Intersubband Transition in GaN/AlN Multiple Quantum Wells for Optical Switches

Norio Iizuka, Kei Kaneko, Nobuo Suzuki, Chaiyasit Kumtornkittikul, Toshimasa Shimizu, Masakazu Sugiyama, and Yoshiaki Nakano

***Abstract*—Intersubband transition in GaN/AlN quantum wells was investigated from the viewpoint of application to ultrafast all-optical switches. Two types of device structure were examined; GaN-based and AlN-based waveguides. With GaN-waveguide, a gate switch operation was achieved with the gate width of 230 fs and the extinction ratio of greater than 10 dB. With AlN-waveguide, the possibility of switching with wavelengths of 1.3 and 1.55 μm was confirmed.**

***Index Terms*—Gallium nitride, intersubband transition, optical switch, quantum well**

I. Introduction

INTERSUBBAND transition (ISBT) in semiconductor quantum wells (QWs) is expected to be applied to high-speed all-optical switching devices. Quantum well structures such as InGaAs/AlAs, InGaAs/AlAsSb, (CdS/ZnSe)/BeTe and GaN/Al(Ga)N have been investigated as candidates for the application. Above all, nitride-semiconductor QWs have several advantages, namely: 1) the absorption recovery time is considerably lower than 1 ps, 2) a wide range of wavelengths is available with a less-complicated QW structure, 3) the homogeneous line width is sufficiently broad due to the short dephasing time, 4) two-photon absorption does not interfere with the saturable absorption due to the wide band-gap, and 5) the material is robust and less toxic. Since the application of GaN QWs to all-optical switches was proposed by Suzuki in 1997, there have been many studies on this subject.

In this paper, the authors' investigations are reported with regard to the application of the ISBT in GaN QWs to all-optical switches that can be operated at optical communication wavelengths.

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N. Iizuka, K. Kaneko and N. Suzuki are with Corporate Research & Development Center, Toshiba Corp., Kawasaki 212-8582, Japan (e-mail: nori.iizuka@toshiba.co.jp).

C. Kumtornkittikul, T. Shimizu and Y. Nakano are with Research Center for Advanced Science and Technology, Univ. of Tokyo, and Solution Oriented Research for Science and Technology, Japan Science and Technology.

M. Sugiyama is with the Department of Electronic Engineering, Univ. of Tokyo, and Solution Oriented Research for Science and Technology, Japan Science and Technology Agency.

II. Device Fabrication and Measurements

The samples had a waveguide structure consisting of GaN or AlN layer with GaN/AlN MQWs at the middle of the layer. Until recently, ISBTs in GaN QWs were observed at optical communication wavelengths only with QWs grown by molecular beam epitaxy (MBE). Generally, however, an MBE-grown layer has more edge dislocations than a layer grown by metal-organic chemical vapor deposition (MOCVD) does. The edge dislocations were found to bring about excess propagation loss in transverse magnetic (TM) mode [1]. In our studies, one sample had multiple intermediate layers (MILs) as dislocation filter and the others were grown on an MOCVD-grown buffer layer. These structures led to suppression of the excess polarization-dependent loss (PDL). Ridge or high-mesa waveguide structures were fabricated by using dry-etching technology. The waveguide length was 400 μm.

The measurements of saturable absorption and gate switch operations were carried out by utilizing an optical parametric oscillator (OPO) excited by a mode-locked Ti:sapphire laser with a repetition rate of 80 MHz. The pulse width was nominally 130 fs. The pulses were input through a polarization-maintaining dispersion-shifted fiber (PMDSF).

III. Gate Switch Operation of GaN-Based Sample

Gate switch operations were examined utilizing the signal (1.55 μm) and the idler (1.7 μm) from the OPO. Figure 1 shows the result of the pump-probe measurements with multiple probe pulses[2]. The measurements were carried out with the sample with MILs. The wavelength and the energy of the control pulse were 1.7 μm and 100 pJ, and those of the signal pulses were 1.55 μm and 4 pJ, respectively. The signal pulse interval varied from 2 to 0.67 ps. When the control pulses coincided with one of the signal pulses, the transmittance increased. This verifies that demultiplexing operation was achieved for the pulse train with an interval of less than 1 ps.

Extinction ratio of more than 10 dB was also verified. Figure 2 shows a gate-switch performance for the sample grown on an MOCVD-grown buffer [2]. Pulse energies for control and signal were 150, and 5 pJ, respectively. The extinction ratio was 11.5 dB and the gate width was 230 fs.

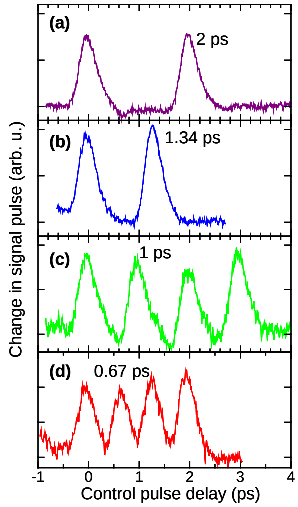

Fig. 1. Change in the transmitted signal intensity as a function of signal delay for the sample with an MIL buffer [2]. The signal pulse interval is (a) 2 ps, (b) 1.34 ps, (c) 1 ps, and (d) 0.67 ps.

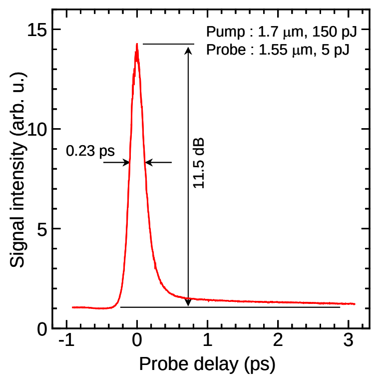

Fig. 2. Dependence of transmitted probe intensity on the pump-probe delay for the sample grown on an MOCVD-grown GaN [2]. The wavelengths and the pulse energies are 1.7 μm and 150 pJ for pump, and 1.55 μm and 5 pJ for probe, respectively.

IV. Saturable Absorption of AlN-Based ISBT

The AlN-based waveguide with GaN/AlN MQWs at the center has the advantages of good carrier confinement to the QWs and of shortening the ISBT wavelength due to the greater piezoelectric field in the wells. In Fig. 3, the characteristics of the absorption saturation are shown for the sample with GaN/AlN MQWs grown on MOCVD-grown AlN [3]. The upper AlN-cladding was grown by MBE. The absorption saturation of 10 dB was achieved at a pulse energy of 100 pJ with a wavelength of 1.5 μm.

The absorption saturation at a shorter wavelength is shown for another sample in Fig. 4 [4]. The absorption saturation of 7 dB was achieved at a pulse energy of 200 pJ with a wavelength of 1.43 μm. The ISBT absorption spectrum shown in the inset indicates that the AlN-based structure can be expected to realize all-optical switching at wavelengths of 1.3 –1.55μm.

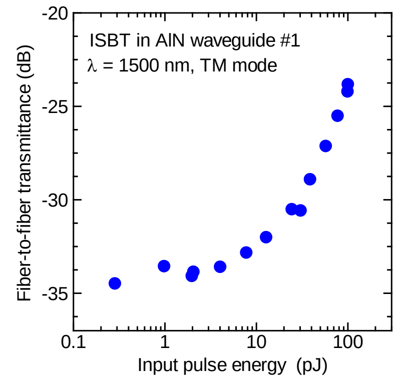

Fig. 3. The absorption saturation at a wavelength of 1.5 μm for a sample with AlN waveguide [3].

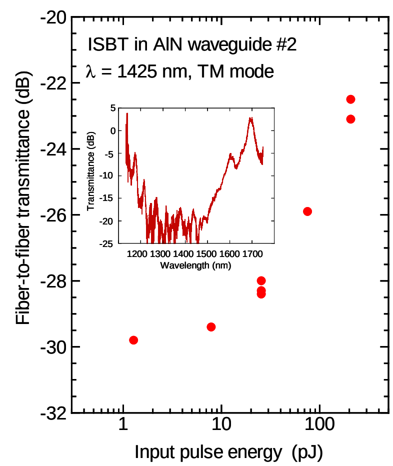

Fig. 4. The absorption saturation at a wavelength of 1.43 μm for a sample with AlN waveguide. The ISBT absorption peak was 1.3 –1.4 μm, as shown in the inset [4].

V. Summary

ISBT in GaN/AlN MQWs was investigated with a view to applying it to optical switches. With GaN waveguides, all-optical gate switching was verified. With AlN waveguide, the possibility of switching at wavelengths of 1.3 and 1.55μm was confirmed. It is concluded that ultrafast all-optical switches can be realized by utilizing ISBTs in GaN QWs.

References

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