SEMICONDUCTOR OPTICAL AMPLIFIER WITH SPOT SIZE	BỘ KHUẾCH ĐẠI QUANG BÁN DẪN CÓ VÙNG HOẠT TÍNH CHUYỂN

CONVERTER ACTIVE REGION AND SOME NONLINEAR PROPERTIES	ĐỔI KÍCH THƯỚC CHÙM VÀ MỘT SỐ TÍNH CHẤT PHI TUYẾN
ABSTRACT checked	TÓM TẮT
Semiconductor optical amplifier (SOA) modules based on the InGaAsP/InP (Ằ ~1,55 ụ,m) traveling wave amplifier (TWA) chips with angled-facet (7o) active region which has spot size converter in order to minimize the polarization dependence have been prepared and characterized. Four-wave-mixing (FWM) as a nonlinear effect has been investigated in dependence on the change of optical power, polarization and frequency shift of the input optical signals as well as on the pump current for the SOA modules. The results of study show the possibility of using SOA for the s such as new wavelength source in WDM technology.	Bài báo này chế tạo và nghiên cứu các mô-đun bộ khuếch đại quang bán dẫn (SOA) cấu thành từ các chip khuếch đại sóng chạy InGaAsP/InP (Ằ ~1,55 ụ,m) với vùng hoạt tính mặt nghiêng (7^0) có bộ chuyển đổi kích thước chùm (laser) để giảm thiểu sự phụ thuộc phân cực. Chúng tôi nghiên cứu sự phụ thuộc của hiệu ứng trộn bốn sóng (FWM) với tư cách là một hiệu ứng phi tuyến vào sự thay đổi công suất quang học, sự phân cực và sự dịch chuyển tần số của các tín hiệu quang học đầu vào cũng như sự phụ thuộc vào dòng bơm đối với các mô-đun SOA. Kết quả nghiên cứu đã chứng tỏ khả năng sử dụng SOA cho các ứng dụng chức năng chẳng hạn như một nguồn bước sóng mới trong công nghệ WDM.
INRODU CTION	[redacted]
Semiconductor optical amplifier (SOA) is the photonic device that can be used for both amplification and functional functions in the modern fiber optic networks. They find their applications in both fiber optic communication windows of 1310 nm and 1550 nm while Erbium Doped Fiber Amplifier (EDFA) can be used only in the wavelength region of 1550 nm. That is why SOAs are intensively studied in the laboratories related with the photonic study and telecommunications in the recent years [1,2,3]. Among the many advantages of the SOAs such as compactness, low voltage supply, high gain coefficient and large amplification bandwidth, etc. They	

also have the backwards such as high insertion loss, high polarization dependence of the gain and instability with the environment temperature changing. Having the tapered active region or so-called active region with spot size converter is one of the solutions for minimizing the polarization dependence of the SOA gain.

In this report we present the result of SOA module preparation based on the new kind of 1550 nm- InGaAsP/InP SOA chips with spot size converter and their improved characteristics. Four-Wave-Mixing as a nonlinear effect in the prepared SOA modules also has been presented. This effect can be used for generation of the new wavelength source in WDM technology and at the same time it can produce so-called FWM noises in the fiber optic communication networks that must be considered.

EXPERIMENT RESULTS AND DISCUSSIONS

The 1550 nm-InGaAsP/InP SOA chips with angled-facet (7O) spot size converter active region were prepared at Heindrich-Hertz Institute (HHI) in Berlin. The chip length is 1250 ụ,m and its active region has the width of about 2 ụ,m with the tapered regions at both sides (active region end width is 0.8 ụ,m). The SOA facets are coated with the AR TiO2/SiO2 layer in order to have very low reflection coefficient (R<10-4). This new kind of SOA chips is designed for having larger amplification bandwidth and less polarization

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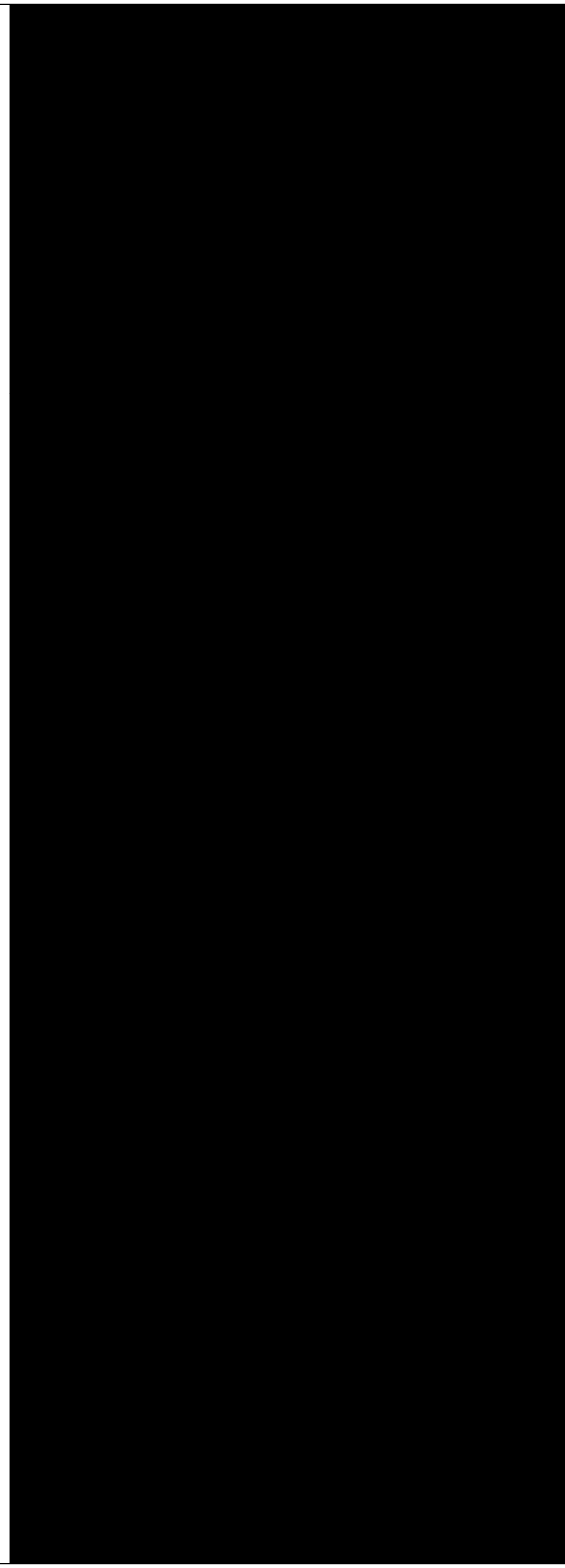
dependence of the gain. At Institute of Materials Science (VAST) we prepare the SOA modules by fiber-to-fiber optical coupling and module’s packaging. The module preparation processes are the same as in the our previous works [4].	[redacted]
Fig. 1. ASE spectra of SOA module at operating current of 50 mA (1), 70 mA (2), 90 mA (3), 110 mA (4) (T = 25oC)	[redacted]
It means that at first we attached the SOA chip on the gilded copper heatsink with electrically and thermally conducting epoxy Epo-tex H20E, then the 25 ụ,m diameter gold wires were bonded with the metallic contacts on the chip for current supply. The thermal sensor (10 KQ at 25oC) was also attached to the heatsink with thermally conducting epoxy. The heatsink was attaches to the peltier element. The SOA chip was coupled with the single mode 9/125 tapered fibers with the taper end diameter of about 15 ụ,m. The alignment system used here includes the Melles Griot six axis positioning system Nanomax-HS and high magnification stereomicroscope Carl Zeiss Stemi-2000. After having good alignment, the fibers were fixed on the heasink with thermally curing epoxy Araldite 2014. The capping process finishes the SOA module packaging and then the modules are kept in the temperature case at 50oC during 8 hours for stabilization of the module characteristics.	[redacted]
The amplified spontaneous emission	[redacted]

(ASE) curves at the different SOA module operating dc currents IsoA of the prepared modules show that the ASE 3dB bandwidths (about the same as the amplification bandwidths) are much larger than those that we observed before. The optical spectra were measured with the optical spectrum analyzer (OSA) Advantest Q8384 (RBW = 0.01 nm). The spectrum measurement decision was ± 0.01 nm. For the SOAs without spot size converters the ASE 3dB-bandwidth was 30 or 35 nm [4] while here we can see the 3dB-bandwidth of 75, 66, 62 and 48 nm for the SOA operating currents of 50, 70, 90 and 110 mA, respectively (Fig. 1). Full bandwidth in the wavelength range of 1450 V 1620 nm increases with the increasing of the SOA module operating current from 50 mA to 110 mA and the ASE maximum shifts towards shorter wavelength (from 1550 nm to 1517 nm) according to the carrier distribution changing in the conduction and valence bands of SOA. We know that the gain contours are approximately the same as the ASE curves for SOA. The lager ASE bandwidth or larger gain bandwidth shows the better performance of the spot size converter SOAs because the larger bandwidth the more signals can be amplified or processed in the communication networks. From the ASE curves we also can see the ripples of less than ~ 1dB for the SOA operating current of less than 100 mA. The small ripples show the good quality of antireflection coating on the SOA facets. At the higher SOA operating currents the



laser oscillation may occur due to the SOA re

Fig.2: Dependence of Fiber-to-Fiber Gain on optical output power at ISOA of 80 mA (1), 100 mA
(2) and 120 mA (3) (T = 25°C)

The SOA module's gain curves in dependence on input and output powers also were measured with the input signal from cooled DFB laser module emitting the light of À/4 - shifted 1544.30 nm (T = 25oC). The input signal power was changed with the variation optical attenuator (VOA) and input and output signal powers were measured with OSA. Fig.2 shows that the small signal gains at different SOA operating currents are lower than the values obtained by us before for the SOA without spot size converter [4]. This may be due to the fact that the light spot size on the SOA facet (0.2 |0,m x 0.8 |jm) is much less than the case of SOA without spot size converter (0.2 |0,m x 2.0 |0,m). The coupling of light from SOA active region into fiber and vise versa here is more difficult although the far field distribution of light is improved. However, the small signal gain curve is rather flat (~ 10 V 14 dB for ISOA = 80 V 120 mA) for all the SOA operating currents and the 3 dB saturation gain gives higher saturation output power (3 V 5 dBm) than before (~ 0 dBm). The noise figure is still rather high (10 V 14 dB) for the input signal of -20 dBm because the fiber-to- fiber coupling is still not optimum. Especially, by using the fiber polarization controller for the 1550nm wavelength we have

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received the dependence of the gain on the polarization of input light of the prepared SOA modules of less than 1.5 dB while it was ~ 4dB for the SOA without spot size converter [4]. It is very important for application of SOA in the fiber communication systems for both amplification and functional functions because any possible twisting or vibration of fiber can cause the light polarization changing leading to the instability of SOA gain. That is why we desire to have as small as possible the polarization dependence of SOA gain.

Fig. 3: SOA module gain vs. operating current
(Tsoa = 25oC), Pin = -30 dBm

Fig. 3 shows the dependence of SOA module gain on the operating current. With the increase of SOA current the gain increases and tends to the saturation at the currents larger than 160 mA. The measurement also showed that when operating current is small (< 30 mA) negative gain or absorption for SOA module occurs.

With the rather good characteristics such as large bandwidth, low polarization dependence and high saturation output power our prepared SOA modules can be used for amplification and especially for functional functions such as the wavelength conversion, modulation, optical gate, etc. where the nonlinear effects in SOA are used.

Fig. 4: FWM in the prepared SOA

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module: Pp(0)

For the study of the nonlinear properties of the prepared SOA modules we performed the setup for Four-Wave-Mixing effect measurement similar the cases for SOA without spot size converter [4] with the expectation of having better FWM. In fact, for the prepared SOA modules of such kind we could easily observe more clear FWM effect. Fig. 4 shows FWM spectrum when the dc pump signal (^1= 1543.67 nm) and probe signal (Å̌2 = 1544.44 nm) from cooled Å̌/4 - shifted DFB laser modules prepared by us serve as the input signals. These signals are combined with 50:50 fiber coupler before being putted into the SOA. The fiber polarization controllers were placed between DFB laser modules and coupler and the isolator was placed at the coupler output. With the change of the relative positions of the fiber coils of the polarization controllers we can have the best efficient FWM. At the SOA module output we observed the appearance of the new conjugate wavelength at Å̌3 = 1542.87 nm and the higher order of FWM spectrum at x4 = 1545.33 nm. The wavelength or írequency shift (or so-called írequency detuning) between pump and probe signals is the same as the shift between pump and conjugate signals.

The conversion efficiency of FWM in SOA was calculated as the following formula [1]:

where Pc(L) is the optical power of the conjugate wave at the output of SOA which depends much on the SOA length

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L and Ps(0) is the optical power of the probe wave at the SOA input. The best FWM conversion efficiency can be obtained if the polarizations of pump and probe light are the same and the ratio of the pump and probe signal power is optimum. We have to note that the pump signal power must be high enough in order to produce the nonlinear effects in SOA, in this case SOA must be saturated.

Fig. 5: Dependence of the FWM conversion

The dependence of the FWM conversion efficiency on the frequency detuning is the most important characteristic of the FWM effect. For changing the detuning between pump and probe signals we change the temperature of the cooled DFB laser module which serves as probe signal source while the pump DFB laser module was kept at the constant temperature (T = 20oC). With the change of the probe DFB laser temperature from 15oC to 45oC by using peltier cooler inside the module we can have the wavelength shift of probe wavelength of about 4.4 nm (dǍ/dT ~ 0.1 nm/oC). The VOA was placed at the probe laser output for keeping constant VOA output power during the laser temperature change. As the result, the probe signal changed its position from the right to the left of the pump wavelength and we have positive and negative detuning respectively. In order to increase the detuning we also use another DFB module (Ǎ2 = 1537 nm at T = 25oC) for probe signal source with the same signal power and by changing its temperature

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from 15oC to 50oC we can have the wavelength shift of 4.2 nm. By this way we could enlarge the positive detuning curve as shown in Fig. 4. The conversion efficiency decreases with the increasing of the detuning. The mechanism of Four-Wave-Mixing in SOA can be understood as following:

For detuning írequencies less than a few gigahertz, the largest contribution to the FWM susceptibility is due to carrier density modulation (CDM) which arises from the beating of the pump and probe waves. The intensity beating due to the pump and the probe leads to a pulsation of the population inversion in the medium. This pulsation of the total carriers leads to a gain modulation as seen by the traveling waves, which gives rise to the FWM sidebands. Due to the slow recovery of the carrier density, determined by the carrier lifetime TS, which is on the order of several hundred picoseconds, the efficiency of FWM mediated by CDM drops off for írequency detuning much larger than 10 GHz. At the large detuning frequency, that is suitable for our case, the gain and index gratings are formed by intraband processes, such as carrier heating (CH) and spectral hole burning (SHB) [1]. Instead of a pulsation of the total carriers in the conduction and valence bands of the semiconductor, the occupation probabilities of the individual transition levels are modulated to form the gain and index gratings that give rise to the FWM sidebands. The pulsation of the occupation probabilities create distortions in the equilibrium Fermi

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distribution functions of the carriers, which relax back to their equilibrium State through different scattering processes, such as CH and SHB. SHB arises from carrier-carrier scattering which tend to restore a quasi-equilibrium Fermi distribution function. Typically, carriers scatter each other at a time scale, Tshb, which is of the order of 50-100 femtoseconds. The quaSi-equilibrium Fermi diStribution function iS characterized by a temperature which iS different from the lattice temperature. The relaxation to the lattice temperature is through the emission of optical phonons with a time constant due to carrier-phonon scattering lifetime, TCH, which is of the order of 0.5-1 picoSecondS. ThuS the relaxation of the carrierS can be explained as a three step process: (1) the carriers first Scatter with each other to create a quaSi-equilibrium Fermi diStribution which haS a temperature Tx that iS different from the lattice temperature (SHB), (2) the temperature of the carrierS then relaxeS to the lattice temperature through carrier-phonon scattering (CH) and (3) the carriers then recombine through stimulated recombination.

The detuning curves in Fig.4 qualitatively well correSpond the theoretical calculationS where the conversion efficiency of FWM depends on the SOA saturated gain Gsat, input pump power Pp(0) (in dBm) and the detuning as the following formula [1]:

Fig. 6. Dependence of the FWM conversion efficiency on the SOA

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operating current when Pp(0)

where Tề is lifetime of the above processes CDM, CH and SHB which correspond to ề = 1,2 and 3, reSpectively and cề iS the complex coupling coefficient. We alSo obServed the Strong increaSe of the converSion efficiency when the SOA operating current increaSeS while input pump and probe Signal powerS and frequency detuning between them were kept conStant and it tends to the saturation (~ -15 dB) at the currents of more than 160 mA like the SOA gain behavior in Fig. 3. The low efficiency FWM also can be observed at the Small ISOA when no gain in SOA occurS. The increaSing of the FWM converSion efficiency when input pump power increaSeS alSo waS obServed while little changing of converSion efficiency occurred when we changed the input probe Signal power.

CONCLUSIONS

Semiconductor Optical Amplifier moduleS baSed on the 1550 nm angle-facet InGaAsP/InP SOA chips with Spot Size converter have been prepared and characterized. The reSultS Show that the packaging proceSS iS more difficult in compariSon with the caSe of the SOA chipS without Spot Size converter due to Small Size of the tapered active region. However, many propertieS of the moduleS are improved Such aS high gain bandwidth, high Saturation output Signal power and low polarization dependence of gain. The four- wave-mixing aS a nonlinear effect in SOA

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moduleS waS inveStigated with the main characteriSticS that qualitatively well correSpond to the theoretical model. Improving the coupling fiber-to-fiber efficiency we can have the SOA moduleS for both amplification and functional functions.	[redacted]