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Quasi-Phase-Matched Second-Harmonic Generation in AlGaAs Waveguides Pumped at 1.5 μm

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1. Introduction

Quasi-phase-matched (QPM) difference-frequency generation (DFG) devices working in the communication wavelength region have been extensively studied because of their potential applications to wavelength converters in wavelength division multiplex optical communication networks. Demands for wavelength conversion devices include large bandwidths, high conversion efficiencies, robustness and compactness. AlGaAs waveguiding QPM devices have been investigated because AlGaAs has attractive properties. Since they exhibit much higher quadratic nonlinearities than conventional nonlinear optical crystals such as $LiNbO_3$, AlGaAs QPM devices have a potential for realizing high conversion efficiencies with relatively short device lengths and/or lower pump intensities. Moreover, they can potentially be integrated with pumping laser diodes monolithically. Wavelength conversions in the 1.5 μm wavelength region using QPM AlGaAs waveguides reported to date have, however, been suffered from severe propagation losses which hinder efficient nonlinear optical interactions over reasonably long lengths.[1-3] High propagation losses in QPM AlGaAs waveguide are due to corrugations on the core/clad interfaces which are formed inevitably during the processes of AlGaAs regrowth on the periodically-inverted patterned GaAs templates. In this paper, we report an improved process for fabricating AlGaAs QPM waveguides with suppressed corrugations. Results of a second-harmonic generation (SHG) experiment are also reported.

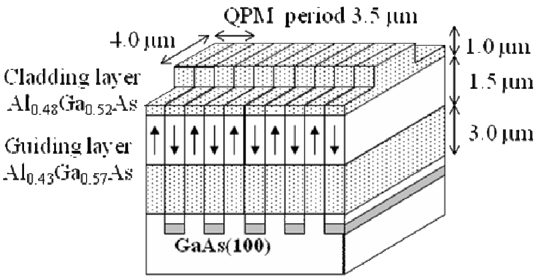

Fig. 1 Schematic drawing of the designed QPM-DFG waveguiding AlGaAs device

2. Device Fabrication

Figure 1 schematically shows an AlGaAs waveguiding device designed for QPM DFG in the 1.5 μm wavelength region pumpable with AlGaAs laser diodes oscillating around 0.78 μm. We adopted the ridge waveguide structure in order to suppress scattering losses due to side wall roughness. The ridge stripe is parallel to <011> upon which pump, signal and idler light waves interact via the nonlinear optical coefficient d_{14}, a single nonzero component of the nonlinear optical coefficient tensor of zincblende-type crystals.

We have fabricated QPM AlGaAs waveguides by using a standard solid-source molecular-beam epitaxy (MBE) based on sublattice-reversal epitaxy technique [4,5] we have developed for fabricating spatially inverted GaAs epitaxial crystals. Outline of the fabrication process was as follows: 1) a spatially inverted GaAs layer is epitaxially grown on a Ge interlayer deposited on a GaAs (100) substrate misoriented toward $[0\bar{1}1]$ by 2 degree: 2) the GaAs epilayer and the Ge interlayer were periodically etched with the designed QPM period so that inverted and noninverted GaAs surfaces are alternately exposed; 3) a thick GaAs epilayer was regrown on the template; 4) the corrugated surface of the regrown GaAs epilayer was planarized by chemical mechanical polishing; 5) AlGaAs clad/core/clad structure was formed on the planarized template by MBE regrowth: 6) 4-μm-wide ridges running along [011] were formed by chemical etching.

We paid special cares in the process of AlGaAs regrowth for fabricating waveguiding structures. We have adopted the low temperature growth technique in order to suppress the corrugation formation during the regrowth process which are caused by the anisotropic surface migration of Ga atoms on GaAs (100) surfaces.[6] We have grown lower and upper cladding layers of $Al_{0.58}Ga_{0.42}As$ at 350^{o}C. For the growth of the guiding layer where almost all the light powers are confined, we grew the $Al_{0.53}Ga_{0.47}As$ layer under the standard high-temperature (520^{o}C) condition because the low-temperature growth of the guiding layers resulted in relatively high propagation losses. Figure 2 shows the cross-sectional SEM image of the stain-etched waveguide. Although some imperfections are observed, the designed periodically-inverted AlGaAs waveguiding structure has been successfully fabricated.

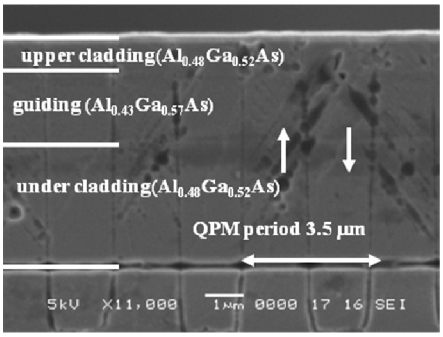

Fig. 2 SEM image of stain-etched cross section of a QPM AlGaAs waveguide

3. SHG Experiment

We have characterized wavelength conversion performance of the fabricated devices by SHG pumped by a fundamental light source oscillating in the 1.5 μm wavelength region. Experimental setup of the SHG experiment is schematically shown in Fig. 3. The fundamental light source we used was a tunable external cavity InGaAsP laser diode (NEWFOCUS, 6328-H). The TE-polarized fundamental light was fed into the sample waveguide by end-fire coupling. TM-polarized second-harmonic output generated by the type I QPM was detected with a Si photodetector and the signal was amplified by using the lock-in technique. A 1.5-mm-long waveguide was mounted on a temperature-controlled stage and the device temperature was kept at 85°C in order to achieve 1st-order QPM in the tuning range of the fundamental light source.

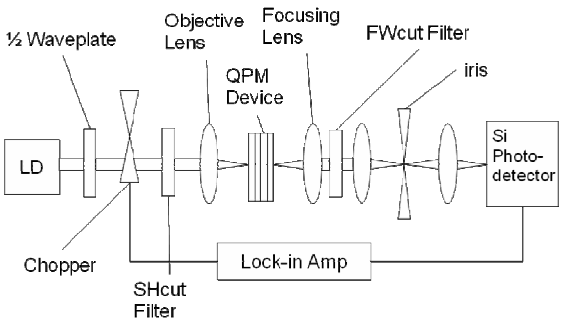

Fig. 3 Experimental setup

The obtained second-harmonic intensities are plotted as a function of the fundamental wavelength in Fig. 4. The 1st-order QPM has been achieved at the fundamental wavelength of 1522 nm. The theoretical tuning curve calculated assuming a lossless 1.5-mm-long device closely fits the experimental result indicating that almost all the length of the waveguide contributes the wavelength conversion. It should also be noted that the observed short-period oscillations superimposed on the sinc-squared tuning curve due to the Fabry-Perot resonances imply a low propagation loss in the waveguide.

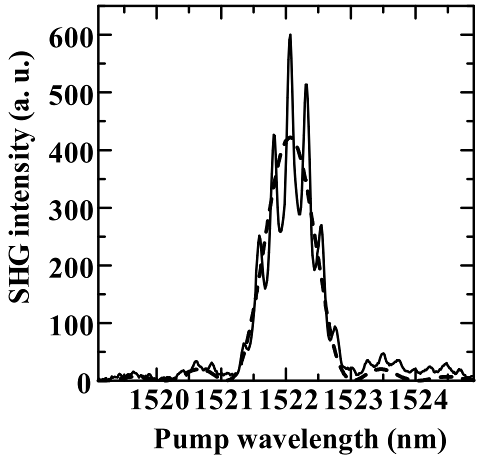

Fig. 4 Second-harmonic intensity vs. fundamental wavelength. Solid and broken lines represent experimental and theoretical tuning curves, respectively.

4. Conclusions

We have improved the process for fabricating high-quality AlGaAs QPM waveguiding devices. By combining standard high-temperature MBE growth with low-temperature MBE growth for suppressing corrugation formation, we have succeeded in fabricating periodically-inverted AlGaAs waveguides with relatively small corrugations on the core/clad interfaces. We fabricated a device with a 3.5-μm QPM period for the 1st-order QPM in the 1.5 μm wavelength region using the improved process. We observed the QPM SHG in a 1.5-mm-long AlGaAs waveguide and confirmed that the propagation loss was satisfactorily small in the waveguide. Accurate measurements of the waveguide losses and conversion efficiencies using longer devices are now in progress.

Acknowledgements

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