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Experimental investigation on gain-dependent chromatic dispersion of the semiconductor optical amplifier

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HIGHLIGHTS

- A simple method is used to measure the dispersion of SOA over the range of 80 nm.
- The dispersion can be adjusted by changing the bias current and the input optical power to SOA.
- Under the optimal experiment condition, dispersion curves have same characteristics.
- Increasing bias current will broaden the three near-zero dispersion regions.
- Increasing the input optical power will narrow the near-zero dispersion regions.

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ABSTRACT

Using a chromatic-dispersion analysis method based on K–K transformation of the gain spectrum, we experimentally investigated the chromatic dispersion of semiconductor optical amplifier in detail within the wavelength range from 1530 nm to 1610 nm. Experimental results demonstrate that there are three typical dispersion regions, which are abnormal dispersion, flatten dispersion and normal dispersion region, and three zero-dispersion points, which exist around 1550 nm, 1580 nm and 1600 nm, over the wide wavelength range of 80 nm. With an increase in bias current on SOA, wavelengths of the three zero dispersion points all had a blue shift and the three near-zero dispersion regions corresponding became wider. However, the three near-zero dispersion regions corresponding became narrower when the input optical power increased. Therefore, the dispersion of SOA can be flexibly adjusted by changing the bias current and input optical power to SOA.

1. Introduction

Semiconductor optical amplifiers (SOAs) have many attractive features such as high nonlinearity, broad and tunable gain spectrum, high efficiency, compact size, and low cost. These make them widely used as a key device in optical switch, wavelength conversion, all-optical regeneration, optical amplifier [1–4]. For the purpose of the effective application of SOA, it is necessary to clearly know their internal parameters. Up to now, some internal parameters related to the SOA as the amplifier, such as the carrier lifetime, gain spectrum, line width enhancement factor and reflectivity, have been investigated in theory and experiment in detail [5–8]. However, SOAs are useful not only for the amplifier but also for wavelength conversion, all-optical regeneration and so on. Especially for the application of high efficiency wavelength conversion with FWM, it is necessary to know the dispersion of SOA and thus it is very important for measuring the dispersion of SOA to develop the related applications of SOA in wavelength conversion and all-optical regeneration.

Generally, the phase-shift method, time baseband amplitude modulation (AM) response method and phase modulation to intensity modulation (PM–IM) conversion effect method are used to measure the chromatic dispersion of the passive components [9–12]. For the active devices, Hall et al. used the time domain method to measure the chromatic dispersion of a V-groove active waveguide at a wavelength near 1.5 μm [13]. For SOAs as a kind of the active devices, there are a lot of factors, such as the bias current, temperature, input signal, gain and the nonlinear effects i.e., XGM, XPM and FWM, affecting their chromatic dispersion and it is more complicated to measure their chromatic dispersion. So up to now, there are few reports on the chromatic dispersion measurement of SOAs.

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Considering the importance of the chromatic dispersion of SOAs for the applications of wavelength conversion and all-optical regeneration, we carried out the experimental measurement of the chromatic dispersion of SOAs by using a chromatic-dispersion analysis method based on K–K transformation of the gain spectrum. Instead of using a pulse signal in other phase-shift method, we adopted a CW light to inject into SOA to avoid self-phase modulation in SOA. That makes the experiment setup very simple in our method. The dispersion coefficient curves can be obtained as the gain of the optical signal is measured according to K–K transformation showed in Appendix. Measurement results show that there are three zero-dispersion wave lengths existing in the wavelength range from 1530 nm to 1610 nm. With increasing of bias current of SOA, the dispersion curve turned flatten, every zero-dispersion wavelength had a blue shift and the near-zero dispersion region $\Delta\lambda$ increased. However, increasing the input signal power would make the near-zero dispersion region narrower. With applying an appropriate bias current and the input signal power to SOA, the dispersion curve can be tailored to satisfy the requirements of different applications. The measurement will be useful for improving the interval and efficiency of FWM conversion, and make SOA significant in high speed and large capacity in all-optical signal processing networks.

2. Experiment principle and setup

Assuming that the input optical signal to SOA is denoted by A_0, the output signal of SOA can be expressed as:

$$A(z,t) = A_0 \exp\left(-\beta_j z\right) \exp\left[j(\beta_r z - \omega t)\right] \tag{1}$$

where β is transmission constant with the real part β_r who stands for phase delay in transmission process and the imaginary part β_j who stands for device gain, ω is the frequency of light, z is the length of active region in SOA and t is the propagation time of the optical signal.

When the optical signal pass through SOA, the signal gain G can be derived from the intensity of the output signal and the input signal, as shown in Eq. (2).

$$G = \left|\frac{A^2(z,t)}{A_0^2}\right| = \exp\left(-2\beta_j z\right) \tag{2}$$

In term of k–k relationship [14], the signal phase shift can be expressed as:

$$\varphi = -\frac{\beta_r}{2\beta_j} = -\frac{1}{2}\beta_c \ln G \tag{3}$$

where β_c is the line width enhancement factor.

Therefore, the dispersion can be deduced as:

$$D = \frac{\lambda^2\beta_c}{4\pi czG^2}\left[\frac{d^2G}{d\lambda^2}G - \left(\frac{dG}{d\lambda}\right)^2\right] + \frac{\lambda\beta_c}{2\pi czG}\frac{dG}{d\lambda} \tag{4}$$

For a given SOA, the gain curves could be obtained by measuring the power of input signal and the output signal at different wavelength and thus the dispersion induced by gain would be deduced from Eq. (4). The chromatic dispersion in SOA mainly includes two aspects: the gain-induced refractive index dispersion and the waveguide dispersion. The former one will be dominated since the gain per unit length is high enough in SOA. So this paper mainly research on the gain-induced dispersion and the dispersion mentioned in the follow paragraph all refers to it.

Fig. 1 shows the experimental setup for measuring the dispersion of SOA. The SOA (Model IPSAD1501, INPHENIX) measured is an InGaAsP diode with the active region length 1 mm and its line width enhancement factor is set to 5 as usual [15]. A CW light from a wavelength tunable laser (Model TSL-210, SANTEC) was injected to the SOA. Two optical power meters (Model FTM-200, RADIANTECH) were used to measure the powers of the input signal and output signal of the SOA by using two 50:50 couplers. Meanwhile optical spectrum analyzer (Model AQ6317C, YOKOGAWA) was also used to monitor the output signal of SOA.

3. Results and discussion

3.1. Optimization of measurement condition

The dispersion of SOA is related to the gain and thus it is crucial to obtain the gain curve of SOA. Since SOA is an active device with the function of amplification, measuring the dispersion of SOA is different from that of passive optical components because it must minimize the influence of the gain saturation effect and noise interference. For this reason, we investigated gain saturation effects and the signal-to-noise ratio of output signal under different experimental conditions firstly.

By changing the output wavelength of the tunable laser from 1530 nm to 1610 nm by the step of 0.5 nm and recording the power of input signal and output signal of SOA, we could deduced the gain curve. Fig. 2 shows the gain curve of SOA measured for different power of the input signal at a fixed bias current of 115 mA. The powers of the input signal are 45 μW, 65 μW, 85 μW, 105 μW, 150 μW and 400 μW, respectively.

It can be clearly seen from Fig. 2 that the gain of SOA decreases with an increase of the power of input signal to SOA. When the power of input optical signal to SOA is relatively low, for instance in the case of 45 μW, 65 μW, 85 μW, the relative high gain can be

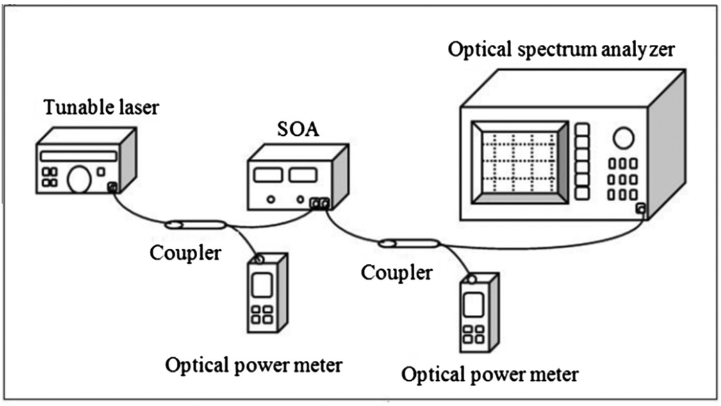

Fig. 1. Schematic diagram of experimental setup.