Abstract

Dramatic growth in fiber-optical network traffic demand is driving the need for new high-bandwidth optical components including optical switches. Many technologies; for example, microelectro mechanical systems (MEMS), silica-on-silicon planar lightwave circuit (PLC), polymer optical waveguide, intersubband transition (ISBT) in quantum nanostructure, optical non-linearity in semiconductor optical amplifier (SOA), have been proposed as a candidate for a solution of high optical traffic demand. Each technology possesses unique advantage and disadvantage properties. Among these competitors, intersubband transition in semiconductor multiple quantum wells (MQWs) has an outstanding merit which is the ultrafast response. In the fiber-optic communications, the conventional wavelength window, known as the C band, covers the wavelength range 1.53-1.57 μm, and the new dry fiber has a low-loss window promising an extension of that range to 1.30-1.65 μm. Hence, material systems with large enough conduction band offset to accommodate intersubband transitions at these relatively short wavelengths include InGaAs/AlAsSb, (CdS/ZnSe)/BeTe, GaInNAs/AlAs, and GaN/Al(Ga,In)N MQWs. Among these materials, GaN/AlN MQW structures are promising owing to their large conduction band offset allowing a short intersubband transition wavelength in a simple quantum well structure. Moreover, the extremely fast intersubband relaxation in the order of sub-picoseconds due to the large longitudinal optical phonon energy and the large electron effective mass promotes intersubband transition in nitrides immensely interesting for the development of ultrafast photonic devices capable for 0.1-1 Tb/s bit rate.

However, in the past few years, the number of publications of all-optical switches using intersubband transition in nitride MQWs is not as much as that of GaN-based light emitting devices and high electron mobility transistors. It has also been overwhelmed by fiber-based and phosphide-based optical switches. This is because of the growth of GaN/AlN MQWs realizing short intersubband transition wavelength is not an easy task, especially the growth by metalorganic vapor phase epitaxy (MOVPE) technique which is a large-scale fabrication system. The short intersubband transition in GaN/AlN MQWs has been long for only realized by molecular beam epitaxy (MBE) technique. Furthermore, the issue of high power consumption for operating nitride-based all-optical switches is considerably one of major obstructions. Due to

these reasons, the research of intersubband transition in GaN/AlN MQWs as well as their applications has been developed in a slow manner.

In this work, the MOVPE growth and fabrication of all-optical switches utilizing intersubband transition in GaN/AlN MQWs have been investigated. The issue of the realizing of short intersubband transition wavelength in MOVPE grown GaN/AlN MQWs has been first conducted by extracting the factors that hinder the short wavelength. A growth method called pulse injection method has been investigated and used for suppressed the problem caused by the conventional MOVPE growth. By tailoring the strain in GaN/AlN MQWs using AlGaN interlayer inserted between GaN/AlN MQWs and AlN buffer layer, 1.5-μm-range intersubband transition has been fully realized using pulse injection MOVPE. The properties of intersubband transition are excellent in terms of transition wavelength, absorption intensity and full-width at half-maximum of absorption peak.

Later in this dissertation, AlN-based waveguides with GaN/AlN MQWs grown by MOVPE have been designed and fabricated. The measurement and characterization of fabricated AlN-based waveguide has demonstrated the existence of intersubband absorption in waveguide structure which is an important step toward the fabrication of all-optical switches. The propagation loss in AlN-based waveguide has been investigated and analyzed by comparing with MBE fabricated samples. Later, the spot-size converter has also been introduced as an answer for high coupling loss issue in the plane waveguide structure. Each of AlN-based waveguides fabricated in this thesis exhibited the saturable absorption indicating the functionality of all-optical switch.

This dissertation has demonstrated the potential of all-optical switch application in MOVPE grown AlN-based waveguide with GaN/AlN MQWs absorption core. This achievement is an important milestone in the development of optical devices utilizing intersubband transition in MOVPE grown GaN/AlN MQWs. Furthermore, the succeed in the growth procedure indicates the capability of MOVPE system for the growth of high quality GaN/AlN MQWs and may renew the interest of intersubband transition in nitride semiconductors.