REVIEW ON A NOVEL APPROACH FOR DYNAMIC GAIN ADJUSTMENT IN OPTICAL AMPLIFIERS

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Abstract: The semiconductor optical amplifier (SOA) is a technology that may be crucial in future optical networks, as a low-cost in-line amplifier or as a functional element. As fibre networks extend closer to the end user, economical ways of improving the reach of these networks are important. SOAs are small, relatively inexpensive and can be readily integrated into photonic circuits. Problems persist with the development of SOA, however, in the form of a relatively high noise figure and low saturation power, which limits their use in many circumstances. The aim of this work to outline a concept to increase the saturation output power so that the SOA can achieve the performance required. Also, to improve the applicability of SOA in a switched environment, there must be a provision for varying the clamped gain. For this, distributed feedback grating or distributed Bragg reflector are integrated into the SOA for inducing lasing oscillation. It is well known as gain-clamped SOA (GC-SOA), in which the induced lasing oscillation clamps the gain and suppresses the gain saturation. It has already been studied the methodology for adjustable gain clamping which will give us an insight into how the clamped gain can be varied instead of being fixed. In the present work, a model is constructed which has been designed with unbalanced grating configurations combined with non-uniform current injection.

Index Terms - Dynamic gain clamped semiconductor optical amplifier (AGC-SOA), Gain clamping, gain adjustment, gain clamped semiconductor optical amplifier (GC-SOA), Output saturation power, noise figure.

I.INTRODUCTION

Optical amplifiers, as their name implies, operate solely in the optical domain with no inter conversion of photons to electrons. Therefore, instead of using regenerative repeaters which require optoelectronic devices for source and detector, together with substantial electronic circuitry for pulse slicing, retiming and shaping, optical amplifiers are placed at intervals along a fiber link to provide linear amplification of the transmitted optical signal.

The electronic regeneration system earlier used in place of optical amplifiers is shown in Fig 1. The optical amplifier, in principle, provides a much simpler solution in that it is a single inline component which can be used for any kind of modulation at virtually any transmission rate. Moreover, such a device can be bidirectional and if it is sufficiently linear it may allow multiplex operation of several signals at different optical wavelengths (i.e. wavelength division multiplexing). In particular with single-mode fibre systems, the effects of signal dispersion can be small and hence the major limitation on repeater spacing becomes attenuation due to fibre losses. Such systems do not require full regeneration of the transmitted digital signal at each repeater, and optical amplification of the signal proves.

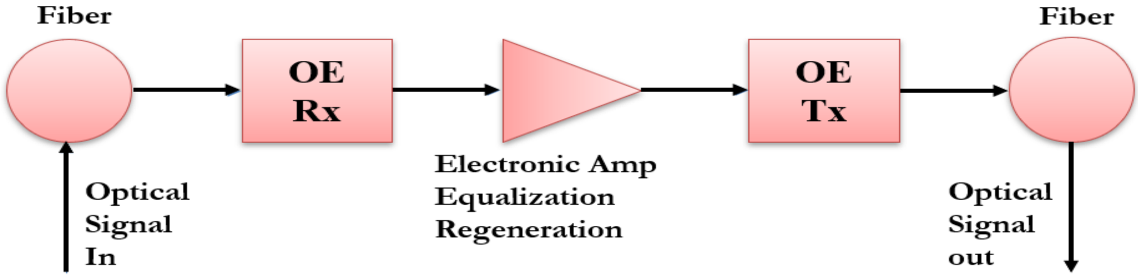


Figure 1: Optoelectronic module

Semiconductor optical amplifiers (SOAs) have been studied for as long as semiconductor lasers, since they are a very similar technology. SOAs are effective semiconductor lasers with anti-reflection coated facets. An electrical current is injected to the device in order to achieve optical gain for an injected signal. The signal itself is confined through refractive index guiding to an area called the active region, which is where optical gain takes place. The active region is surrounded by doped semiconductor regions called cladding regions, and some of the signal leaks into these areas. The amplification of the optical signal is accompanied by noise (Giuliani and D'Alessandro, 2000) which is an unavoidable aspect of the amplification process. SOAs, like semiconductor lasers, are heavily based on the III-V group of semiconductor materials. Early work on SOAs was carried out on GaAs/AlGaAs material systems, but from the 1990s onwards, research focused on SOAs based on InP with InGaAsP active regions. This material was chosen due to its ability to amplify signals in the 1300–1600 nm wavelength range, which became the wavelength region of choice for the expanding technology of optical fiber communications. A basic schematic of an SOA is shown in Fig 2.

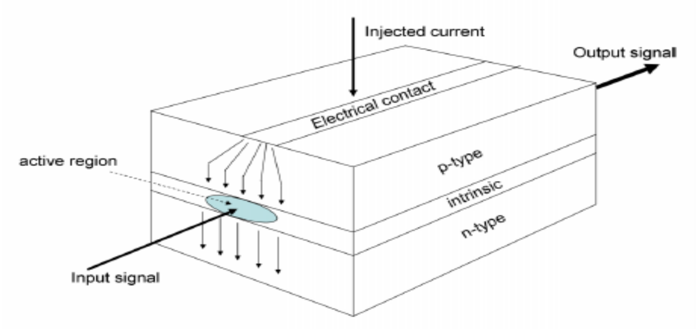


Fig 2: Schematic of semiconductor optical amplifier

II. GAIN-CLAMPING

When the (optical or electrical) pump power of a laser gain medium is increased, this will usually lead to an increase in the resulting optical gain. However, there are situations where the gain is firmly clamped to some precisely defined value which cannot be exceeded even with strongly increased pump powers. In particular, this is the case when laser action occurs. The gain is then clamped exactly to the value of the optical resonator losses; any increase of gain would lead to an exponentially rising laser power, which is obviously not consistent with steady-state conditions. This mechanism leads to a much more precisely defined gain e.g. saturation of the gain for high pump powers.

Gain clamping is sometimes exploited in fiber amplifiers for stabilization of the optical gain. Here, lasing is deliberately allowed at some wavelength outside the range of signal wavelengths; this can be achieved by incorporating fiber Bragg gratings (Bauer, Henry, and Schimpe, 1994) into the device. Fluctuations of the pump or signal power will then have only a small effect. Gain clamping stabilizes only the steady-state gain; transient phenomena can still occur, for example for fast changes of pump or signal input power.

III.GAIN-CLAMPED SOA

Gain nonlinearity arises from the very short carrier lifetime (100-500ps) that allows the gain to change in a lapse of time shorter than the bit width of the signal. In a conventional amplifier, the amplified signal output power has to be maintained well below (6-10dB) the maximum available output power of the SOA so as to prevent signal distortions. This considerably limits the practical dynamic range of power at the input of SOA. The gain clamping concept in SOA was investigated and has been recognized as an attractive approach to reduce the nonlinearities induced by gain saturation that plagues SOA. The gain then becomes insensitive to the fluctuations of amplified signal power as long as this one does not exceed oscillating power. As shown in the Fig 3. the gain curve with respect to output power, of such an amplifier is quite flat and saturates abruptly without the gentle saturation region as in conventional SOA. Consequently, all the available power of the amplifier can be extracted without introducing distortion of the amplified signal.

Fig 3: Typical gain vs signal output power characteristics for conventional SOA and the same SOA with gain clamped

One another important feature of gain clamped feature is that it offers the flexibility to control separately the gain and the available output power. The gain is fixed by the feedback level whereas the available output power is given by the driving current. In contrast for a conventional SOA, the gain and the output power are not separately controlled. With the gain-clamped concept, it becomes possible to increase considerably the dynamic range of input power by maintaining the gain at a moderate value. For this Distributed feedback or Distributed Bragg gratings are integrated into the SOA for inducing lasing oscillations as shown in Fig.4 and 5.

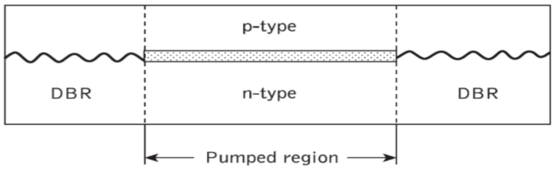


Fig 4: GC-SOAs with DBR

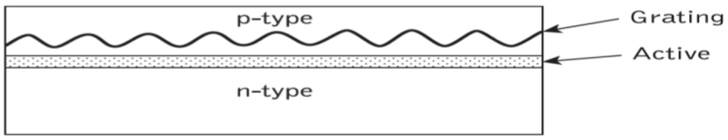
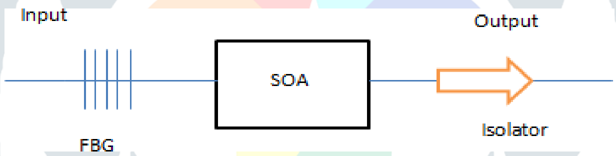


Fig 5: GC-SOAs with DFB

IV.TECHNIQUES USED FOR GAIN CLAMPING

- Distributed Bragg Reflectors DBR [4] or Distributed Feedback gratings DFB [5] are monolithically integrated into the SOA. This results in incorporating longitudinal lasing oscillations. However, in this technique, the gain is fixed by the device design and even the wavelength of the internal laser being used is predetermined.
- Using Vertical Cavity Side Emitting Laser, VSCEL structure [6] for transverse lasing oscillations.
- Using an amplified spontaneous emission (ASE) reflector [7, 8] in which the backward ASE power generated is



reflected by the feedback gratings (FBG) and gets amplified while passing through the SOA as shown in Fig.6. The gain clamping operation is performed by compensating effect between signal and ASE.

Fig 6: Schematic diagram of the proposed GC-SOA

- Monolithically integrating GC-SOA in a Mach-Zehnder interferometer (MZI) configuration [9].
- Using a range of linear and ring external cavities.
- Employing narrow bandwidth filters in the feedback loop to control the light generated by ASE of the SOA [10].

V. TECHNIQUES USED FOR ADJUSTABLE GAIN CLAMPING

A. Ring Cavity Topology

The data path is defined through signal SOA i.e. SOA1. SOA2 forms the control SOA. The laser cavity consists of both SOA1 and SOA2 the combination of the complex gain provided by both the SOAs sets the condition for the onset of lasing. SOA1 is provided with a fixed current during operation. Thus, as the drive current to SOA2 changes, the gain imparted by SOA1 also changes and hence this allows signal amplification by SOA1 at a clamped gain varied by SOA2.

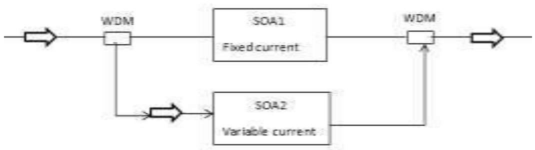


Fig: 7. Counter propagating ring AGC-SOA

B. Fiber Grating Wavelength Tuning Method

In this methodology [14], the semiconductor optical amplifier consists of two similar, active fibre gratings at each end. A continuous supply of current is provided to the gain section during operation. Wavelength tuning of the gratings is performed by infusing bias current into them. Thus, by tuning the grating wavelength, the lasing oscillation conditions can be regulated and in turn the gain can be adjusted. Therefore, the structure simplicity of this method as shown in fig.3 helps it to be useful in modulation at high data rates.

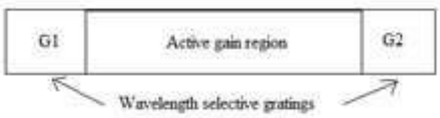


Fig: 8. Conceptual schematic of AGC-SOA

VI. LITERATURE SURVEY

Quereshi et al. [10] demonstrated a simple design of gain- clamped semiconductor optical amplifier. The intensity of the feedback light generated by amplified spontaneous emission was automatically controlled by using a thin film tunable bandpass filter in the feedback loop. It has been presented experimentally that the proposed amplifier had good gain fixing characteristics. The dynamic gain variations in an SOA have also been reduced significantly using this technique. The performance of GC-SOA has been examined by employing feedback laser at variable wavelengths. Kim et al. [18] illustrated a gain-clamped semiconductor optical amplifier optical amplifier which had gratings of different lengths at both ends of the active waveguide region. With different combinations of grating lengths, the gain and noise characteristics of the SOA have been studied. There were in total four sample chips fabricated for the experiment. Two out of the four were symmetric whereas the other two were asymmetric gratings. It has been shown that as the length of the symmetric gratings was increased, it exhibited higher side mode suppression ratio (SMSR), lower gain and larger saturation output power. Also for asymmetric gratings, higher saturation output power and lower noise figure was obtained when the input signal was put into the longer grating side. Another gain clamping scheme using an amplified spontaneous emission reflector has been experimentally illustrated by Ahn et al. [7]. This technique of gain clamping was free from any lasing induced pitfalls. Both the input FBG type GC-SOA and output FBG type GC-SOA have been studied in this technique. Michie et al. [11] illustrated the operation of an AGC-SOA which uses ring cavity topology this type of sub-system finds its application in packet and burst mode environment where there is a need for linear amplification of wavelengths and power equalization of the channels or bands.

Davies et al. [17] demonstrated an adjustable gain clamped semiconductor optical amplifier by using a sampled grating laser in which the feedback from the gratings was tuned by current injection. Variable gain clamping of 14 dB has been achieved using this novel technique in the EDFA operating window i.e. 1530 to 1545 nm operating range.

Akbar et al. [14] illustrated fibre grating wavelength tuning method for monolithic integration of an adjustable gain clamped semiconductor optical amplifier. In this technique, the gain of the amplifier was varied without much loss of saturated output power. Tuning of the grating wavelength gave an opportunity for adjusting the lasing threshold conditions. Also, this technique did not have any influence on gain bandwidth and polarization sensitivity of the SOA. Wada et al., 2018, demonstrated gain-clamped semiconductor optical amplifier (GC-SOA) based on the distributed Bragg reflector (DBR) structures is investigated by a comprehensive broad-band time-domain traveling wave model. Critical factors, e.g., the material gain profile, the waveguide grating structures, the longitudinal variation of the optical field, and the carrier density as well as the broad-band spontaneous noise emission are considered in the model. The effects of operation parameters (e.g., the electrical bias current and the input optical power) and design parameters (e.g., the normalized coupling coefficient and the lasing wavelength position) on device performance are examined in detail. Kharraz et al., 2018, presented a new method to accelerate the carrier lifetime in semiconductor optical amplifiers (SOAs) is experimentally demonstrated, a pair of fiber Bragg gratings is utilized to generate pre-spectral sliced seed light channels as FWM inputs, by reflecting the backward amplified spontaneous emission from the SOA in a gain-clamped configuration.

Fujiwara et al., 2016, presented novel burst-mode automatic gain-controlled semiconductor optical amplifiers (AGC-SOAs) that are utilized as one upstream channel of a repeater in long-reach time- and wavelength-division multiplexed passive optical networks (WDM/TDM-PONs) Two SOAs are cascaded in the AGCSOAs to achieve high gain. Two-stage gain switching with a fast feed forward (FF) control circuit is applied to the first SOA and the second SOA equalizes output burst frame powers regardless of input powers; the combination plays a key role in expanding the system operating range of long-reach systems. Thus, the important findings of the various papers reviewed in literature survey are tabulated in Table.1

Table.1. Literature Survey

S.NO.	Technique Used	Findings
[1]	Amplified spontaneous emission reflector	• Fixed gain of about 18 dB
[2]	ASE reflected by Fiber Bragg grating	• Gain clamped at 20 dB • Noise figure approximately 5 dB
[3]	Bandpass filter in the feedback loop	• Steady state transient ratio reduces from 0.353 to 0.048 upon channel add drop at 20.9 kHz
[4]	Ring cavity topology	• Gain adjustment dynamic range >30 dB • Noise figure=7.5 dB • No significant power penalty for 8 channels separated by 200 GHz.
[5]	Fiber grating wavelength tuning method	• Adjustable gain over a range of 4 dB • Max. saturated output power= 21 dBm • Noise figure= 8 dB
[6]	Variable three-contact tunable laser	• Gain variation of about 10dB • Noise figure=7.9 dB
[7]	Tunable sampled grating laser	• Range of variable gain= 12 dB • Gain flatness better than 4 dB over a wavelength range of 1530-1545 nm
[8]	Distributed Bragg reflectors with different lengths on both sides of active region	• Higher saturation output power and lower noise figure when input signal put into longer side
[9]	Long reach & high-splitting-ratio WDM/TDM-PON system using burst-mode AGC-SOAs	• Reported burst-mode AGC-SOA wherein they have used two SOAs which are cascaded in the AGC-SOA to achieve high gain.
[10]	Acceleration of carrier lifetime in Gain-Clamped SOA.	• Proposed a new method to accelerate the carrier lifetime in SOAs via its backward ASE in GC arrangement. Two FBGs were attached directly at the input of SOA, as to make use of the backward ASE from SOA.

VII. CONCLUSION

The effective cost and easy deployment features of SOAs make them an appealing candidate for extending the range of Passive Optical Networks (PONs) in particular. Problems exist however, due to both noise penalty imposed by the SOA at low optical power and the effects of the gain saturation at high optical powers. Therefore, the gain clamping concept in SOA has been investigated and recognized as an attractive approach to reduce nonlinearities induced by gain saturation. Methods for controlling the lasing threshold and wavelength required for gain clamping include longitudinal lasing from Distributed Bragg reflector and Distributed Feedback, DFB, gratings.

However, gain clamping fixes the gain and as a consequence does not provide a solution to dynamic gain adjustment. Thus, a methodology for adjustable gain clamping has been proposed in this report.

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