# Novel Gain Control Scheme of SOA for High Output Power Operation

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**Abstract** *We propose a simple gain control scheme of SOA. The heater-mounted SOA exhibited a wide input power dynamic range of >17 dB while keeping high output power of +8.0 dBm for 10Gbps NRZ modulated signals.*

## Introduction

A semiconductor optical amplifier (SOA) attracts a lot of attention as a compact optical amplifier for next generation photonic networks [1-2]. In order to expand its range of application, an implementation of SOA gain control, such as automatic output level control (ALC), is indispensable. The gain of SOA can be easily adjusted with drive current, but the saturation output power (Ps) also changes with current. For amplification of signals modulated in NRZ-OOK format, SOA output power must be lower than its Ps by 5 or 6 dB to avoid waveform degradation due to SOA nonlinearity [3]. Therefore, the target output power in ALC operation is limited to very low level because of its small Ps at reduced current condition. Up to now, some alternative gain control schemes have been reported to overcome the above difficulties; that use external control-light injection [3], or control of threshold level in gain-clamp amplifier [4]. However, these schemes are complicated and a new simpler gain control scheme is expected.

In this paper, we propose a novel gain control scheme of SOAs, which adjusts the active layer temperature via heater mounted on a SOA chip. This scheme can maintain a high saturation output power in gain control with a very simple configuration. The device exhibited an improved usable power range and a large input power dynamic range (IPDR) of >17 dB in ALC operation at high output power of up to +8.0 dBm.

## Gain control scheme

The gain of SOA monotonically decreases by increasing the temperature, but the temperature dependence of Ps is smaller than that of the gain. We think that both a decrease in differential gain and a small change in active layer carrier density result in the small dependence of Ps on the temperature. Based on this relation, we propose a new gain control scheme of SOAs using temperature, which can control the gain while keeping a high Ps. In order to realize a faster control speed, we also adopted a tiny build-in heater which can adjust the temperature of the active layer locally.

## Device structure of heater-mounted SOA

The schematic structure of the heater-mounted SOA is shown in fig. 1. We used a strained multi-quantum well (MQW) active layer of 65-nm thickness to obtain both a high saturation output power and polarization insensitivity [5]. The MQW was designed to realize a small PDG over wide temperature range. The active mesa was buried with Fe-doped semi-insulating InP, which has high current confinement efficiency even at high temperature operation [6]. A 6-μm wide heater stripe was formed along the active waveguide. By adjusting a heater current, we can control a temperature of the active layer independently of drive current. The device was packaged into a conventional 14-pin module with optical coupling using lens and isolators.

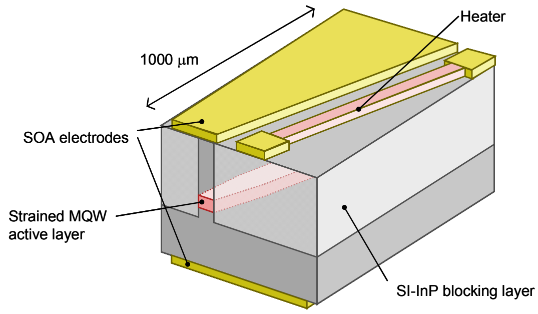


**Fig. 1:** Schematic structure of heater-mounted SOA

## Characteristics for CW signals

Gain control characteristics of the heater-mounted SOA module was measured for 1550 nm CW signal. Figure 2 shows a heater current dependence of the gain and Ps. The drive current of SOA was set to 400 mA. By increasing the heater current from 0 to 100 mA, the temperature of the SOA active layer increased, and the gain was decreased by 11.4 dB. In this control range, the Ps slightly decreased by 3.1 dB, but the high Ps of >+12.5 dBm was maintained. In addition, the PDG was also successfully suppressed to <0.3 dB. The total module power consumption was less than 1.5 W at room temperature operation.

For comparison, fig. 3 shows a gain control characteristics of the same device with a drive current. The gain could be varied by 11.0 dB by reducing the current from 400 to 80 mA, however, the Ps greatly decreased to +8.0 dBm which was 4.5dB lower than that of heater control scheme.

## Level control for 10Gbps NRZ modulated signals

To investigate the influence of above difference in Ps on practical systems, we evaluated the amplification characteristics of 10Gbps NRZ-OOK modulated signal varying both the input power level and the gain with both schemes. Figure 4(a) and (b) are power penalty maps of SOA for heater control and current

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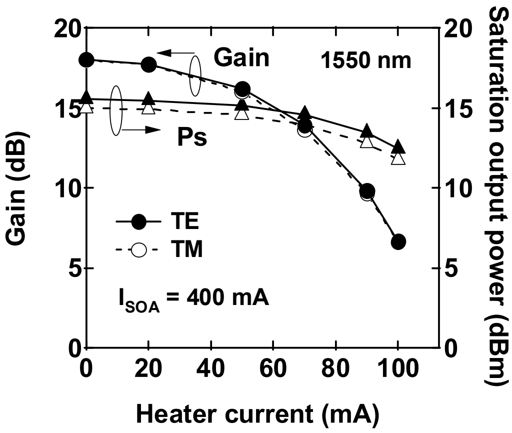


**Fig.2 :** Heater current dependence of SOA characteristics
*Large saturation output power (Ps) of >+12.5 dBm was maintained when the gain was controlled by 11.4 dB*

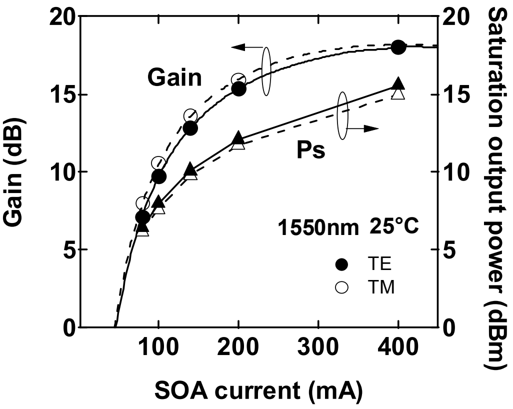


**Fig.3 :** Drive current dependence of SOA characteristics
*Ps was widely decreased to +8.0 dBm when the gain was controlled by 11.0 dB*

control schemes, respectively. The power penalty at BER of $10^{-12}$ was measured using a commercial transponder with a $LiNbO_3$ modulator.

The heater control scheme exhibited small power penalties even at higher input powers, owing to its large Ps in the gain control. Thus, the usable power range with small power penalty of < 1 dB (inside the solid contour in fig.4) was large.

Conversely, in the current control scheme, the power penalties due to pattern effect appeared at high input power region of >+0 dBm. Such large input powers could not be handled with the conventional current control scheme

From the perspective of ALC operation, fig. 5 plots the IPDR dependence on the target output power for both control schemes. The IPDR was defined as the input power variable range with a power penalty of < 1 dB. At relatively low output powers of <+1 dBm, both control scheme exhibit wide IPDR of 18 dB which is determined from a variable range of unsaturated gain. As the target output power increases, however, the IPDR of the current control scheme decreases due to penalties at higher input powers, but the IPDR of heater scheme remains wide. As a result, the heater control scheme drastically improved the IPDR at higher output powers, and a wide IPDR of >17 dB was obtained for the target output power of up to +8.0 dBm.

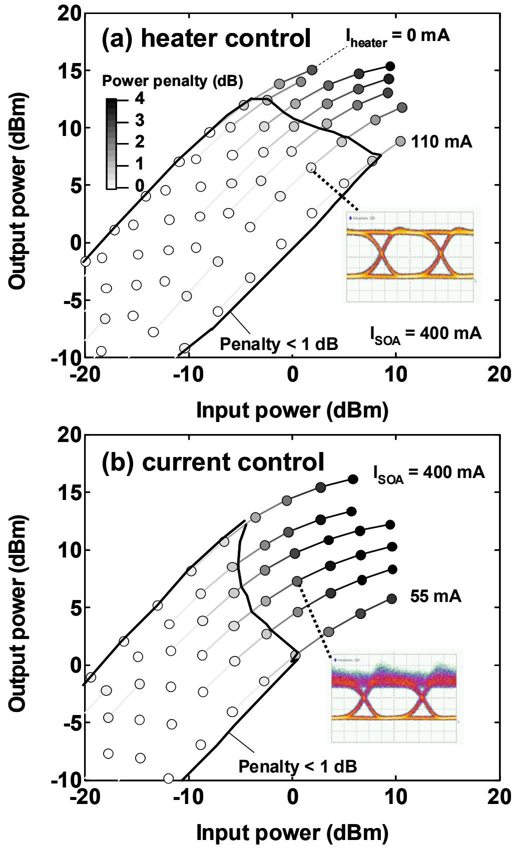


**Fig. 4:** SOA power penalty map at gain control with heater (a) and current (b) ; *Usable power range (solid contour) was improved with heater control especially at high input power*

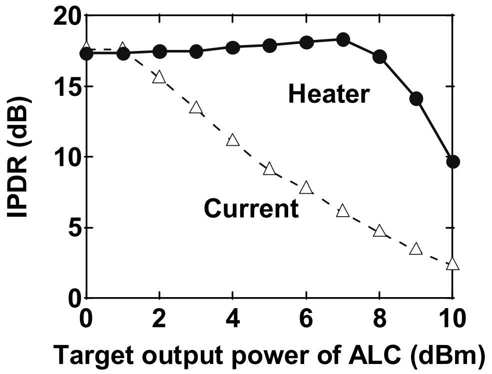


**Fig. 5:** IPDR dependence on target output power at ALC
*In heatrer control, wide IPDR was maintained up to higher* output power

## Conclusions

We have demonstrated a novel gain control scheme using heater-mounted SOA. The device exhibited an improved usable power range, and a wide IPDR of >17 dB in ALC operation at high output power of up to +8.0 dBm. This simple control scheme can be applied to various types of SOAs, which would provide a more functionality of SOA in optical networks.

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