Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp1011-1012

Evaluation of Propagation Losses in Corrugation-Reduced GaAs/AlGaAs periodically-inverted Waveguides

Shumin Wang, Tomonori Matsushita, Takashi Matsumoto, Shigeki Yoshida and Takashi Kondo

University of Tokyo
4-6-1, Hongo, Bunkyo-ku, Tokyo 153-8904, Japan
Phone: +81-3-5841-7094, E-mail: wang@castle.t.u-tokyo.jp

Abstract

We have reduced corrugation height on guiding/cladding interfaces in GaAs/AlGaAs periodically-inverted waveguides by introducing chemical mechanical polishing process during under cladding growth. We revealed that propagation loss at 1.064 μm can be decreased by reducing the corrugation height while the propagation loss at 1.55 μm is increased presumably due to twin defects in GaAs guiding layer.

1. Introduction

Coherent light sources in the mid-infrared region are usable for gas detection and remote sensing. Difference frequency generation (DFG) is a candidate for realizing efficient mid-infrared light sources. GaAs and AlGaAs are promising materials for DFG devices because of their large quadratic optical nonlinearities and wide transparency windows in the infrared. To increase conversion efficiency of GaAs/AlGaAs waveguides, periodically inverted structure is needed for achieving quasi-phase matching (QPM). We have developed periodically-inverted AlGaAs waveguides [1], which are fabricated using sublattice reversal epitaxy technique to grow spatially inverted GaAs [2]. However, the fabricated waveguides suffer from relatively large propagation losses due to corrugation on the interfaces between guiding and cladding layers. The corrugations are shown to be produced by anisotropic diffusion III-group atoms on GaAs (100) surfaces during molecular beam epitaxy (MBE) growth [3]. To decrease the propagation losses, corrugation reduction is indispensable.

In this paper, we report the reduction of corrugation height in a GaAs/AlGaAs waveguide by introducing chemical mechanical polishing (CMP) process during MBE growth process of an under-cladding layer. We evaluated propagation losses of the waveguide at 1.064 μm (a pump wave) and 1.55 μm (a signal wave) bearing application to 4-μm idler wave generation in mind.

2. Device Fabrication

We prepared two periodically-inverted GaAs/AlGaAs waveguides using fabrication processes without and with CMP process introduced during the under cladding growth. The waveguides, which are composed of a 1.0-μm-thick $Al_{0.1}Ga_{0.9}As$ upper cladding layer/a 1.6-μm-thick GaAs guiding layer/a 7.0-μm-thick $Al_{0.1}Ga_{0.9}As$ under cladding layer, were grown on periodically-inverted GaAs (100) substrates by using MBE at 460°C. 5-μm-wide and 0.9-μm-deep ridges were formed by chemical etching. The spatial-inversion periods were 7.8 μm. We used 1.2 g/l INSEC-NIB (NaClO) solution as a surrey to perform CMP. Figure 1 shows cross-sectional SEM images of the strain-etched waveguides. In the waveguide fabricated with CMP process (CMP waveguide), CMP interface was clearly observed in the under-cladding layer. Figure 2 shows AFM images of the fabricated waveguides. The estimated corrugation heights on the interfaces between guiding and cladding layers of the CMP waveguide and the waveguide fabricated without CMP (non-CMP waveguide) were 8 nm and 19 nm, respectively.

3. Propagation losses

We measured propagation losses for TM-polarized 1.064 μm pump and TE-polarized 1.55 μm signal by using Fabry-Perot method. Figure 3 shows temperature dependent transmittance at 1.064 μm where interference fringes due to multiple reflections in the waveguide are superimposed on a single peak curve exhibiting a change in beam coupling efficiency. The estimated propagation losses of the non-CMP and CMP waveguides are 19 dB/cm and 12.6 dB/cm, respectively. By introducing CMP process, the propagation loss at 1.064 μm was reduced as expected. Figure 4 shows transmittance spectra of the waveguides measured around 1.55 μm. The estimated propagation losses were 1.3 dB/cm and 4.5 dB/cm for non-CMP and CMP waveguide, respectively. Although the corrugation height was reduced in the CMP waveguide, the propagation loss at 1.55 μm was increased.

Origins of propagation losses can be classified as follows. Figure 5 shows bar charts of classified propagation losses. The propagation loss of the CMP waveguide at 1.55 μm is dominated by light scattering by corrugations. Since the scattering loss is proportional to wavelength to the minus fourth power and corrugation height squared, the scattering losses can be estimated for another waveguide and wavelength as shown in Fig. 5. The propagation loss in non-CMP waveguide at 1.064 μm is dominated by large scattering and the residual loss can be attributed to absorption in the Urbach tail. We speculate that the additional losses in the CMP waveguide (3.9 dB/cm at 1.55 μm and 1.064 μm) are due to twin defects which are clearly seen as slanted lines in Fig. 1 (a). These twin defects are produced by inadequate treatment/growth procedure resulting in three-dimensional growth in the early stage of the regrowth process of the under cladding layer. We have to improve MBE regrowth process on the AlGaAs CMP surfaces in order to further decrease propagation losses.

4. Conclusions

We have successfully reduced heights of corrugations on the interfaces between guiding GaAs and cladding AlGaAs layers in a periodically-inverted GaAs/AlGaAs waveguide by introducing CMP process during the regrowth of the AlGaAs under cladding layer. As a result, propagation losses due to scattering are decreased by about 1/4, although additional losses due to twin defects are introduced.

References

[1] J. Ota, W. Narita, I. Ohta, T. Matsushita, and T. Kondo, Jpn. J. Appl. Phys. **48** (2009) 04C110.

[2] S. Koh, T. Kondo, M. Ebihara, T. Ishiwada, H. Sawada, H. Ichinose, I. Shoji, and R. Ito, Jpn. J. Appl. Phys. **38** (1999) 508.

[3] T. Yamamura, T. Matsushita, T. Koitabashi, and T. Kondo, Jpn. J. Appl. Phys. **44** (2005) 1397.

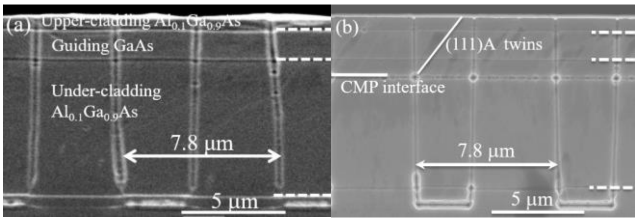

Fig. 1 Cross-sectional SEM images of the waveguides fabricated without CMP process (a) and with CMP process (b).

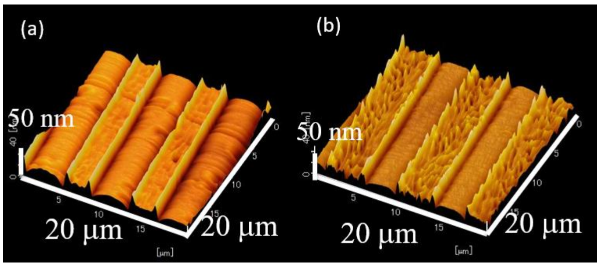

Fig. 2 Surface AFM images of the waveguides fabricated without CMP process (a) and with CMP process (b).

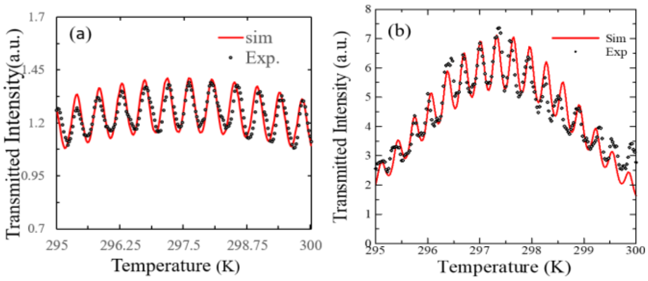

Fig. 3 Temperature-dependence of transmitted light intensities at 1.064 µm (TM polarization) for the waveguides fabricated without CMP process (a) and with CMP process (b).

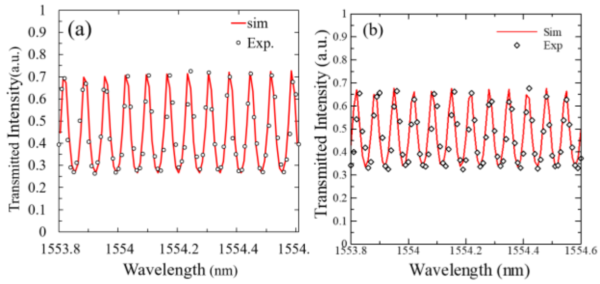

Fig. 4 The transmitted-intensity spectra around 1.55 µm (TE polarization) of the waveguides fabricated without CMP process (a) and with CMP process (b).

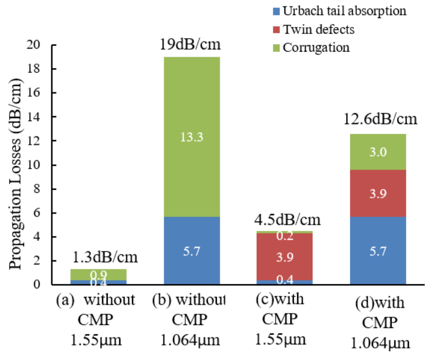

Fig. 5 Bar charts of propagation losses of the waveguides fabricated without CMP process (a)(b) and with CPM process (c)(d). (a) and (c) are measured at 1.55 µm (TE polarization), and (b) and (d) are measured at 1.064 µm (TM polarization).