All-optical phase modulation effect in InGaAs/AlAsSb quantum well and its application to ultra-fast all-optical signal processing

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***Abstract*—Ultrafast all-optical cross phase modulation (XPM) effect in InGaAs/AlAsSb quantum well is reviewed and its application to ultrafast all-signal processing is presented. Error free demultiplexing operation from 160-Gb/s to 40-Gb/s with low gating power is demonstrated.**

Keywords; ultrafast signal processing; quantum well; cross phase modulation; 160-Gb/s

I. Introduction

The InGaAs/AlAsSb quantum well exhibits ultrafast optical cross phase modulation (XPM) effect. The TM pump pulse corresponding to the intersubband transition (ISBT) energy causes the phase modulation in the TE polarized signal light which is inherently transparent to the quantum well [1]. So far mechanism of this new all-optical phase modulation effect has been made clear ant the guiding principle to realize large XPM has been given [2]. Owing to the response speed of this XPM effect of an order of 1ps, and the inherently lossless XPM for the TE light, this can be used to realize ultrafast all-optical signal processing devices with low insertion loss. We developed Mach-Zehnder type all-optical gate module using a mesa type InGaAs/AlAsSb ISBT device [3]. Achieved are error free demutiplexing (DEMUX) operation from 160-Gb/s to 40-Gb/s with low gating pulse energy of 1.5pJ/pulse, and wavelength conversion for 160-Gb/s signal [4]. Here, we review the achievement so far with this new device.

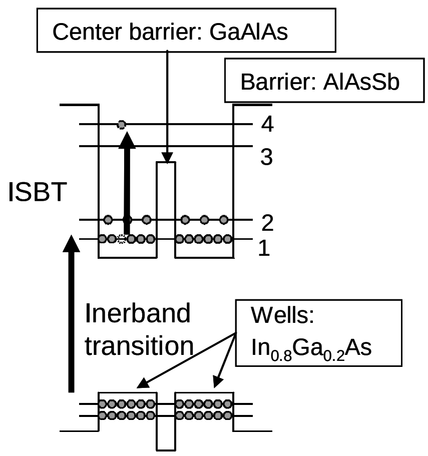

Fig.1 Band structure of coupled quantum well

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II. XPM effect and quantum well

Figure 1 shows typical quantum well structure. We employed a coupled double quantum well structure (CDQW). This structure gives 1.55 μm transition wavelength for the 1 to 4 transition in the conduction band. While the band to band transition wavelength is shorter than 1.55 μm. Then the 1.55μm wavelength range light is not absorbed by the interband transition. TM pump pulse of 1.55μm range causes the phase modulation to the lossless 1.55μm TE light. We investigated the TE light (signal) wavelength dependence of this XPM efficiency. It was shown that shorter the signal wavelength the larger the XPM efficiency. This indicates that this XPM takes place due to the band to band dispersion. Analysis of XPM efficiency using **kp** calculation for the

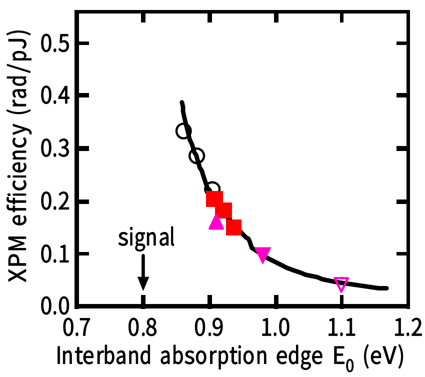

Fig.2 Calculated and measured XPM efficiency as a function of interband transition energy. Plots in the figure are experimental results for various samples [2].

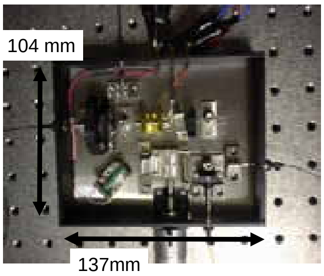

Fig.3 A photograph of Mach-Zehnder module with ISBT device

valence band showed good agreement with experimental results as shown in Fig.2 [2]. Then the guideline for the design of CDQW to achieve large XPM efficiency is to design the quantum well so that the band to band transition energy is close the intersubband transition energy, but within the limit that real band to band transition does not takes place.

Stacked CDQW was grown by molecular beam epitaxy. Initially we fabricated the CDQW with $In_{08}Ga0_{.2}As$ well layer using AlAs center barrier. However, we changed the center barrier to AlGaAs. This barrier enables us to tune the coupling between two quantum wells by adjusting the Al composition. Then we can tune the ground state energy of conduction subband to adjust the band to band transition energy. The other advantage of AlGaAs center barrier is that it compensates the strain of quantum well enabling us to grow high crystal quality stack of CDQWs for the waveguide structure. The mesa type waveguide structure with width of 1μm was fabricated. Tapered structure was attached on both facets for the fiber coupling. Using this mesa type device, the largest XPM efficiency of 0.5rad/pJ was obtained for the Al composition of 0.5 in the center barrier [5].

III. SIGNAL PROCESSING CHARACTERISTICS

Using bulk optics, Mach-Zehnder type gate device as shown in Fig.3 was developed [3]. Owing the low insertion loss of ISBT device for TE mode, total insertion loss of the module was 5-6dB which is mostly due to fiber coupling loss. We performed all-optical demultiplexing (DEMUX) operation form 160-Gb/s to 40-Gb/s. The XPM efficiency of the ISBT device used here was 0.5 rad/pJ. Figure 4 shows the eye pattern,

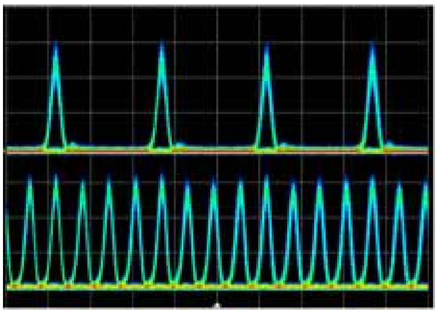

Fig. 4 Input 160-Gb/s signal to Mach-Zehnder ISBT module (lower picture) and DEMUXED 40-Gb/s signal (upper picture).

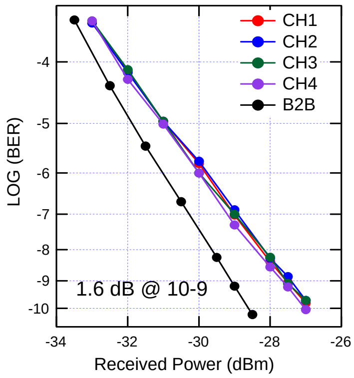

Fig. 5 Bit-error-rates for DEMUX operation form 160Gb/s to 40Gb/s.

and Fig. 5 shows the bit error rate. The gate pulse energy here was 1.5pJ to the fiber. We can confirm clear eye opening and the error free DEMUX operation. We also performed wavelength conversion. Modulated TM polarized RZ signal acts as gating pulse to code the TE CW light. Then the wavelength of the gate signal is converted to other wavelength. We obtained good eye opening even for 160-Gb/s signal [4].

IV. CONCUSIONS

Using the all-optical XPM effect of the ISBT device, all-optical signal processing for 160-Gb/s was attained. This new XPM effect is highly promising for ultrafast signal processing because of its fast response and lossless characteristics.

REFERENCES

[1] H. Tsuchida, T. Simoyama, H. Ishikawa, T. Mozume, and M, Nagase, "Cross-phase-modulation-based wavelength conversion using intersubband transition in InGaAs/AlAs/AlAsSb coupled quantum wells," Optics Lett., vol. 32, pp.751-753, April 2007.

[2] G. W. Cong, R. Akimoto, K. Akita, S. Gozu, T. Mozume, T. Hasama and H. Ishikawa, "Experimental and theoretical study of cross-phase modulation in InGaAs/AlAsSb coupled double quantum wells with a AlGaAs coupling barrier," Phys. Rev. B, vol. 80, 035306, 2009.

[3] R. Akimoto, T. Simoyama, H. Tsuchida, S. Namiki, C.G. Lim, M. Nagase, T. Mozume, T. Hasama, and H. Ishikawa, "All-optical demultiplexing of 160-10Gb/s signals with Mach-Zehnder interferometric switch utilizing intersubband transition in InGaAs/AlAs/AlAsSb quantum well," Appl. Phys. Lett., vol.91, 221115, 2007.

[4] R. Akimoto, S. Gozu, T. Mozume, K. Akita, G. W. Cong, T. Hasama, H. Ishikawa, "All-optical wavelength conversion at 160Gb/s by intersubband transition swithces utilizing efficient XPM in InGaAs/AlAsSb coupled double quantum well," European Confernce on Optical Communication, paper 1.2.2, Viena, Austria, Sep. 2009..

[5] S. Gozu, T. Mozume, R. Akimoto, K. Akita, C. G. Cong, and H. Ishikawa, "Cross phase modulation efficinecy enhanement in $In_{0.8}Ga_{0.2}As/Al_{0.5}Ga_{0.5}As/AlAs_{0.56}Sb_{0.44}$ coupled double auantum wells by tailoring interband transition wavelength," Applied Physics Express, vol.2, 042201, 2009.