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Frequency-dependent electric dc power consumption in ultrafast all-optical semiconductor gates

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Abstract: We developed a model of the power consumption in the all-optical gates in frequencies from 10 to 160 GHz. In it, we assumed a realistic electron-photon conversion efficiency that we experimentally evaluated from up-to-date series of SOA samples.

1 Introduction

All-optical signal-processing gates based on nonlinearlities of semiconductor optical amplifiers (SOAs) are promising devices to realize future OTDM networks, for their capability of ultrafast signal processing [1-5] and low power-consumption [6]. As its capability of ultrafast gating has become clear, the lower limit of electric power consumption and its origin have been important issues from a physical and design viewpoint. There has been no method to design the electric power consumption requirement, however, with practical reliability and simplicity. Also no systematic measurement has been reported, to the best of our knowledge.

For the power consumption, we have insisted on that conversion efficiency from injected-carrier to photon in the SOA should have significant role [7]. In this report we propose a new method to estimate the amount of power consumption of an SOA on the ultrafast gating, from its fundamental parameters including conversion efficiencies. Then we will show measured results of conversion efficiencies for our SOA samples with different structures. Using these results we calculated SOA carrier dynamics, and power consumption requirement. Part of the calculated results will be compared with measured results.

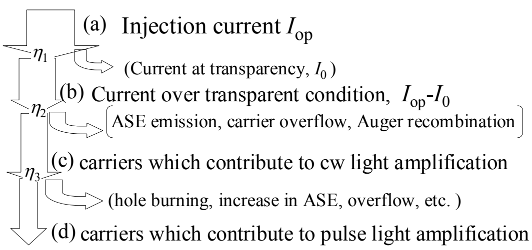

Figure 1. Loss model of the injected carriers and definition of the conversion efficiency

2 Estimation method of the electrical power consumption

In our SOA model [7], the injected carriers suffer losses before stimulated recombination, as shown in Fig. 1. Since our target frequency is 160 GHz or higher, the third process should be taken into account. Then total efficiency η_T depends on the width of the control pulse. To describe the carrier dynamics of the SOA including these effects, we expanded the rate equation that we used in the former analysis [8,9] to the form below:

$$\frac{dn_{pulse}}{dt} = \frac{I_{op}}{qV}\eta_1\eta_2\eta_3 - \frac{n_{pulse}}{\tau_C} - \eta_3\left\{\exp\left(\Gamma L\frac{dg^{cw}}{dn}n_{pulse}\right)-1\right\}\frac{P_{cw}}{\hbar\omega V} - \left\{\exp\left(\Gamma L\frac{dg^{pulse}}{dn}n_{pulse}\right)-1\right\}\frac{P_{pulse}}{\hbar\omega V} \quad (1)$$

(n_{pulse}: carrier density available for ultrafast gating, I_{OP}: injection current, η_1~η_3: conversion efficiencies, τ_c: carrier lifetime, P_{pulse} and P_{CW}: input light intensities, V and L: active region volume and length, q: elementary charge, Γ: confinement factor, dg/dn: differential gain). Note that η_3 is multiplied to the cw-light term, in view of the difference between n_{pulse} and n_{cw} (carrier density available for cw light). Both cw gain and pulse gain are supposed to be determined by n_{pulse}, since we did not observe much difference between them unless gain saturations occur.

Injection of P_{pulse} causes carrier recombination Δn_{pulse}, and nonlinear phase shift

$$\Delta\Phi = k_0\, dn_r / dn\, \Gamma L \Delta n_{pulse}. \quad (2)$$

Injection of holding beam P_{cw} accelerates carrier recovery after depletion by control pulses, at the cost of n_{pulse} and $\Delta\phi$. Since carrier recovery rate $1/\tau_{eff}$ should be larger than the operation frequency B to avoid pattern-dependent intensity noise and $\Delta\phi$ should be as large as ~0.3π for an XPM-based gate [9], maximum frequency can be determined for given I_{OP} and SOA parameter sets. Numerical simulation shows that the maximum frequency is almost proportional to the total conversion frequency η_T and dg/dn, but less sensitive to the intrinsic carrier-recovery rate $1/\tau_C$.

3 Conversion efficiencies of the SOA samples

To observe the influence of SOA structure on the power consumption, we studied several custom-designed SOA samples made by two manufacturers A and B. The SOAs in each series have same active-region width w, thickness d, Γ but different L. The measured conversion efficiencies are summarized in Fig. 2. We see large dependence of total efficiency η_T on the SOA structure. It resulted mostly from η_2. A-series and B-series show opposite η_2 dependence on L. Nevertheless, longer SOAs tend to show larger η_T as I_{OP} increases, due to the contribution of η_3.

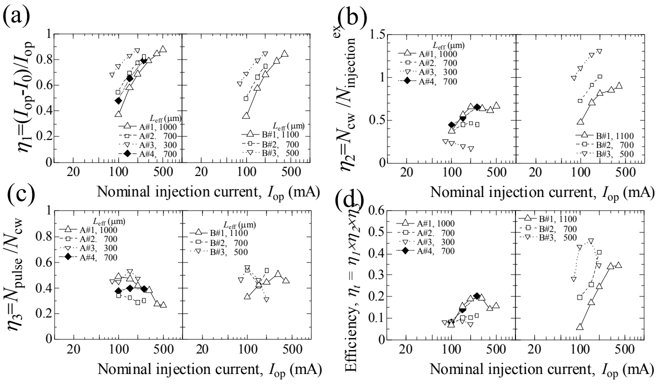

Figure 2. Measured conversion efficiencies of each SOA samples against I_{OP}. (a) η_1, (b) η_2, (c) η_3, (d) total efficiency η_t.
Series A: w~2 µm, d~0.1 µm, Γ= 0.1~0.2.
Series B: w~1.25 µm, Γ~ 0.2.

4 Calculation of holding-beam effect with our model

Before the power estimation based on the model in section 2, we checked to how extent our SOA model can explain the change of SOA property caused by the holding beam. Fig. 3(a)~3(C) show the example of measured and calculated carrier recovery rate, gain saturation against ultrafast pulses, and nonlinear phase shifts. We see that measured and calculated results approximately agree with each other, though for some quantities accuracies are not quite good (~5dB) at the moment.

5 Electric power consumption in SOA

Fig. 4 shows the power consumptions P_{op} calculated for each SOA samples, against carrier recovery rate $1/\tau_{eff}$. We see that B-series show better performance than A-series. When P_{OP} is small, B#3 shows best performance around 20 GHz. As the target frequency increases over 100 GHz, B#1 sample becomes preferable. For A-series, longer sample has higher frequency and shortest sample could not be used for the gating. These characteristics result from those of η_T discussed in section 3. Except for the difference of scale factors, most of the P_{OP}-$1/\tau_{eff}$ profiles in Fig. 4 show some resemblance to corresponding P_{OP}-$1/\tau_C$ profiles. It is due to complicated correlations of SOA parameter changes. Measured P_{OP} for B#3 sample were also plotted in the same figure, and they agree quite well with the calculated results.

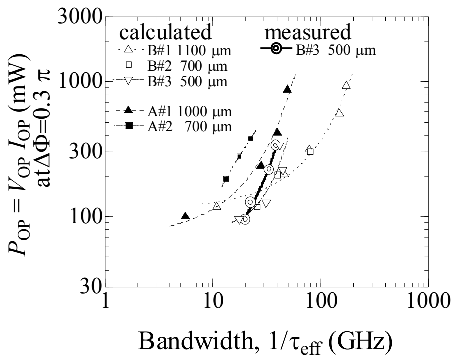

Figure 4. SOA electrical-power consumption vs. carrier recovery rate with holding-beam acceleration. Calculated results for each SOA samples using measured fundamental parameters, and measured results for B#3 sample are plotted. Control pulses of 2-ps width and 340-fJ energy were used.

6 Conclusion

We proposed a new model of the electric power consumption in the SOA used for ultrafast all-optical gating, from SOA fundamental parameters. The power consumptions for actual SOA samples were estimated in good agreement with measured results. Due to their larger efficiencies, longer SOAs are expected to consume less electric power when operation frequency is around 100 GHz. This method will provide the fundamental of all-optical gate design.

7 Acknowledgement

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8 References

1. S. Nakamura *et. al.*, *OFC 2002*, FD3.
2. Y. Ueno *et al.*, *Photonics. Technol. Lett.*, **13,** 469-471, (2001).
3 S. Nakamura *et. al*, *Photonics. Technol. Lett.*, **13**, 1091-1093, (2001).
4. Y. Liu *et. al.*, *OFC2006*, PDP28.
5. E. Tangdiongga *et. al.*, *Photonics. Technol. Lett.*, **18**, 908-910, (2006).
6. Y. Ueno *et. al.*, *Opt. Lett.*, **23**, 1846-1848, (1998).
7. J. Sakaguchi *et. al.*, *OAA* 2006, OTuC4.
8. Y. Ueno, *et. al.*, JOSA **B19,** 2573-2589, (2002).
9. Y. Ueno *et. al.*, *Optics Express*, **14,** 348-360, (2006).

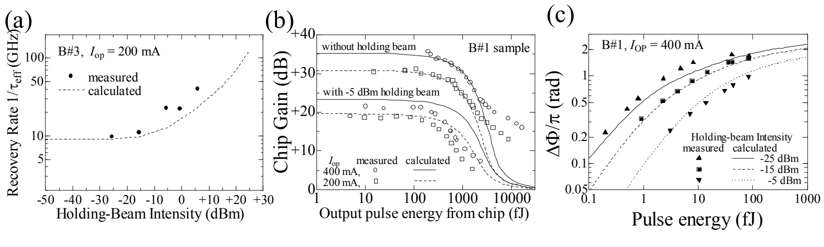

Figure 3. Comparison of measured and calculated SOA properties under holding-beam injection. (a) Carrier recovery rate $1/\tau_{eff}$, (b) gain saturation for 2-ps pulse, (c) nonlinear phase shift $\Delta\Phi$.