論文の内容の要旨
Abstract of Dissertation

GaN/AlN Multiple Quantum Wells and Nitride-Based Waveguide Structures for Ultrafast All-Optical Switch Utilizing Intersubband Transition

（サブバンド間遷移超高速全光スイッチに向けた
GaN/AlN 多重量子井戸及び窒化物系導波路構造に関する研究）

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Intersubband transition (ISBT) in multiple quantum wells (MQW) has drawn much attention for ultrafast optoelectronic devices owing to its wide wavelength-tunability and extremely fast energy relaxation process. Recently, the extension of ISBT wavelength to near-infrared wavelength, especially 1.55 μm, is of particular interest because such wavelength is vital for the development of ultrafast photonic devices for silica-fiber-based optical-communication networks. Among various materials proposed for intersubband transition at 1.55 μm, GaN/AlN MQW structures are promising due to their large conduction band offset of approximately 2 eV. Furthermore, the large electron effective mass and the large LO phonon energy in nitrides make their intersubband relaxation extremely fast in the order of sub-picoseconds. This makes intersubband transition in nitrides immensely interesting for the development of ultrafast photonic devices operating at a bit rate higher than 1 Tb/s.

The intersubband transition at 1.55 μm and shorter wavelengths have been achieved by molecular beam epitaxy (MBE) with the shortest wavelength of 1.08 μm. On the other hand, growth by metalorganic vapor phase epitaxy (MOVPE) has not yielded satisfactory results as the shortest ISBT wavelength reported is merely 2.4 μm. The demonstration of 1.55-μm ISBT by MOVPE, however, is still attractive since much better crystalline quality for device fabrication can be achieved. Moreover, MOVPE also has another advantage over MBE in industrial point of view. Indeed, the ultrafast optical switching utilizing intersubband transition has been demonstrated by MBE-grown GaN ridge waveguide structure with a bit rate higher than 1 Tb/s. However, such device requires optical-pulse switching energy higher than 10 pJ/μm^2 to utilize the saturable intersubband absorption, which is still too large for the applications in conventional optical communication networks. Reduction of the switching

energy is therefore another important issue for the intersubband transition devices. In order to reduce the switching energy, not only the waveguide fabrication process, but also the epitaxial growth technique and the device structure have to be improved.

In this dissertation, the GaN/AlN multiple quantum wells and nitride-based waveguide structures are studied and fabricated for the applications of ultrafast all-optical switch utilizing intersubband transition. The ultrafast intersubband transition device is realized by using AlN waveguide structure with GaN/AlN quantum wells. This AlN-waveguide-based intersubband transition device can operate in the optical communication wavelength range, covering 1.3 μm, the shortest wavelength ever demonstrated for the intersubband transition devices.

In order to perform epitaxial growth of such structure with high quality, MOVPE is more preferable than MBE because the AlN layer can be grown with much better quality by the MOVPE. However, since the MOVPE growth of GaN/AlN MQW for the 1.55-μm ISBT is very difficult, the AlN waveguide structure was fabricated with a combination of both MOVPE and MBE growth techniques: MOVPE growth for AlN buffer layer and MBE re-growth for GaN/AlN multiple quantum wells. With this combination, the high quality waveguide with intersubband absorption in a wavelength range of 1.3-1.55 μm is achieved.

In addition to the improvement in the epitaxial growth technique, this dissertation also discusses on the problems in growing the waveguide structure of both MOVPE and MBE. Moreover, the design and fabrication of nitride-based waveguide structures are studied in details to improve the waveguide quality. The high-optical-confinement waveguide structures are proposed and successfully fabricated for the first time thanks to the successful demonstration of epitaxial growth and the improvement of fabrication process. Additionally, a new waveguide characterization method using the supercontinuum light source is also proposed and demonstrated. With this new characterization method, not only are the direct measurements of intersubband absorption in waveguides realized, but the problems in waveguide quality of the MBE-grown waveguide are also revealed. This provides very useful information for the improvement of fabrication process, especially the epitaxial growth process. The achievements in each area of epitaxial growth, waveguide fabrication process, and characterization, have made contributions to the improvement of waveguide characteristic, leading to the successful demonstration of the first AlN-waveguide-based intersubband transition devices with high performance.