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Novel scheme of assist-light injection through waveguide coupling in a semiconductor optical amplifier for fast gain recovery

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ABSTRACT

We propose a novel scheme for injection of assist-light into the active region of a semiconductor optical amplifier (SOA) for fast gain recovery. In the proposed scheme, the assist-light is coupled into the active region of the SOA through an adjacent channel waveguide. Numerical results based on the well established model for carrier dynamics in SOA show that the gain recovery is faster in the proposed scheme as compared to the earlier reported scheme of counter-propagating assist-light injection. Our analysis shows that a desired power profile of the assist-light can be maintained in the active region of the SOA by tailoring the coupling through suitable design of the adjacent channel waveguide. The dependence of gain recovery on the input power of the assist-light in the proposed scheme has also been studied. Under typical operating conditions, it is found that 20 dBm of assist-light power injection in the proposed scheme is as effective as 27 dBm of assist-light power in the counter-propagating scheme.

1. Introduction

Semiconductor optical amplifiers (SOAs) play a key role as gain elements in optical communication systems and networks. In the recent past, optical nonlinearities in SOAs have been utilized to carry out various optical signal processing operations such as wavelength conversion, optical logic gates and optical switching [1]. For high-speed applications, the optical networks need functional devices with optical signal processing capabilities at 40 GHz or more [2]. However, the speed of an SOA is limited by the relatively slower gain-recovery, which causes bit pattern dependent errors in high bit rate signals [3]. Therefore it is important to reduce the gain recovery time (RT) of an SOA to meet the requirements of high-speed optical communication systems. Quantum dot based SOA is reported to have improved gain dynamics, but it is yet to be integrated in a real systems for the field application, due to certain fabrication issues [4]. Multi-electrode designs have also been reported for improved carrier dynamics [5], but these SOAs require independent biasing current sources for every electrode. The gain RT can also be reduced by increasing the biasing current, but this gives rise to difficulty in dissipating the excess heat generated, and also it affects the stability of SOA [6]. Another method to reduce gain RT is to inject a high-power 'assist-light' in the amplifier's active region along with the signal [7,8]. Here, 'assist-light' refers to a continuous wave (CW) light of appropriate wavelength, injected into the active region of SOA along with the signal, to replenish the carrier concentration in the active region. Several researchers have reported that gain recovery enhance significantly by assist-light injection at transparency wavelength of SOA, which is also known as optical pumping near transparency (OPNT) [9–11]. The counter-propagating assist-light injection is found to be better than the co-propagating assist-light injection in enhancing the gain recovery of SOA [12]. However, these schemes requires combining of assist-light with the signal by using additional wavelength division multiplexing (WDM) components at the input and the output of SOA, for coupling and decoupling of the assist-light. The power level requirement of about 20 dBm for the assist-light has been reported to enhance the speed of SOA considerably [10]. This relatively large level of power can lead to unwanted nonlinear effects in SOA [13], and may lead to damage of the active region in long run.

Recently, we have purposed a scheme of transverse assist-light injection from the top of SOA through a transparent electrode [14]. This scheme of transverse assist-light injection in SOA (TAL-SOA), although results in very fast gain recovery, could have fabrication difficulties related to deposition of the transparent electrode and integration of the light source for transverse injection. In this paper, we propose a simpler scheme to accelerate the gain recovery of SOA by injecting the assist-light into the active region through transverse waveguide coupling from a well-designed coplanar channel, located adjacent to the active region of SOA. Section 2

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discusses the proposed scheme in detail. Designing of the assist-light carrying channel waveguide is discussed in Section 3. Modifications in the existing numerical model for analysis of the SOA, relevant to the proposed scheme of Waveguide Coupled SOA (WC-SOA) for injection of the assist-light through separate waveguide, have been presented in Section 4. Section 5 discusses the simulation results which show performance enhancement of WC-SOA in terms of gain recovery.

2. Proposed scheme of WC-SOA

We propose the use of a non-parallel coplanar waveguide to inject the assist-light in active region of SOA through waveguide coupling, for fast gain recovery. Fig. 1 shows the conventional scheme and the proposed scheme for injecting the assist-light in SOA. In the conventional scheme, as the assist-light propagates along with the input signal, it undergoes attenuation due to absorption in the active region, and therefore the additional carrier generated due to the assist-light is not uniform along the length of the SOA. Also, there is no control over the power profile of the assist-light along the active region. Profile of the assist-light inside the active region plays an important role in the enhancement of gain recovery of SOA. We have found that for a linearly increasing assist-light power profile from the input end, the gain recovery is faster as compared to other power profiles. In the proposed method of injecting assist-light into the active region of the SOA we use a separate waveguide, which can be called as assist-light waveguide (ALW). Fig. 2 shows a schematic of tailoring the coupling in WC-SOA to get any desired power profile inside the active region. The assist-light can be injected along the same direction or from the opposite direction with respect to input signal, which we call as WC co-propagating and WC counter-propagating assist-light injection, respectively. The assist-light from ALW gets coupled into the active region (also known as active waveguide) along the length of SOA. The proposed scheme can transfer a desired fraction of assist-light power over the chosen length of the active region, depending on the inter-channel separation and the width of the ALW. Thus, the loss of assist-light by absorption in the active region is compensated by selective transfer of power due to waveguide coupling which was not possible in the earlier schemes of co- and counter-propagating assist-light injection.

Here both the ALW and active waveguide can be monolithically integrated on the same semiconductor layer. The advantage of placing the waveguides side-by-side is that the bias current which is injected from the top into the active region does not pass through ALW. Thus, the characteristics of ALW are not affected by bias current. The material used for the ALW could be different from the active region, so that the assist-light is not absorbed in this waveguide. The proposed scheme has the extra advantage that it does not require additional WDM components to couple and decouple the assist-light at the input and the output of the SOA. The assist-light, which is at a different wavelength than the signal, can be coupled into the ALW through a separate fiber pigtail [15], just as, it is done for coupling of signal to active waveguide of the SOA. So, in effect, WC-SOA is a stand-alone three terminal device (TTD), without any additional insertion losses for the signal.

3. WC-SOA design

Designing the ALW has two challenges: First, to couple the entire power of the assist-light over a short length of active waveguide (typical length of SOA being 0.5–2 mm), without back coupling. The wavelength of assist-light (which is generally at the transparency point of SOA) is considerably less than the signal wavelength. Therefore for a given waveguide, assist-light is more confined than the signal; hence evanescent-wave coupling of the assist-light is weaker than that of the signal, which is undesirable. The second challenge is to avoid coupling of signal from the active waveguide into the ALW. This would lead to a decrease in the signal power in the SOA, thereby resulting in a reduction of the overall gain. This situation will not be in favor of our objective, which is to minimize the gain recovery time.

In order to overcome these challenges, we choose a smaller width for the ALW as compared to the active waveguide, so that the evanescent field of the assist-light is extended into the cladding; this results in a stronger coupling into the active waveguide [16,17], thereby achieving maximum transfer of assist-light. Also, the width of the active waveguide is such that signal is well confined to the active waveguide; hence minimal evanescent wave coupling of signal takes place. Suitable design of ALW is required

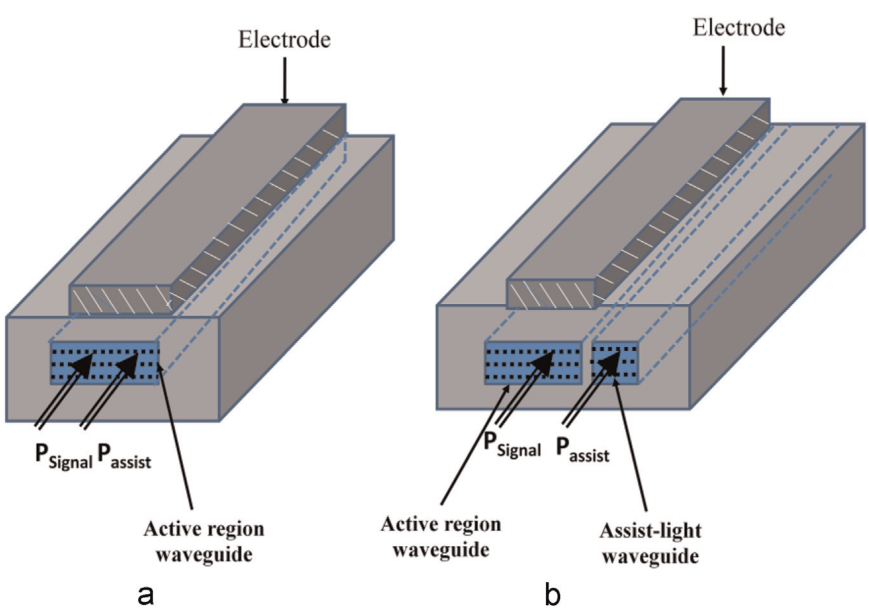

Fig. 1. (a) Conventional scheme of injecting assist-light along with the input signal in the active region (b) proposed scheme of injecting assist-light through a coupled channel waveguide, located adjacent to the active region of the SOA.