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# 50 Gbit/s Transmission at 850 nm with a Surface-Normal Electroabsorption Modulator

M. Gay<sup>(1)</sup>, L. Bramerie<sup>(1)</sup>, L. Laplanche<sup>(2)</sup>, J. Potet<sup>(1)\*</sup>, S. Lobo<sup>(1)</sup>, M. Joindot<sup>(1)</sup>, P. Gavras<sup>(2)</sup>,  
A. Arnoult<sup>(2)</sup>, A. Rumeau<sup>(2)</sup>, S. Calvez<sup>(2)</sup>, C. Viallon<sup>(2)</sup>, G. Almuneau<sup>(2)</sup>

<sup>(1)</sup> Institut Foton, CNRS UMR 6082, Université de Rennes – 22300 Lannion, France, [gay@enssat.fr](mailto:gay@enssat.fr)

<sup>(2)</sup> LAAS-CNRS, Université de Toulouse, CNRS, Toulouse, France, [guilhem.almuneau@laas.fr](mailto:guilhem.almuneau@laas.fr)

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**Abstract** We demonstrate 50 Gbit/s modulation at 850 nm of an AlGaAs surface normal electro-absorption modulator with more than 15 dB extinction ratio and an electro-optical bandwidth of 33 GHz. Propagation over 2 km of standard SMF is demonstrated.

## Introduction

Short reach communication requires high bit rate, low cost, low power consumption transceiver in the 850 nm band. Vertical-cavity surface-emitting lasers (VCSEL) are the current solution that demonstrated the possibility to follow the increase of data rate with electro-optical (EO) bandwidth approaching 30 GHz [1, 2] despite intrinsic optoelectronic dynamic limitations.

We focus on the surface-normal electroabsorption modulator (SNEAM) due to its small footprint and the potential for monolithic integration on top of a VCSEL, as well as its capability for dense integration into 2D arrays. On the InP platform (1550 nm band), SNEAMs have demonstrated bandwidths exceeding 65 GHz. However, at 850 nm, there has not been any report of Gbit/s rate modulation with SNEAMs. Our demonstration of an 850 nm SNEAM achieving NRZ signal transmission over 2 km of standard

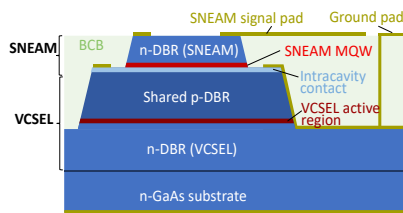


Fig. 1: Device structure.

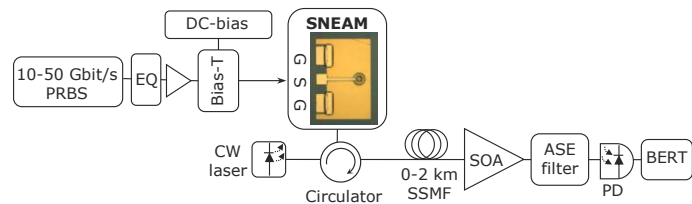


Fig. 2: Experimental setup.

SMF at 50 Gbit/s is, to our knowledge, the first in this optical communication window.

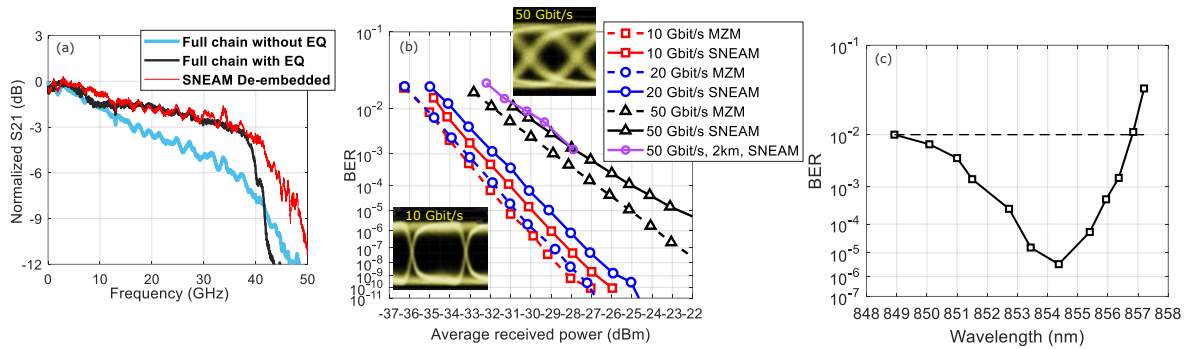
## Design and Fabrication

The vertical structure of the SNEAM modulator (Fig.1) on GaAs substrate consists of two Bragg mirrors surrounding a  $2\lambda$  optical cavity formed by 25 multi quantum wells (MQW). This Fabry-Perot (FP) cavity geometry allows for multiple photon passes, thereby enhancing the absorption contrast under modulated electric field [5]. The lower and upper DBRs of the SNEAM are doped N and P, respectively, and the cavity is unintentionally doped for maximizing the applied field and hence the modulation contrast. In this contribution, we report the results obtained on 24  $\mu\text{m}$ -diameter SNEAM. The process also includes deposition of lower and upper metal intracavity contacts, planarization using BCB polymer, and formation of RF microstrip electrodes.

Finally, it is noteworthy that the SNEAM structure is grown on an 850 nm VCSEL structure. However, in this work, only the SNEAM is analyzed since the underlying VCSEL was dysfunctional due to a technological failure. Despite this, the SNEAM is fully operational. This study thus focuses on determining the performances and limitations of the SNEAM.

## Experimental setup

Fig.2 shows the experimental setup. A tuneable laser around 850 nm illuminates the SNEAM through an optical circulator allowing the separation of the incoming and outgoing reflected signals from the SNEAM. For vertical optical coupling, a cleaved 850 nm single mode fibre is used. Electrical modulation



**Fig. 3:** (a) Electro-optic characterization. (b) Back to back and 2km experiment. (c) 50 Gbit/s tunability assessment.

and DC-bias are applied to the SNEAM thanks to a bias-tee. For modulation a  $2^{15}-1$  pseudo random bit sequence (PRBS) from 10 to 50 Gbit/s is used. This signal is applied to the SNEAM thanks to a ground-signal-ground 40 GHz probe. An analog frequency filter equalizer (EQ) is used in order to compensate for electrical cable and probe frequency dependent losses. The modulated optical signal back-reflected on the SNEAM to the circulator, propagates in standard SMF and must be pre-amplified before detection in a 33 GHz bandwidth photodiode (PD) followed by a bit error rate (BER) analyzer. The pre-amplification is required in our experimental setup as the output power of the circulator is lower than our receiver sensitivity. Amplification is performed using a 25 dB gain semiconductor optical amplifier (SOA) whose amplified spontaneous emission (ASE) bandwidth is limited to 1 nm using an optical filter.

### Electro-optic Bandwidth

Fig. 3 (a) shows the electro-optic bandwidth measured with a vector network analyser. In a first step we characterise the electro-optical frequency response of the SNEAM under the experimental conditions composed by 1m-RF cable, 50 GHz bias-tee, 40 GHz RF probe, SNEAM and 33 GHz PD. We obtain the blue curve on Fig.3 without equalizer. The electrical frequency response of all elements but the SNEAM (RF cable, Bias-tee, PD, probe) are then measured and removed from total frequency response to obtain the SNEAM de-embedded response (red curve). A 3 dB-bandwidth of 33 GHz is obtained for the SNEAM. Finally, the black curve is the full E-O-E transmission chain including the driver and equalizer added for the system assessment, showing that the equalizer essentially compensates for extra RF components attenuation.

### Back to back Experiment

NRZ modulation was then applied at 10, 20 and 50 Gbit/s as depicted on Fig. 3(b) with DC-bias of 3.8 V and with 5 Vpp modulation amplitude. BER was compared to a reference 40 GHz LiNbO<sub>3</sub> MZM modulator. We observe 1-to-2 dB penalty at 10 and 20 Gbit/s respectively and up to 2 dB at  $10^{-5}$  at 50 Gbit/s although the SNEAM extinction ratio and the swing voltage are comparable to those of the MZM. The reason for this penalty is still being investigated and may be attributed to fluctuations in the SNEAM EO frequency response. After 2km of standard single-mode fiber, no penalty is observed (Fig. 3 (b)). Finally, we show an operation over 8 nm (between 849 and 857 nm) under the LDPC FEC limit of  $1.10^{-2}$  (Fig. 3(c)). This wavelength tuneability can be sufficient to consider the integration of a VCSEL as proposed in [6].

### Conclusions

We report on the fabrication and high bit rate characterization of an 850 nm AlGaAs surface-normal electroabsorption modulator, which demonstrates a 33 GHz EO bandwidth and an extinction ratio exceeding 15 dB. Data transmission at 50 Gbit/s was successfully achieved over distances of more than 2 km using standard single-mode fiber (SMF).

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