1550nm InGaAsP/InP Semiconductor Optical Amplifier (SOA):  
the first study on module preparation and characterization

Vu Doan Mien\textsuperscript{a}, Vu Thi Nghiema, Dang Quoc Trung\textsuperscript{a} and Tran Thi Tam\textsuperscript{b}

\textsuperscript{a} Institute of Materials Science, Academy of Science and Technology of Vietnam,  
18 Hoang Quoc Viet Str., Cau Giay, Hanoi, Vietnam  
\textsuperscript{b} Faculty of Technology, Vietnam National University,  
144 Xuan Thuy Str., Cau Giay, Hanoi, Vietnam  
e-mail: vdmien@ims.ncst.ac.vn

Semiconductor Optical Amplifier (SOA) modules based on 1550nm InGaAsP/InP angled-facet SOA chips have been prepared and characterized. SOA amplified spontaneous emission (ASE) output power – current curves, ASE spectra and fiber-to-fiber gain curves were measured using DBR Er-dopped fiber laser as input signal source. The SOA modules have ASE bandwidths from 1530nm to 1560nm and gain coefficients of more than 10dB. Signal gain saturation was observed at SOA output power of about 7 dBm.

\textbf{Key words}: Semiconductor Optical Amplifier, Er-dopped fiber laser, ASE spectra, gain coefficient

1. Introduction

The first studies on Semiconductor Optical Amplifiers (SOAs) were carried out around the time of the invention of the semiconductor laser in the 1960’s [1]. Early studies concentrated on AlGaAs SOAs operating in the 830 nm range. In the late 1980’s studies on InP/InGaAsP SOAs designed to operate in the 1.3 \( \mu \)m and 1.55 \( \mu \)m regions began to appear [2]. SOAs can be classified into two categories: the Fabry-Perot (FP) amplifier, and the traveling-wave (TW) amplifier. An FP amplifier has considerable reflectivity at the input and output ends, resulting in resonance amplification between the mirrors. The TW amplifier, by constract, has negligible reflectivity at the end, resulting in signal amplification during a single pass. Developments in anti-reflection coating technology enabled the fabrication of true traveling-wave SOAs. The optical spectrum of a TW amplifier is quite broad and corresponds to that of the semiconductor gain medium. Most practical TW amplifiers exhibit some small ripple in the gain spectrum arising from residual facet reflectivities. Therefore, TW amplifiers are more suitable for fiber optic communications. Prior 1989, SOA structures were based on anti-reflection coated semiconductor laser diodes, in 1989 SOAs began to be designed as devices in their own right, with the use of more symmetrical waveguide structures giving much reduced polarization sensitivity or with the use of angled-facet to lower the facet reflectivity. Besides of the amplification functions, developments in SOA technology are ongoing with particular interest in functional applications such as photonic switching and wavelength conversion. The use of SOAs in photonic integrated circuits (PICs) is also attracting much research interest [3].
In this report we present the first studies on 1550nm InGaAsP/InP SOA module packaging and characterization. The prepared module could be used firstly for the research of the above mentioned applications and for training purposes in fiber optic communications as well.

2. Experimental results and discussion

The 1mm-long angled-facet (tilted) InGaAsP/InP SOA chips used here were fabricated at Heindrich- Hertz Institut (HHI) in Berlin. They have buried heterojunction structure with a tensile strained layer (0.15%) to keep the polarization dependency as small as possible. To prevent back reflection the SOA is designed 7° off axis with respect to the crystal axis and the facets are anti-reflection (AR) coated with a TiO₂/SiO₂ double layer. The facet reflection coefficient is expected lower than 10⁻⁴ as the result of both effects of angled-facet and anti-reflection coating [4]. The SOA chip was then soldered on the gold plated diamond heatsink, then the heatsink was soldered on copper plate attached to the peltier cooler or the SOA chip was directly attached to the copper plate with electrically and thermally conducting epoxy. The electrical contacts were made by welding 25 µm gold wires using Westbond 7400C welding machine. The thermal sensor was also attached to the copper plate for controlling the SOA temperature. In order to have good optical coupling efficiency between 9/125 single mode fibers and SOA chip we tapered the fibers using electrical arc. The fibers are coupled at 23° angle relatively to the crystal axis in order to have the best coupling efficiency. The tapered fiber with the tip diameter of about 15 µm gives the coupling efficiency of about 25%. The fibers were fixed to the copper plate with epoxy as shown in Fig.1. Here the most difficulty is how to fix the fiber without shifting down due to the shrinkage of epoxy during its hardening. The thickness of SOA active region is about 0.5 µm while the shift may be more than 1 µm leading to the optical misalignment. The gap between fiber and copper plate must be as small as possible to reduce this misalignment. Finally the module was packed with the multi-pin can and the fibers are ended with FC connectors. In addition, the coupling process of the SOA modules is much more difficult than that of the transmitter laser modules [5].

![Fig. 2 Dependence of SOA module’s ASE output power on operating current for both its sides (T= 25°C)](image)

![Fig. 3: ASE spectra of the SOA module at different operating current: I=50mA (curve 1); 55mA (curve 2) and 60 mA (curve 3), T=25°C.](image)
The amplified spontaneous emission (ASE) spectra of the SOA module measured from its both sides using Melles Griot Laser Diode Controller 06DLD103 are shown on Fig.2. PIN InGaAS photodiode module was used for monitoring ASE output power. This measurement and spectral measurements were carried out at room temperature (300K). The ASE output power-current curves show rather high ASE power (p= 2.0 mW and 2.40mW at I=80mA). ASE spectra and signal optical spectra were measured on computerized spectroscopic system basing on monocromator SPM-2, Selective Nanovoltmeter 237,… (Fig. 4)

Fig. 3 presents the ASE spectra at different SOA operating currents. The ASE bandwidth extents from $\lambda$=1520nm to $\lambda$=1570nm with maximum at ~ 1545nm and 3dB bandwidth of about 30nm. It is clear from Fig.3 that the ripples as the result of residual reflectivity of SOA facets are small in comparison with the ASE power. When SOA operating current increases, the ASE spectrum intensity increases and when the current exceeds 60mA some Fabry-Perot mode appear on the ASE background at $\lambda$=1550nm. The condition for oscillation where the amplifier becomes a laser appears probably due to the fact that stray reflections (reflections from the coupled fiber ends) in the system can provide additional feedback to the amplifier pushing the overall gain of the amplifier towards oscillation for moderate pumping [6]. In order to reduce this effect one can change the tapered fiber diameter or filling the air gap between SOA facet and fiber end with index matching oil or making AR coating on the fiber ends. In our case, to avoid misalignment ability due to the thermal expansion of fixing epoxy as mentioned above, we used not very small diameter of the fiber tips so that the optical feedback may be not negligible. However, further work must be done to study the influence of the optical feedback on the SOA operation.

Fig.4 presents the spectral measurement setup, where the DBR Er-dopped fiber laser excited with 980nm laser diode serves as the input signal source. 60mW of pumped power gives the fiber laser output power of 0 dBm. The fiber laser radiated single mode monochromatic light at 1549.64nm (T=25°C) width $\Delta \lambda<0.1$nm. We used fixed fiber laser output power and changed it with variable optical attenuator (VOA). The signal at the SOA input was changed from –35 dBm to 0 dBm. The optical spectra of the input and output signal of the SOA module were measured for
different input powers at SOA operating currents of 50mA, 55mA, 60mA where the influence of optical feedback is still negligible and gain coefficients were calculated as the ratio of the integrated output and input spectra. One of these spectra for input signal of -19 dBm are shown on Fig. 5. The SOA module gain - input optical power curve is shown on Fig. 6. At the input power less than –5dBm, the gain coefficient changes a little (between 12 to 18dB), at the higher input power the saturation effect is observed and the gain coefficient decreases quickly and reaches several dB at input power of 0 dBm or more. We also measured the SOA gain coefficient in dependence on output powers for different SOA operating currents. The gain increases with the increasing of SOA operating current, and the gain saturation occurs when output power is more than 7dBm (Fig.7). The pumping source creates a fixed amount of population inversion at a particular rate, and on the other hand the amplification process is continuously draining the inverted population by creating stimulated emission. As we increase the input power, a point arrives where the rate of draining due to amplification is greater than the rate of pumping, such that the population inversion level can no longer be maintained at a constant value and starts to fall. Thus the gain of the system starts to fall.

In general the gain of an SOA depends on the polarization state of the input signal, our SOA chip was made to keep the polarization dependency small as said before. To verify this we measured the SOA module output signal spectra while regulating the polarization controller made of fiber cycles. We calculated the maximal change of the gain based on the spectra with maximal and minimal intensity due to input light polarization change and received this maximal change in gain of less than 5dB (at the input level of -19dBm and SOA operating current of 55mA). This dependency is due to a number of factors including the waveguide structure, the polarization dependent nature of anti-reflection coatings and the gain material [3,6]. This rather high value of polarization dependence may be related also on the optical feedback.

Conclusion

In this report we present some results of the first study on 1550nm SOA module preparation based on angled-facet SOA chips and their characterization. The prepared module presents high ASE power, low ripple and amplification coefficient is more than 10 dB for small input signals and the saturation of gain was observed when output signal power exceeds 7dBm. The change of the input light polarization still influences considerably on the SOA gain. The optical feedback from the fiber ends causes the Fabry-Perot laser oscillations when the SOA operating current is rather high was observed. More works should be done in order to reduce optical feedback, to have better fiber-to-fiber

Fig. 6: SOA fiber-to-fiber gain versus input signal power at different operating current: 1) I=50mA, 2) I=55mA, 3) I=60mA

Fig. 7: SOA fiber-to-fiber gain versus output signal power at different operating current: 1) I=50mA, 2) I=55mA, 3) I=60mA
coupling efficiency for increasing the amplification coefficient and to have the operating stability with the time of SOA modules. Nevertheless, the prepared SOA modules can be used for amplify small single mode light from fiber laser or for study the functional applications such as photonic switching and wavelength conversion.

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References


