modes.

2. Multilayer cavity samples

Two multilayer structures shown in Figs. 1(a) and 1(b) were grown on a (001) and (113)B-oriented GaAs substrate, respectively, by a solid-source MBE. Each structure contains a two-wavelength-thick (2λ) cavity layer. The 2λ cavity of the (001) epiwafer consists of three layers of self-assembled InAs QDs [2.1 monolayer (ML)] embedded in 7-nm-thick $In_{0.15}Ga_{0.85}As$ and four GaAs spacer layers (180 nm). On the other hand, a 744-nm-thick GaAs layer was used as the 2λ cavity of the (113)B epiwafer. As shown in Fig. 1(c), two epiwafers were directly bonded at room temperature using the surface activated bonding method. In this manner, two 2λ cavities were coupled by the 11.5 period GaAs/AlAs (93 nm/110 nm) DBR multilayer. In order to measure surface emission, the (001) GaAs substrate was completely removed.

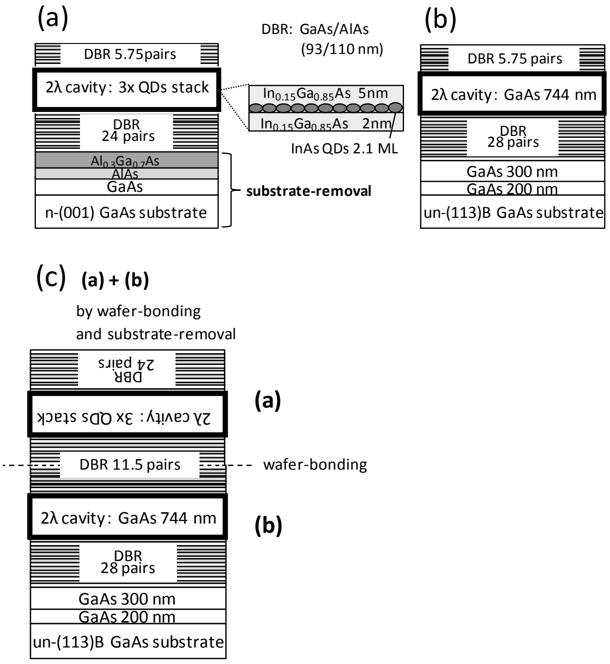

Fig. 1 (a),(b) Layer structures of two epiwafers grown on a (001) and (113)B-oriented GaAs substrate, respectively. (c) Structure of the coupled multilayer cavity by wafer-bonding and substrate-removal.

Figure. 2 shows a cross-sectional view of the wafer-bonded multilayer cavity observed by Scanning Electron Microscope (SEM) before the substrate-removal. It is clear that the designed coupled cavity structure were successfully fabricated by MBE and wafer-bonding.

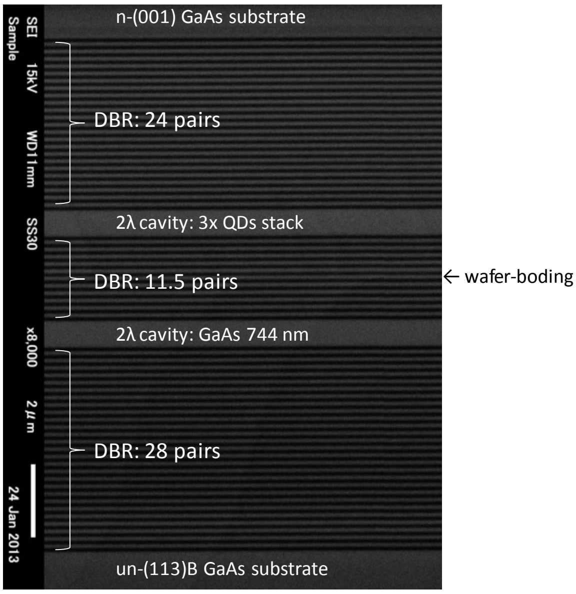

Fig. 2 A cross-sectional view of the coupled multilayer cavity observed by SEM.

3. Optical properties

Figure. 3(a) shows spectra of the optical reflection and photoluminescence (PL) of the coupled cavity structure measured at room temperature. The optical reflection spectrum was measured in the normal incidence configuration on the sample surface, while PL emission from the QDs was observed from the edge using an objective lens. In the PL spectrum, two peaks were observed due to the ground state and first excited state transitons. The PL emission band was extended over the entire region of the high-reflection band of the coupled cavity structure. This means that the ensemble of self-assembled QDs may act as an optical gain medium covering the wide range of frequency difference between two modes.

Figure. 3(b) shows the surface emission spectrum observed at an excitation power of 131 mW. The excitation source was a multimode semiconductor laser with a nominal wavelength of 920 nm, which was operated in a cw mode. The measurements were performed at room temperature. Two mode emissions were clearly observed at 1228.9 nm and 1248.1 nm. Full-widths at half maximum (FWHMs) of both sharp peaks were less than 1 nm. The observed optical frequency difference between two modes was 3.8 THz. Emission intensities of two modes were quite different from each other. Similar feature was also measured in a coupled multilayer cavity grown on a (001) GaAs substrate, and the result was explained by layer-to-layer thickness variation caused by slight and gradual changes of Ga and Al fluxes during MBE of the multilayer structure [4].

4. Conclusions

We fabricated a GaAs/AlAs coupled multilayer cavity structure by wafer-bonding. Two epilayers were grown by MBE. One of them contains self-assembled InAs QDs which were inserted only in the 2λ cavity layer of the epiwafer on a (001) GaAs substrate as gain materials. Two epiwafers were directly bonded at room temperature. Two mode emissions at wavelengths of 1228.9nm and 1248.1nm were successfully demonstrated under room temperature cw operation by optical pumping. The results indicated that the coupled cavity structure with QDs fabricated by wafer-bonding is applicable to two-color lasing source for planar-type terahertz emitting devices based on DFG of two cavity modes.

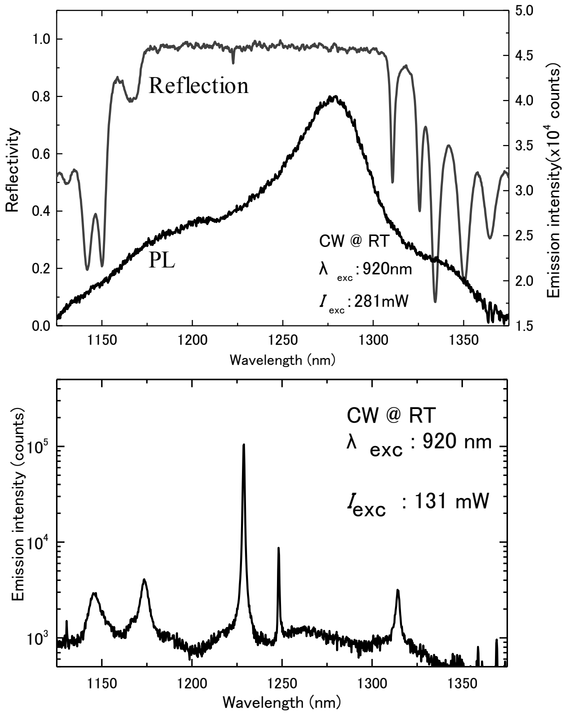

Fig. 3 (a) Optical reflection and PL emission spectra. (b) Surface emission spectrum. The emission intensity is plotted in a log scale.

Acknowledgement

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