論文の内容の要旨

Abstract of Dissertation

Microstructural investigation of compound semiconductor waveguiding wavelength conversion devices

(化合物半導体導波路型波長変換素子の微細構造評価)

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Compound semiconductors AlGaAs have large quadratic nonlinear optical susceptibilities and thus are advantageous materials for nonlinear optical applications. However the optical isotropy of cubic semiconductor crystals prevents birefringent phase matching (BPM). To overcome the drawback of isotropic materials, various phase matching methods have been suggested and realized. Among the phase-matching techniques, quasi-phase matching (QPM) is the most popular and promising phase matching method. Some QPM devices are now commercially available, such as periodically-poled $LiNbO_3$ (PPLN) waveguides. Recently, periodically-inverted AlGaAs QPM waveguides, fabricated through sublattice-reversal epitaxy technique, have shown remarkable results and various possibilities. Although the AlGaAs QPM waveguides are expected to show more advanced properties, however, internal microscopic structure of the periodically-inverted AlGaAs QPM device are not fully understood, yet. To enhance quality of the periodically-inverted AlGaAs QPM waveguides fabricated with sublattice-reversal epitaxy technique, it is obvious that the microstructural investigation must be conducted.

I investigated the microstructures of the periodically-inverted GaAs-core and AlGaAs-core QPM waveguides fabricated through the sublattice-reversal epitaxy technique with transmission electron microscope (TEM). In the dark-field TEM image observations on a GaAs-core QPM waveguide, I have succeeded in direct observation of the artificial antiphase structure, which has only been predicted through indirect investigation, and confirmed growth of the self-annihilating non-inverted GaAs domains is strongly affected by facet direction of Ge layer steps.

For an $Al_{0.5}Ga_{0.5}As$-core QPM waveguide, I performed electron diffraction pattern and conventional TEM image analyses. Based on the obtained TEM images and diffraction patterns dominated by twin axes and streaks, I have revealed that both of the inverted and non-inverted AlGaAs domains include (111)A and $(1\bar{1}\bar{1})$A twin planes. In particular, it should be emphasized that not only non-inverted domains but also inverted domains suffer from the intensive (111)A and $(1\bar{1}\bar{1})$A twin formation which has not been clarified by the conventional SEM observations. These planar defects are presumably due to lattice mismatch between AlGaAs and GaAs, and should be reduced to improve wavelength conversion performances.

As an alternative approach to achieve phase matching in AlGaAs waveguides, I have fabricated and characterized high-index-contrast birefringent phase matching (HIC-BPM) waveguides which are expected to be highly efficient with a relatively simple structure. The fabricated HIC-BPM waveguides are composed of 103-nm-thick $Al_{0.5}Ga_{0.5}As$ cores sandwiched between oxidized $Al_{0.93}Ga_{0.7}As$ cladding layers and widths of the fabricated HIC-BPM waveguides are 1.7, 1.78, 1.84 and 1.86 μm. By characterizing the HIC-BPM waveguides, phase matched SHG signals were observed in the 1.55-μm fundamental wavelength range for the first time. The experimental result of guide-width dependence of the phase-matching wavelength is in close agreement with the numerical simulation.

In summary, I have identified the artificial antiphase structure in a GaAs-core QPM waveguide and found twin planes in both non-inverted and inverted domains of a AlGaAs-core QPM device with the direct TEM observation. As another approach for efficient wavelength conversion, AlGaAs HIC-BPM waveguides were fabricated and characterized. The realization of the HIC-BPM waveguide and the microscopic analysis of the QPM devices fabricated by sublattice-reversal epitaxy technique are expected to give new insight for improving the performances of the semiconductor nonlinear optical devices.