BACK TO 1310 nm -- WITH SEMICONDUCTOR OPTICAL AMPLIFIERS

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Abstract

Semiconductor optical amplifiers (SOAs) provide a cost-effective optical amplification scheme at 1310 nm. Although they have already been used in enhancing the performance of high-bit-rate digital systems, their use in CATV systems has been limited so far because of their distortion performance. However, recent research suggests that this can be overcome by using a new technique called 'gain-clamping'. In this paper, we will review the performance of presently available SOAs and discuss their performance enhancements using gain-clamping. We will then indicate potential applications of SOAs along with some applicable system tradeoffs with special emphasis on analog networks.

INTRODUCTION

Optical amplification schemes at 1550 nm using Erbium Doped Fiber Amplifiers (EDFAs) have demonstrated their superiority over conventional optical repeaters in terms of noise and distortion performance. They are already being used in connecting headends and in other analog supertrunk applications. However, their use in dense CATV systems has been rather slow because the externally modulated transmitter that is required to combat dispersive effects at the 1550 nm low loss window is very expensive. Semiconductor optical amplifiers (SOAs), on the other hand provide amplification at the low dispersion, 1310 nm optical window. Furthermore, the electronic control of these amplifiers is similar to that of present-day DFB lasers, so they help preserve present system architectures. SOAs are now available as a fully packaged product and have already been used to enhance the performance of digital systems [1, 2, 3]. Their use in CATV applications has been limited because their optical gain varies with instantaneous changes in input signal level. This generates distortions that cannot be tolerated by conventional AM-VSB signals.

Recent research suggests that this drawback can be overcome using a new technique called *'gain-clamping'*[4]. For gain-clamped SOAs, output powers in the range of 10-15 dBm, and IMD products approaching that of linear DFB lasers, are predicted to be possible. This paper reviews the performance of presently available SOAs and discusses the prospects for linearizing their performance using the gain-clamping technique. Finally, we will review their potential applications in conventional AM-VSB systems with respect to optical budget, cost and flexibility.

SEMICONDUCTOR OPTICAL AMPLIFIERS

Semiconductor optical amplifiers are now available as a fully packaged and pigtailed product, with a size and power consumption comparable to that of the well-known 1480 nm pump lasers. The only difference is an additional input-optical fiber. The semiconductor optical amplifier chip inside this package is based on a high-performance multiple quantum well semiconductor laser structure of proven design. The chip employs a 10° angle stripe and high-quality AR coatings to suppress cavity effects and to obtain the optimum performance. Their fabrication technology is identical to that of semiconductor lasers.

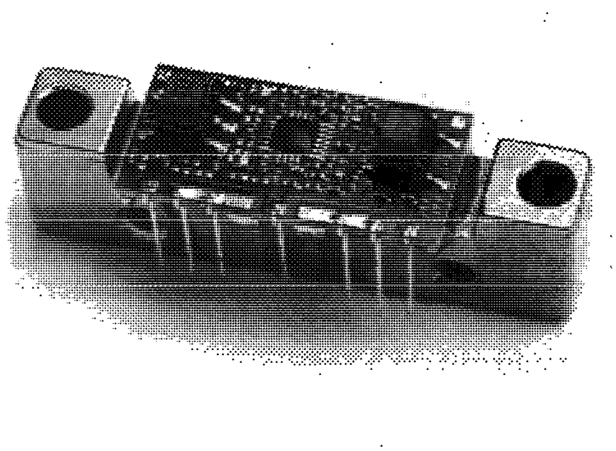

Fig. 1. Photograph of a fully packaged Semiconductor Optical Amplifier

Unfortunately, so far this optical amplifier has been considered unsuitable for use in cable TV fiber optic transmission, mainly because of its nonlinear transfer characteristics. The dashed line in Fig. 2 shows the characteristic output power versus input power of a conventional optical amplifier. The decrease in output power for high levels of input power is caused by gain saturation in the active medium.

Although an EDFA has a transfer function similar to the one shown, the gain mechanism in the EDFA is very slow (about 10 ms) compared to the typical modulation frequencies applied in the CATV transmission. Hence, the above transfer function applies only to average signal levels rather than to instantaneous changes in input signal levels. Therefore, the EDFA can amplify the signals in the CATV frequency band undistorted.

The major obstacle towards using semiconductor optical amplifiers for the same type of application is the fact that their gain mechanism is very fast (about 0.2 ns). This means that even instantaneous changes in input signal levels will modulate their gain. This gain-modulation eventually results in the generation of generally unacceptable levels of second and third-order distortion products.

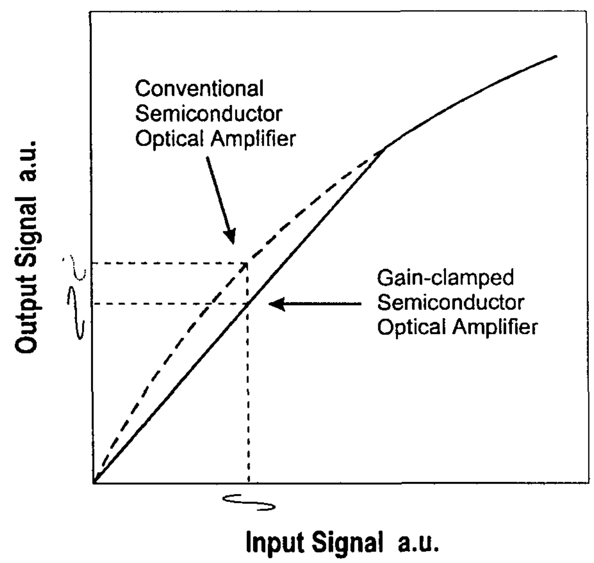

Fig. 2. Diagram illustrating the transfer characteristics of conventional and gain-clamped SOAs

Recently, we demonstrated that '*gain-clamping*' is an effective technique to overcome the problem of gain modulation in the SOA. With this technique, laser action is initiated at an out-of-band wavelength of 1290 nm by a weak 1 - 5 % reflective Bragg grating, which is monolithically integrated with the amplifier chip. This grating is transparent for the 1310 nm CATV signal. Lasing at 1290 nm clamps the carrier density to the laser threshold level, and thus stabilizes the optical gain efficiently. This is illustrated by the solid curve in Fig. 2.

When this gain-clamped amplifier is operated well above the lasing threshold for

1290 nm emission and a fiber Bragg grating filter is used to block the 1290 nm emission, a highly linear 10 to 15 dB fiber-to-fiber gain around 1310 nm is obtained.

Results based on preliminary analysis indicate that after design optimization second-order IMD products in the range of -69 dBc are possible. This is for output powers in the range of +10 dBm using a two-tone modulation frequency pattern of 125 MHz and 226 MHz with a modulation depth of 35%. For the same system, third-order IMD products in the range of -100 dBc are possible. These numbers are better than the corresponding numbers for a DM DFB laser.

SOA PERFORMANCE EVALUATION

Digital

SOAs have already been used to enhance digital performance at 1310 nm. In one experiment, a 1310 nm polarization insensitive semiconductor optical pre-amplifier enabled a power budget of close to 40 dB, at a bitrate of 10 GB/s. This is sufficient to bridge 102 Km of standard singlemode fiber. In another experiment, a cascade of four polarization insensitive amplifiers transmitted a 20 GB/s soliton signal over 200 Km of standard singlemode fiber.

Digital systems are very forgiving of noise and distortions and can tolerate gain-modulation effects inherent in SOAs. Also, the average power levels for these systems is quite low, where the SOA distortions are considerably weaker. These examples prove that SOAs work well in digital systems.

Analog AM-VSB

For conventional analog systems the power at any optical node is roughly 0 dBm. This requirement puts a premium on the output power of the SOA. Presented below is the Pin versus Pout performance of an SOA for varying bias currents.

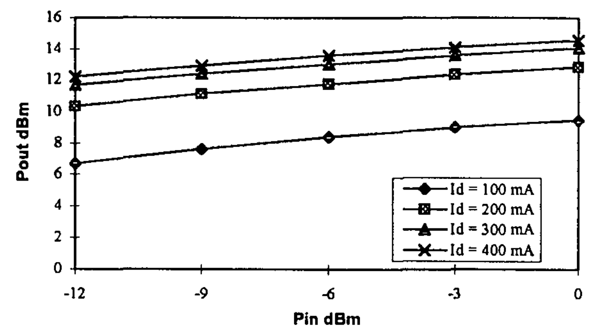

Fig. 3. Pin Vs. Pout graph for an SOA for different bias currents.

The SOA output power saturates at higher bias currents. This graph demonstrates that SOAs can provide enough power gain for CATV level inputs.

However, the requirements on distortion and noise performance for conventional CATV systems are far more aggressive. Shown below is a test set-up for SOA testing.

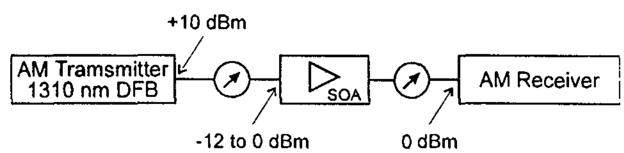

Fig. 4. Test set-up for measuring AM performance of an SOA

Based on tests conducted on the SOAs, using the above set-up, and a 40 channel loading (300- 550 MHz), typical CNR of 40 dB and CTB of 40 dB were measured with presently available SOAs. This clearly indicates that the noise and distortion performance of SOAs in the present form is unsuitable for conventional CATV systems. The gain-clamped version should help in this case.

FM Transmission

FM transmission on fiber closely imitates digital transmission. Shown below is the test set-up for a 16 channel FM test. The output of the transmitter is a set of 16 unmodulated CW carriers which are incident on the FM receiver at an optical power of -10 dBm, as consistent with FM requirements.

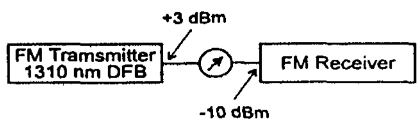

Fig. 5a. FM test set-up

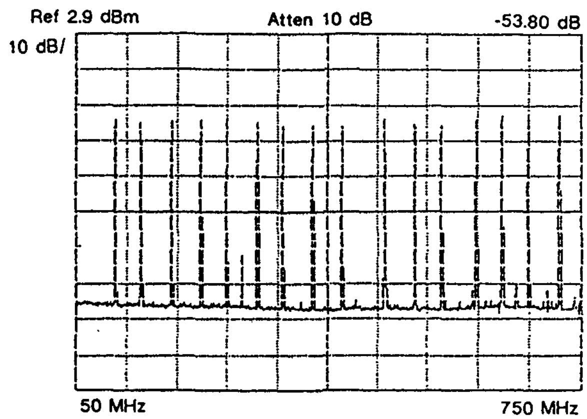

Fig. 5b. FM response with -10 dBm input to the receiver (RBW 300 KHz, VBW 3 KHz)

Now, the SOA is inserted between the transmitter and the receiver. As is clear from the diagram below, the SOA has an input of -10 dBm and gives an output of +10 dBm. Then, as above, -10 dBm is incident on the receiver.

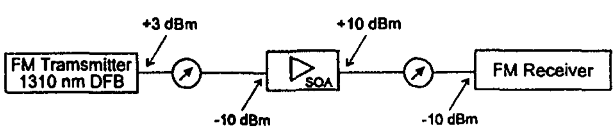

Fig. 6a. Test set-up for measuring FM SOA performance

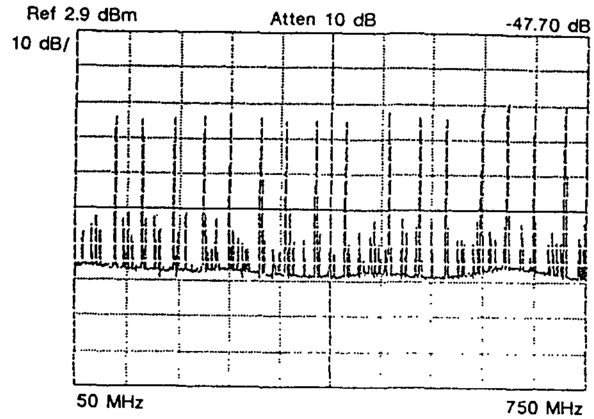

Fig. 6b. Response with SOA with -10 dBm at the FM receiver (RBW 300 KHz, VBW 3 KHz)

A comparison of the two responses indicates that the noise floor has degraded by 6 dB, allowing a CNR of 47 dB and that the distortions are limited to about -35 dBc. The addition of the SOA has also resulted in an enhancement of the link budget by 20 dB, roughly corresponding to 60 km of fiber length.

This is just the preliminary result, and we expect that with optimization of the SOA parameters and optical filtering of the amplifier spontaneous emission noise, cascading of several SOAs while maintaining low noise and distortions is possible.

Return Systems

SOA testing for a return system was carried out using 20 - 80 channels of QPSK at T1 rates in a fiber. The results involving SOAs are inconclusive. This is because the laser used to transmit the QPSK channel is an FP laser with no isolator protecting it from back-reflections. This is not a major concern for normal systems. However, when an SOA is inserted in the signal path, the amplified spontaneous emission (ASE) of the laser along with the Rayleigh back-scatter feed-back into the FP laser, thus increasing the laser noise and affecting its performance. Further work needs to be done to identify this problem precisely and to propose a cost effective solution.

DISCUSSION

Development of viable optical amplifiers at the 1310 nm window is a great opportunity for the CATV industry to protect its investment in presently deployed 1310 nm systems [5]. Clearly SOAs in the present form are not suitable for use in analog CATV networks, other than for FM systems. However, improvements in SOA technology will in all probability lead to better devices that can handle analog CATV signals.

To be fair, we must mention two other competing amplification schemes that exist at 1310 nm. They are the Praseodymium Doped Fiber Amplifiers (PDFAs) [6] and the Raman Fiber Amplifiers [7]. Both these amplification alternatives are bulky and expensive. Since these amplifiers use multiple high-power pumps and special types of doped fibers, their reliability with respect to continuous use has not yet been confirmed. The manufacturing process of building SOAs, on the other hand, is the same as that for DFB lasers. This mature technology and the associated high reliability, at prices competitive to DFBs, make the future of SOAs secure. With this in mind, we need to compare SOAs to conventional repeaters and to 1550 nm Externally Modulated systems.

The superiority of a fully functional gain-clamped SOA over a conventional optical-RF-optical repeater is considerable. SOAs will help in eliminating cost and complexity associated with maintaining a separate receiver and transmitter at each location. This would reduce congestion in dense headend locations. SOAs would also be able to provide optical budgets for bridging medium distances and for multiple splitting options. And they do all of this while maintaining the present system architectures at competitive prices.

In supertrunk applications, especially in providing headend-to-headend connection over long distances (in the range of 80 - 100 km), EDFAs have some obvious advantages. Fiber attenuation at 1550 nm is almost half that of 1310 nm, while the passive split losses are the same at the two wavelengths. In all likelihood, EDFAs will continue to have an upper hand in this sector. However, these systems involve at least one externally modulated 1550 nm transmitter and a combination of EDFAs depending on the specific application.

The design of good external modulators to compensate for Stimulated Brillion Scattering (SBS), Double Rayleigh Backscatter (DRBS) and fiber dispersion is expensive and non-trivial. Maintaining low noise figure (NF) in EDFAs with high reliability is non-trivial as well. The resulting system, while it works well when properly designed, is expensive and complex.

In high-split applications, an additional amplifier is provided at the last headend. The output of the amplifier is split into multiple fiber lines and distributed directly to the hybrid fiber coax network. Here, both amplification schemes have equal loss budgets since splitter losses are the same at both wavelengths.

Hence, if the system configuration calls for short hops followed by multiple splits, SOAs have the distinct advantage. This is because total compatibility of 1310 nm wavelength is maintained. The full potential of narrow casting or broadcasting can now be realized, while preserving all existing 1310 nm networks.

CONCLUSIONS

In this paper, presently available semiconductor optical amplifier technology was reviewed. The basic architecture of these amplifiers including gain-clamping of SOAs for linearizing their performance was briefly explained. Performance of presently available SOAs in different transmission schemes were then discussed in detail. Finally, potential applications of 1310 nm SOAs and how they compare to currently used solution were indicated. The chief advantages of 1310 nm SOA technology are: flexibility, scalability, dispersion immunity, compatibility with existing systems, and low cost. Now, for the first time, both power budget and dispersion are non-factors in transmitting optical signals.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help of Eric Schnettler in testing SOAs. One of the authors (VM) would like to thank Kerry LaViolette for helpful discussions on systems aspects of SOAs.

REFERENCES

1. L. F. Tiemeijer, "High performance MQW laser amplifiers for transmission systems operating in the 1310 nm window at bit-rates of 10 Gbit/s and beyond", Proc. of ECOC-95, paper Tu.B.2.1, 1995

2. H. de Waardt et al., "2 x 10 Gbit/s WDM 1310 nm optical transmission over 63.5 km standard single-mode fiber using optical preamplifiers", IEEE Photonics Technology Letters, 104-107, Jan 1995

3. L.F. Tiemeijer, "33 dB fiber-to-fiber gain +13 dBm fiber saturation power polarization independent 1310 nm MQW laser amplifiers", PD1-2, Optical Amplifiers and Their Applications, June 1995

4. L.F. Tiemeijer et al., "Reduced intermodulation distortion in 1300 nm gain clamped MQW laser amplifiers", IEEE Photonics Technology Letters, 284-286, March 1995

5. L. F. Tiemeijer and V. G. Mutalik, "Applications of semiconductor optical amplifiers in CATV networks", SCTE Emerging Technologies conference, Jan. 1996

6. Y. Ohishi, et al., "Recent progress in 1.3 um fiber amplifiers", TuG1, OFC, Feb/Mar 1996

7. A. J. Stenz, et al., "Raman ring amplifier at 1.3 um with analog-grade noise performance and an output power of 23 dBm", PD17, OFC, Feb/Mar 1996