10 Gbit/s modulation of Reflective SOA without any electronic processing

G. de Valicourt[1,2,*], D. Maké[2], C. Fortin[2], A. Enard[2], F. Van Dijk[2] and R. Brenot[2]

[1]Institut Télécom, Télécom ParisTech, LTCI CNRS, 46 rue Barrault 75634 Paris Cedex 13, France
[2]Alcatel – Thalès III-V Lab, a joint Laboratory of "Alcatel Lucent Bell Labs" and "Thales Research & Technology", Route Départementale 128, 91767 Palaiseau cedex, France. Phone: +33 1 69 41 57 33, Fax: +33 1 69 41 57 3
**Corresponding author:: guilhem.devalicourt@3-5lab.fr*

Abstract: For the first time, we demonstrate that the use of a long RSOA as remote modulator enables short distance transmission on SMF below the FEC limit at 10 Gbit/s without any electronic processing.

OCIS codes: (060.2330) Fiber optics communications; (250.5980) Semiconductor optical amplifiers; (230.4110) Modulators

1. Introduction

Next-generation access networks might comprise remote modulators for improved flexibility and network reconfigurability. Reflective Semiconductor Optical Amplifiers (RSOA) have been already deployed in Korea [1]. The modulation bandwidth of RSOA is limited to 2 GHz [2-3]. Active research on bandwidth extension has led to the following results: (i) 7 GHz small-signal bandwidth with bi-electrode devices [4-5] but no large signal operation, (ii) 10 Gbit/s operation with EDC [6], OFDM [7] or electronic filtering [8]. Increasing the modulation bandwidth of RSOA is still a challenge, at least to simplify the architecture and reduce power-hungry electronic processing. There is no predictive model to explain why RSOA cannot be directly modulated at 10 Gbit/s, contrary to Directly Modulated Lasers having the same active structure. In DML, carrier density is smaller than in RSOA, since it is clamped by the lasing effect. Besides, photons remain in the cavity longer than in a RSOA because of the reflections. Since carrier lifetime is mainly governed by stimulated emission rate, we have decided to increase the length of our RSOA to increase photon density, hence reducing carrier lifetime.

This paper presents the impact of length increase on the modulation bandwidth, either in small-signal or large-signal operation conditions. Carrier lifetime measurements confirm the impact of photon density on the dynamic behavior. Long RSOA are used as remote modulator and enable operation at 10 Gbit/s in back-to-back configuration and over 2 km single mode fiber. Limitation due to the chirp using high bit rates modulation is observed and confirmed by transmission results over SMF, however chirp reduction in RSOA has been demonstrated using multi-electrode devices [9].

1. Lifetime measurements from spontaneous emission (SE) measurements

The carrier lifetime is inversely proportional to the recombination rate. The recombination rate can be described using two different terms: one directly proportional to the spontaneous emission and non-radiative recombination (due to the defect or Auger process) and a second one depending on the stimulated recombination. This second parameter is directly proportional to the photon density inside the device and mainly controls the carrier lifetime. For short devices, the carrier density is closed to be homogenous and strong carrier depletion appears for longer devices at the output of the device. Carrier depletion is caused by large photon density. Spontaneous emission from the active stripe is measured at the input/output or mirror section (Fig. 1). With the longer devices, carrier density is not homogeneous along the active stripe. Carrier depletion is caused by large photon density.

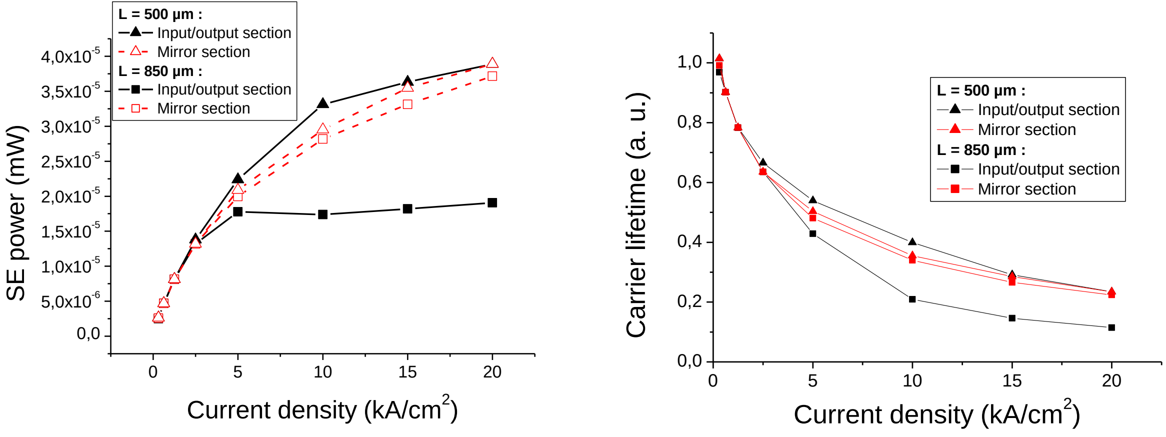

Fig. 1: SE power and effective carrier lifetime of 500µm and 850µm long RSOA as a function of the current density.

At the input/output facet of the longer RSOA, carrier lifetime is reduced by the large photon density when current density exceeds 5 kA/cm^2.

2. Modulation experiments and transmission measurements

The active structure is composed of a standard bulk material, with an anti-reflection coating at the input/output facet, and a high-reflection coating at the mirror facet. RSOA length has been varied from 300 µm to 850 µm to increase the gain and Amplified Spontaneous Emission (ASE) power. The chips have been mounted on a HF-submount, and modulated at 10 Gbit/s with a 2^{31}-1 PRBS sequence.

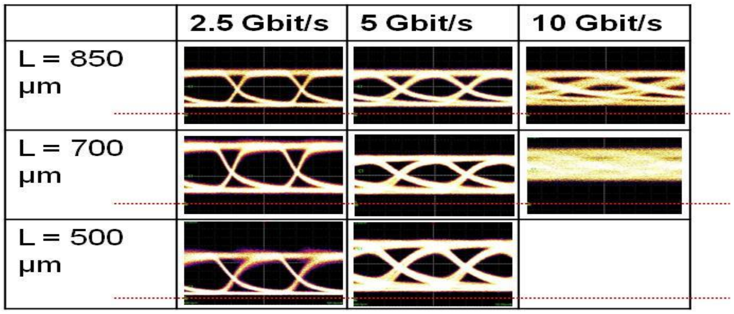

Fig. 2: Eye diagrams at various bit rates of RSOA whose length varies from 500 to 850 µm. The collected power is pure ASE. Red lines are the dark levels.

Bit-Error Rate (BER) measurements have led to a BER floor of 10^{-6} in the ASE regime. Error-free operation can either be obtained with Forward Error Correction codes, or under certain optical injection regimes.

One can observe from Fig. 2. (2.5 Gbit/s eye-diagrams) that the optical power decrease between a '1' and a '0' displays two different time constants. It is very fast at the beginning, then a much slower decay leads to patterning effects at larger bit-rates. This slow decay is commonly observed on all RSOA. It can be reduced either by decreasing the extinction ratio, or in very strong optical injection regimes. In order to correlate this decay times with the injected current, we have measured the E/O modulation bandwidth (Fig. 3). When the current decreases, the carrier dynamic is slower because photon density decreases.

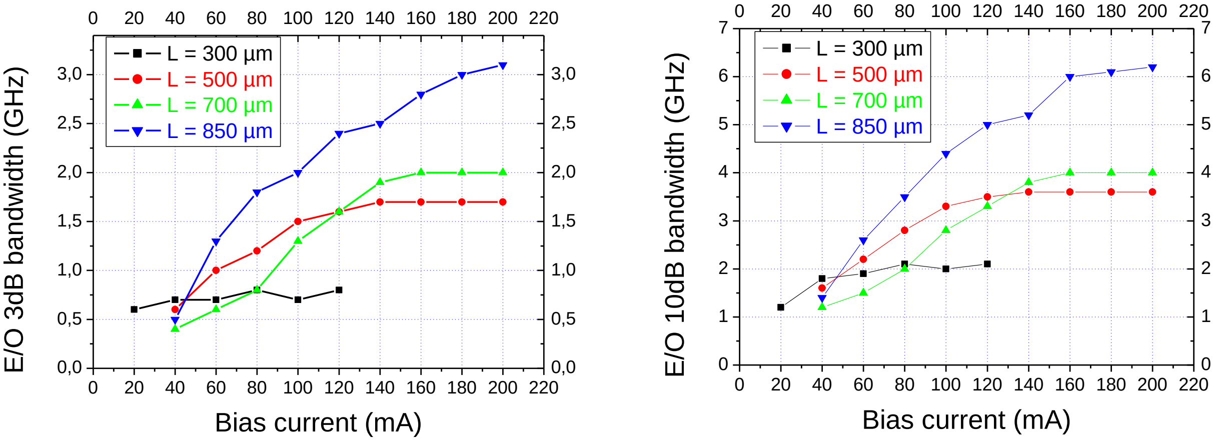

Fig. 3: 3 dB and 10 dB small-signal modulation bandwidth of various RSOA as a function of the injected current.

An external cavity laser (ECL) is used to launch a 4.5 dBm CW signal into the system through an optical circulator (OC). The signal is coupled into the RSOA which is modulated and generates the upstream signal. The RSOA is driven by a 2^7-1 pseudo-random bit sequence (PRBS) at. 10 Gbps, with a DC bias current of 160 mA. The upstream signal propagates on various SMF lengths. A variable optical attenuator is placed in front of the receiver in order to analyze the performance of the system as a function of the received power. Bit-error-rate (BER) measurements are done using an Avalanche Photo-Diode receiver and an error analyzer. BER measurements have led to a BER floor of 10^{-6} in the ASE regime. With optical injection, penalties below the FEC limit in BtB and 2km transmission are obtained (Fig. 4) Error-free operation can either be obtained with Forward Error Correction codes, or under certain optical injection regimes. However we can clearly see that the eye diagram starts to be closed due to the chirp over long distances. Multi-electrode devices can be used in order to compensate this effect.

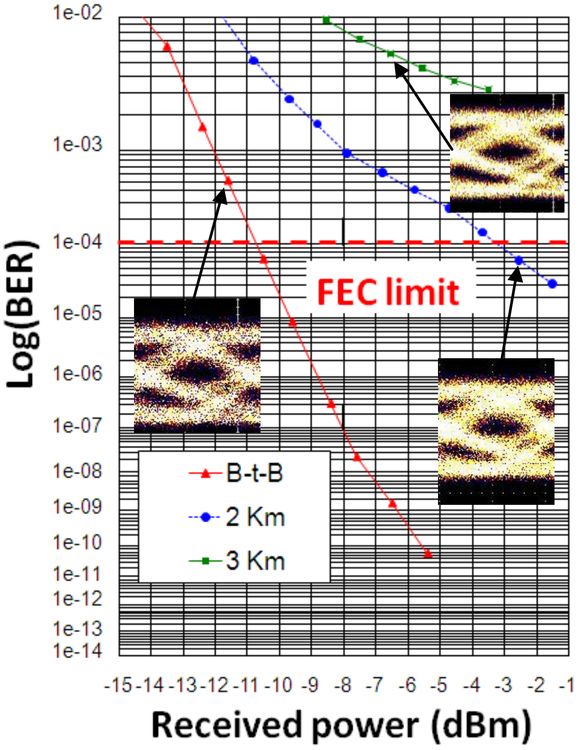

Fig. 4. BER value as a function of the received power for 850 µm mono-electrode at 10 Gbps.

3. Conclusions

The modulation speed of RSOA is limited by photon density. In the large signal regime, the slow decay is attributed to photon escape from the RSOA, which increases carrier lifetime. 3 GHz modulation bandwidth can be obtained with 850 µm long RSOA, which has led us to the first eye-opening of a RSOA at 10 Gbit/s without electrical equalization or strong optical injection. . Limitation due to the chirp is observed and further works are underway to overcome this effect using multi-electrodes devices. Longer devices and dual-electrode devices will be studied to improve the modulation and transmission properties.

4. Acknowledgements

This work was supported by the European Commission under Grant Agreement No. FP7-ICT-2007-215533 (FUTON)

5. References

---

[1] Han-Hyub Lee et al, “First commercial service of a colorless gigabit WDM/TDM hybrid PON system”, in Proc. OFC’09, PDPD9, 2009.
[2] G. de Valicourt et al, “High Gain (30 dB) and High Saturation Power (11dBm) RSOA Devices as Colourless ONU Sources in Long Reach Hybrid WDM/TDM -PON Architecture”, Photon. Technol. Letters, Vol. 22, No. 3, Feb. 1, 2010, pp. 191-193
[3] K.Y. Cho et al, “10-Gb/s Operation of RSOA for WDM PON”, Photon. Technol. Letters, Vol. 20, No. 18, Sept. 15, 2008, pp. 1533-1535
[4] R. Brenot et al, “High modulation bandwidth reflective SOA for optical access networks”, in Proc. ECOC’07
[5] H.S. Kim et al, , Proc. Of ECOC’09, paper P2.17.
[6] D. Torrientes et al, “RSOA-based 10.3 Gbit/s WDM-PON with pre-amplification and electronic equalization”, in Proc. OFC’10, paper JThA28.
[7] T. Duong et al, “Experimental demonstration of 10 Gbit/s upstream transmission by remote modulation of 1 GHz RSOA using Adaptively Modulated Optical OFDM for WDM-PON single fiber architecture”, Proc. ECOC’08, paper Th.3.F.1.
[8] B. Schrenk et al, “Direct 10-Gb/s Modulation of a Single-Section RSOA in PONs With High Optical Budget“, Photon. Technol. Letters, Vol. 22, No. 6, Mar. 15, 2010, pp. 392-394
[9] G. de Valicourt et al,“Chirp Reduction in Directly Modulated Multi-electrode RSOA Devices in Passive Optical Networks”, Photon. Technol. Letters, Vol. 22, No. 19, Oct. 1, 2010, pp. 1425-1427