Dependences of dc-power consumptions in ultrafast all-optical semiconductor gates on their input-data's optical center frequencies

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***Abstract*— We have evaluated the power consumption of the bulk-SOA to be used for ultrafast all-optical gate. Consumption power of SOA is measured by a pump-probe technique setup. Consumption power is estimated by the carrier-recovery rate, small signal gain and phase dynamics of a bulk InGaAsP SOA. We measured two states, the length of the activity layer of SOA, and the input optical center wavelength.**

Keywords-mode-locking; all-optical; semiconductor optical amplifier (SOA); optical pulse generator

I. INTRODUCTION

Recent years, the demand for broadband network is increasing in the world, therefore more high speed and large capacity communication is necessary. We conduct research on the optical pulse generator using DISC (Delayed-Interference Signal-wavelength Converter) [1] type all-optical gate (Figure 1). All-optical gates based on cross-phase modulation in semiconductor optical amplifiers (SOAs) are promised for devices for future high-capacity optical networks, due to their fast response, low power consumption, and integration potential [2,3]. These all-optical gates at repetition frequency 160 GHz typically consumed at 750 mW electrical power [4]. In order to develop a higher operation frequency and lower power consumption of SOAs.

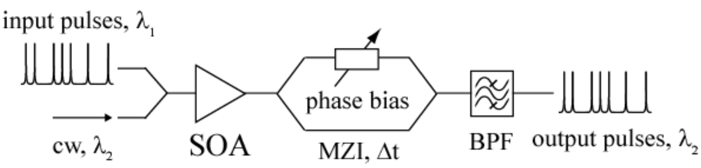
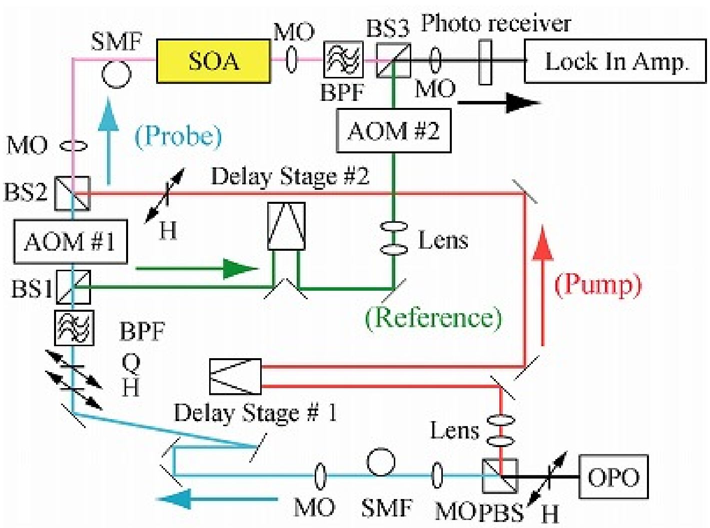


Figure 1. Schematic of heterodyne pump probe experimental set up

In this work, we have systematically characterized the dependence of carrier recovery rate (CRR) and nonlinear phase shift (NPS) of bulk-type SOA on injection current, signal wavelength and active layer length. NPS is a quantity of probe light's phase shift caused by XPM, and NPS contributes the extinction ratio of output signal. Generally DISC type all-optical gate is necessary 0.3-π to NPS. The all-optical gate, CRR decides operation speed. By measuring these characterized results CRR and NPS, we are estimated SOA power consumption in DISC. We believe that these results will be useful in designing the nano-structure for ultrafast and low-power-consumption SOAs in future.



OPO: Optical Parametric Oscillator, AOM: Acousto-Optic Modulator, PBS: Polarizing Beam Splitter, SMF: Single Mode Fiber, BPF: Band pass Filter, BS: Beam Splitter, MO: Microscope Objective, H: Half wavelength plate, Q: Quarter wavelength plate

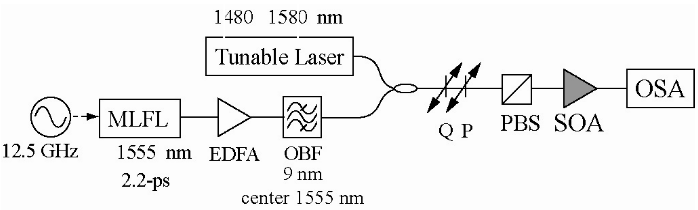
Figure 2. Schematic of heterodyne pump probe experimental set up

II. EXPERIMENTAL ARRANGEMENT

Figure 2 shows the schematic view of our heterodyne pump probe measurement system. This system allows us to measure the CRR and NPS simultaneously. The OPO provides TE-polarized, 1 ps width pulses at a repetition frequency of 80

MHz and tunable wavelength range of 1480-1600 nm. The OPO light is split into three beams that are pump, probe, and reference. The pump beam passes through a motorized delay stage 1, to control the time delay, between the pump and probe pulses. AOMs upshift the frequency of the probe and reference beams by 81.2 MHz and 78.7 MHz, respectively. Pump pulse (1 pJ) and probe pulse (0.06 pJ) are then recombined at the input to the SOA. The motorized delay stage 2 allows probe pulses recombined with reference pulses temporally to produce a 2.5 MHz beat signal. An RF lock-in amplifier detects the amplitude and phase of this beat signal.

Figure 3 shows Experimental set up for measurement SOA Gain and NPS spectrum. The pulse is generated by MLFL. The pulse energy was 50 fJ at a wavelength of 1555 nm and the pulse width at the input of the SOA was measured to be 2.0 ps FWHM using an autocorrelator. Tunable Laser is a three-cascaded etalons scheme for broad-band tunable CW laser [5]. With this scheme we experimentally achieved a tunable width of 100 nm, signal-to-noise ratio of over 25 dB CW laser source. Figure 4(a) shows of this experiment setup.



MLFL: Mode Lock Fiber Laser, EDFA: Erbium Doped Fiber Amplifier, OBF: Optical Band Passfilter, OSA: optical Spectrum Analyzer

Figure 3. Experimental set up for measurement SOA Gain and phase spectrum

III. EXPERIMENTAL RESULTS

We measured the InGaAsP SOA. (Chip type, active layer length L= 700 μm, Inphenix Inc.) We are estimated by consumption power of SOA $P_{op}=V_{op}I_{op}$ (V_{op}: SOA voltage, I_{op}: SOA injection current). The required amount of NPS depends on the function of the gate: for 3R regeneration or wavelength conversion it is ~ 0.3π [6]. Therefore, calculations were done down to nearly the low power limits, where NPS = 0.3π can be satisfied.

Figure.4 (a) shows measurement results of SOA in Gain spectra and NPS spectrum by using figure 3 experiment setup. Figure.4 (b) shows dependence on NPS of SOA energy consumption power. Figure 6(a) concluded the results of figure 4(a) and (b). Input optical center frequency dependence on SOA consumption dc power seems linearly proportional to input optical frequency. This is derived from Kramers-Kronig integration (1).

$$\Delta n(\omega)=\frac{c}{\pi}\int_0^\infty \frac{\Delta g(\omega)}{\omega'^2-\omega^2}d\omega'. \tag{1}$$

Here, where n is the refractive index, g is the gain, c is the speed of light in vacuum, and ω is the probe frequency given by $\omega = 2\pi/\lambda$, where λ is the probe wavelength. This expression shows which the probe light of a short wavelength makes refractive index increase. Therefore NPS increase in short wavelength and high frequency of input optical pulse. In order to obtain consumption power of SOA at NPS 0.3, input pulse is short wavelength better than long wavelength. This trend is consistent with the Kramers-Kronig integration. Input optical short wavelength reduces to consumption power of SOA 30%.

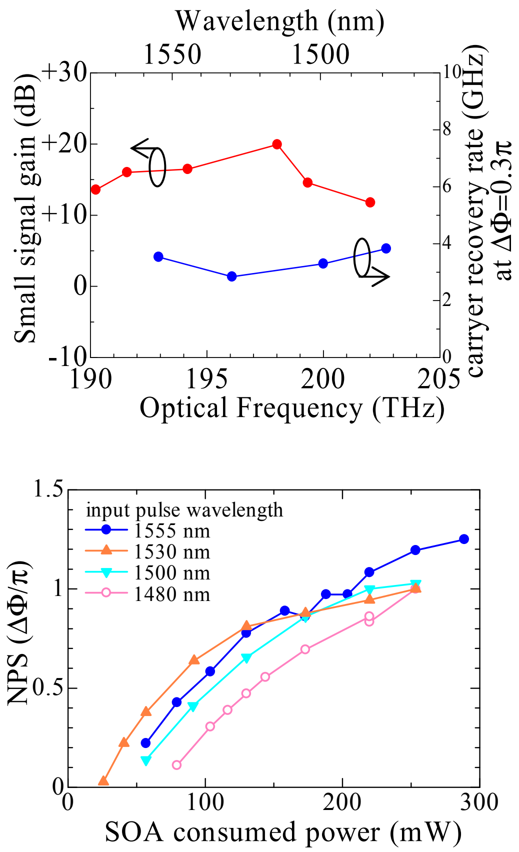


Figure 4. (a) Input pulse wavelength (1480 to 1555 nm) dependencies on carrier recovery rate. (b) NPS dependencies on consumption power @ Input pulse energy 50 fJ.

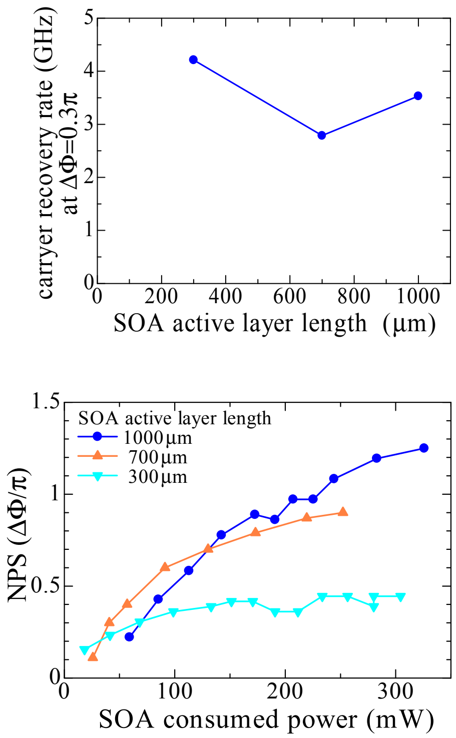


Figure 5. (a) SOA active layer length dependencies on carrier recovery rate @ NPS 0.3π. (b) NPS dependencieson consumption power @ Input pulse energy 50 fJ.

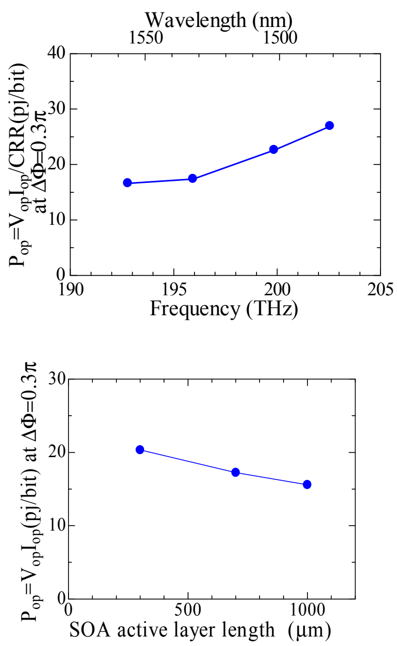


Figure 6. (a) Input pulse wavelength (1480 to 1555 nm) dependencies on consumption power. (b) SOA active layer length dependencies on consumption power.

Figure 5 (a) shows carrier recovery rate dependent on SOA active layer length (300 to 1000 μm) at NPS 0.3π. Figure 5 (b) shows NPS dependent on consumption power of SOA (input pulse energy 50 fJ). We calculated consumption power of SOA $P_{op}=V_{op}I_{op.}$ Figure 6 (b) concluded the results of figure 5 (a) CRR and (b) NPS, where NPS = 0.3π can be satisfied. The longer active layer length SOA decreases consumption dc power. For this reason the number of carriers is received by the input light. 300um active layer carrier density is high power efficiency is good with low current injection state. However, the higher the carrier density injected current long active layer also exceeds 100mA. Long active layer is improved power efficiency and therefore increases the injection current. Long activity layer length can be reduced to consumption power of SOA 20%. When power consumption is low, short active layer length is higher NPS than long activity layer. But when power consumption is high, long activity layer length is higher NPS than short activity layer. When SOA carrier density is high, NPS is increased. Moreover propagation distance is longer; the effect of NPS which gives input light is large. Because long activity layer SOA is low power consumption to getting same NPS.

IV. Conclusion

We have experimentally showed that increasing the injection current into SOA can increase NPS of SOA. Input optical wavelength can be reduced to consumption power of SOA 30%. Long activity layer length can be reduced to consumption power of SOA 20%. We also can raise NPS of SOA by using short wavelength signal and short SOA. But these have their limitation because of the trade-off relation to NPS. For this reason, to realize a SOA for 200~500 GHz of operation frequency, 0.3 pJ/pulse of power consumption all-optical gates. In the future, we will measure different structure, for example quantum well SOA for low power consumption operation of all optical gates.

Next research is SOA at acceleration by input holding beam verifies carrier recovery rate. This measurement such accelerating effect verifies low consumption power is better for all-optical semiconductor gate.

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