論 文 の 内 容 の 要 旨

論文題目 Study on Characterization of Intersubband Transition in Non-polar m-plane AlGaN/GaN Quantum Wells
（非極性m面AlGaN/GaN量子井戸におけるサブバンド間遷移の評価に関する研究）

氏　　名　小谷　晃央

Intersubband (ISB) devices have been attracting much interest especially in the infrared (IR) and Terahertz (THz) spectral range. Since III-nitrides have a much larger longitudinal optical phonon energy and band offset than conventional GaAs-based materials, III-nitrides are considered as promising for high-speed switching devices operating at telecommunications wavelength, and Quantum Cascade Lasers (QCLs) in THz range.

Studies on ISB transitions in III-nitrides have mainly been done on c-plane multiple-quantum wells (MQWs). However, in c-plane MQWs, the spontaneous and piezoelectric polarization make the subband design and transition energy tuning much more complex, especially in the mid-IR/THz ranges.

A non-polar nitride QW is one solution for ISB devices in the long wavelength range. Recently, high-quality m-plane GaN bulk substrates have become commercially available, and high-quality interband devices have been developed. Since non-polar QWs do not have a built-in electric field, the design of ISB devices using non-polar structures should be more flexible. However, there have been no studies on ISB transition of m-AlGaN/GaN QWs before we started this research.

For ISB device applications, it is important to understand the fundamental physics of ISB transition such as absorption properties, many-body effects, temperature dependences. In addition, the development of crystal growth technique for high-quality QWs, and the numerical design based on relevant modeling and simulation technique are also important.

This thesis focuses on those research issues and original research conclusions for the ISB transition in non-polar m-plane AlGaN/GaN QWs are presented in the following.

First, we have succeeded to grow high-quality m-plane AlGaN/GaN QWs by metalorganic chemical vapor deposition (MOCVD), and observed the ISB absorption from MOCVD-grown m-plane AlGaN/GaN for the first time.

Second, we have quantitatively explained the many-body and scattering effects in ISB transition in m-plane AlGaN/GaN QWs by both experimentally and theoretically. In addition, we have extracted the material parameter sets nicely reproducing the ISB absorption.

Third, we have, both experimentally and theoretically, shown that the subband structures of m-plane AlGaN/GaN QWs are much more stable in temperature change (a few meV shift between below 10 K to 300 K) than that of the other III-V materials.

Finally, using the extracted material parameter sets, we have theoretically demonstrated that the non-polar m-plane AlGaN/GaN QCLs can be operated at much higher temperature in THz than the conventional AlGaAs/GaAs QCLs. This simulation results suggest that non-polar m-plane AlGaN/GaN QWs are promising materials for THz emission devices.

This thesis is organized into eight chapters.

In Chapter 1, the background the objective of this research are presented. The current situation of III-nitride based ISB device, and the motivation and the scope of this research are presented.

In Chapter 2, the general material properties of III-nitride semiconductor presented.

In Chapter 3, the optimization of m-plane AlGaN/GaN QWs growth is presented. Several growth conditions such as growth temperature and carrier gas are optimized. The optimized m-plane AlGaN/GaN QWs have atomically flat surface with periodic step-terrace structures with surface roughness of 0.1 nm range, and abrupt interface confirmed by X-ray diffraction measurement. The crack-free thick AlGaN was also grown by inserting a thin AlN interlayer between GaN and AlGaN layer.

In Chapter 4, the optical properties of non-polar m-plane AlGaN/GaN QWs are presented. The observed photoluminescence (PL) at room temperature is in good agreement with the simulation based on 6-band k.p method. The ISB absorption in mid-infrared range was clearly observed.

In Chapter 5, the doping density dependent ISB absorption properties are presented. As doping density increases, the peak of ISB absorption blueshifts and the linewidth gets broader. We have theoretically analyzed the influence of many-body and scattering effects to ISB absorption spectra. We found that the screening in many-body effects plays an important role and our simulations nicely reproduce the doping dependent absorption spectra.

In Chapter 6, the temperature dependence of ISB absorption spectra is presented. We found that the ISB absorption in m-plane AlGaN/GaN does not show significant shift when the temperature is decreased to ~8K. The amount of shift of ISB absorption in m-plane AlGaN/GaN QWs is much smaller than that in other III-V materials. This suggests that the ISB device by m-plane AlGaN/GaN may be robust in temperature change.

¥par

In Chapter 7, m-plane AlGaN/GaN QCL structures are designed by non-equilibrium Green's function (NEGF) method. It is demonstrated that m-plane AlGaN/GaN QCLs shows superior temperature performance to the conventional AlGaAs/GaAs QCLs. And, the new m-plane

AlGaN/GaN QCL structures showing large gain even at room temperature are designed.

In Chapter 8, the conclusion, and the future perspective of this research are presented.