# All Optical Demultiplexing from 160 to 40-Gb/s Utilizing InGaAs/AlAsSb Quantum Well Intersubband Transition Switch

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## Abstract

*We demonstrated all optical demultiplexing from 160 to 40-Gb/s by intersubband transition switch. This was enabled by quantum well with high XPM efficiency and bi-directional pump configuration.*

## Introduction

All optical demultiplexing is one of the key functions for optical signal processing in high-bit-rate (above 160 Gbit/s) optical time division multiplexing system. Currently, demultiplexers based on fiber and semiconductor optical amplifier have been investigated intensively at data-rates of 160-Gb/s and beyond. The latter is semiconductor-based and has advantages such as miniaturization of the system, high stability and low switching power, however, a pattern effect due to a slow carrier relaxation, inherent of interband transition, is regarded as a potential issue at high-speed operation. Intersubband transitions (ISBT) in semiconductors quantum wells (QWs) is another candidate for a semiconductor-based demultiplexer, since a typical ISBT carrier relaxation time in a QW is of the order of sub- to a few picoseconds (ps), expecting it is free from the pattern effect. In ISBT switch utilizing InGaAs/AlAs/AlAsSb QWs, a novel modulation mechanism can be adopted, in which TE light immune to the absorption is phase-modulated by ISBT excitation by TM light [1,2]. This is interesting modulation mechanism, since TE light does not suffer from a large insertion loss due to the strong intersubband absorption. Thus we could realise a device with low insertion loss at switch-on state by using this novel mechanism. All-optical wavelength conversion at 10-Gb/s [1] and demultiplexing from 160 to 10-Gb/s [3] has been reported. In this contribution, we successfully demonstrated a demultiplexing operation of 160 to 40-Gb/s by Mach-Zehnder Interferometer (MZI) ISBT switch by use of improved quantum well structure and bi-directional pump configuration.

## MZI-ISBT switch and bi-directional pump

Figure 1(a) shows the schematic of the MZI-ISBT switch module. The detail of the operation principle of the MZI-ISBT switch was already reported elsewhere [3]. In the present module, a 150 μm-long high-mesa waveguide chip with improved XPM efficiency (about two times higher, compared with a previous waveguide) is installed, where InGaAs/AlAsSb coupled double quantum wells with InAlAs coupling barrier is used [4]. Moreover a bi-directional pump configuration is adopted, since it can increase an amount of phase shift without damaging a waveguide facet due to high optical power input necessary for 40-Gb/s switching operation. A TM pump light (active to ISBT) is spit into two and they are launched into the both facets of waveguide as shown in Fig.1(a).

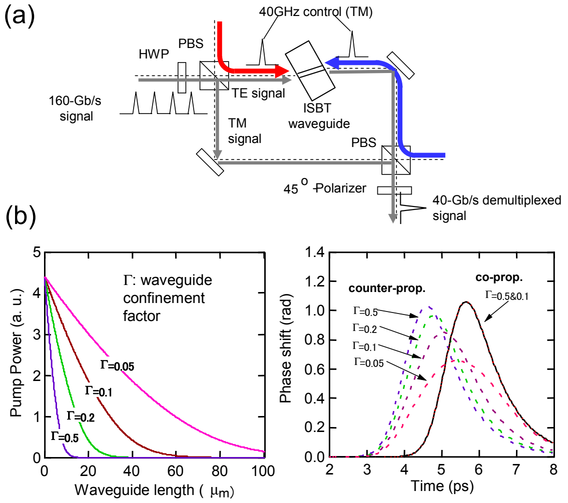

*Figure 1: (a) schematic of MZI-ISBT switch with bi-directional pump. (b) Numerical simulation of pump power attenuation (left) and phase shift of cw probe signal with co- and counter pump propagation (right).*

We simulate a temporal phase change imposed on cw TE probe with different TM pump propagation directions, i.e., co- or counter propagation with respect to the probe. In the calculation, an interband dispersion model is employed to account a refractive index change [5]. As shown in Fig. 1(b) in the case of co-propagation, a temporal phase change is not affected by a magnitude of waveguide absorption coefficient, where absorption is varied by adjusting a waveguide confinement factor (Γ). In contrast, a temporal phase change becomes weak and broadened in the case of counter propagation, as the absorption coefficient is reduced and hence the pump pulse penetrates more deeply into the waveguide. In the present waveguide, we expect there is no substantial difference in XPM efficiency between two propagation directions, since the pump penetration depth is much smaller than the spatial extension of the pump pulse in the waveguide.

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## Experimental procedure

The experimental set-up for all optical demultiplexing from 160 to 40-Gb/s by a MZI-ISBT switch is explained below. Two actively mode-locked fiber lasers (MLFLs) with a pulse width of 1.7 ps and repetition rate of 10 GHz are used as the control ($\lambda c$ = 1560 nm) and signal ($\lambda s$ = 1541 nm) light sources. The 10-GHz optical clock pulse from MLFL1 is data-coded at 10 Gb/s with a pseudo-random bit sequence (PRBS = $2^7$-1) using a $LiNbO_3$ intensity modulator. Then, the 10-Gb/s signal is multiplexed to generate 40-Gb/s signal using a fiber-based multiplexer that maintains the PRBS sequence. The 40-Gb/s signal is further multiplexed to generate 160-Gb/s OTDM signal pulse (40-Gb/s x 4 channels) by another multiplexer. The 40-Gb/s signal before the second multiplexer is used for a bit error rate (BER) measurement in the case of a back-to-back. The 10-GHz pulse from MLFL2 is multiplexed to attain a 40-GHz control light that is split into two fiber lines for bi-directional pumping. The control and the OTDM signal pulses are injected into the MZI-ISBT switch module via the pump-in and probe-in ports, respectively. The intense control pulse opens a gate of the switch module at 40 GHz to extract a specific 40-Gb/s channel from the OTDM input signals by adjusting two optical-delay lines at the outside of the module. The 40-Gb/s depmultiplexed signal after a receiver is further demultiplexed to 4x10-Gb/s sub-channels by an electrical demultiplexer to evaluate BERs by an error rate detector. The received power is defined as a power injected into a pre-amplifier just before the receiver.

## Results

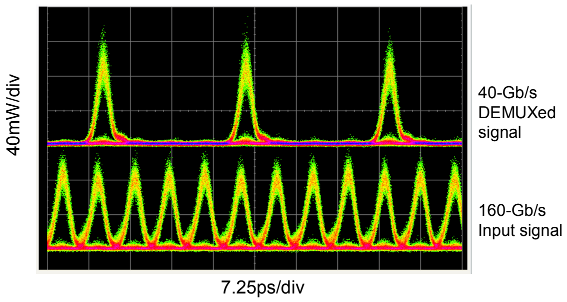

*Figure 2: 40-Gb/s demultiplexed signal (upper) and 160-Gb/s input OTDM signal.*

Figure 2 shows eye diagrams of the 160-Gb/s input OTDM signal (lower) and the demultiplexed 40-Gb/s signal (upper) measured by an optical sampling scope with 500 GHz band width. For the demultiplexing experiment, control pulse energy of 2pJ/pulse/facet (total 4pJ) is input into the MZI-ISBT module by the bi-directional pump configuration as mentioned before. While the average optical power injecting into the waveguide per facet is 80 mW that was kept below the damage threshold of ~100mW, phase shift is doubled due to the bi-directional pump configuration. As shown in Fig.2, the demultiplexed 40-Gb/s signal has an open and clear eye that is fairly identical to the eye diagram of 160-Gb/s input signal, indicating an excellent performance of demultiplexing. To quantitatively investigate the demultiplexing performance of the MZI-ISBT switch, we measured BER of the 40-Gb/s demultiplexed signal. Figure 3 shows the result of the BER measurement for the demultiplexed 40-Gb/s data pulses as a function of the optical power received by the pre-amplifier. The control pulse (2pJ/pulse x 2) is injected in the bi-directional pump configuration. The power penalty measured from the back-to-back line is as low as 1.6 dB at a BER of $10^{-9}$. We also compared power penalty for different pump configuration, i.e., bi-directional pump and single pump (co- or counter propagations). It is found that the power penalty does not depend on the pump configurations. In contrast, the power penalty is mainly affected by a magnitude of MZI extinction ratio between the most constructive and destructive interference conditions. We observed that the power penalty increases as MZI extinction ratio becomes worse.

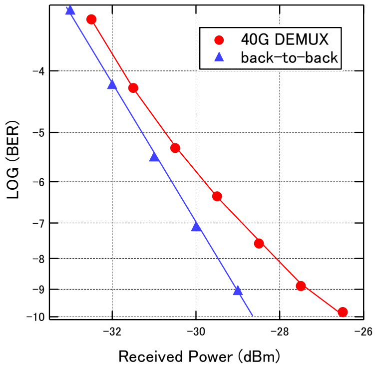

*Figure 3: Bit error rate measurement result.*

## Conclusions

We have demonstrated all optical demultiplexing from 160 to 40-Gb/s by intersubband transition switch. This was enabled by improved active layer quantum well with high XPM efficiency and bi-directional pump configuration.

## Acknowledgement

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## References

1. H. Tsuchida et al., Opt. Lett., 32 (2007) 751.
2. H. Ishikawa et al., Jpn. J. Appl. Phys., **46** (2007) L157.
3. R. Akimoto et al., Appl. Phys. Lett., **91** (2007) 221115.
4. M. Nagase et al., OFC 2008, paper JThA42.
5. Cong et al., submitted to Phys. Rev. Lett.