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Record High Power 13dBm Electro-Absorption Modulated Laser for 50G-PON

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Abstract *We present a 50Gb/s electro-absorption modulated laser emitting at 1342-1358nm and optimised to provide high output power and efficient modulator extinction. With a record modulated output power of >13dBm (ex-facet) and a 6dB dynamic extinction ratio it can serve for 50G-PON as unamplified transmitter.*

Introduction

Passive optical networks (PONs) are widely deployed to distribute broadband network access. The recent trend of increasing line bitrates is induced by prompt growth of delivered services, such as advanced video services. This demand found its response in the standardization work conducted by two leading standardization groups from IEEE and ITU-T. The IEEE and ITU-T standards for new generation PON systems have been developed with focus on 25Gb/s (double channel) [1] and 50Gb/s (single channel) [2] line rates, respectively. The downstream wavelength is agreed to be 1340-1344nm by the two institutions to comply with several requests such as coexistence with legacy PONs, compatibility with the exiting optical distribution networks (ODNs) and low dispersion which limits inter-symbol interference over ODN. The IEEE wavelength plan also implies the use of 1356-1360nm line for 25G-EPON or 2×25G EPON.

One of major challenges in PONs is the high-power budget requirement in the absence of optical amplification, which imposes transmitters with extremely high modulated output power, and high dynamic extinction ratios (ERs). A minimum fiber launch power of 10dBm may be required for the higher budget classes in 50G-PON [3], which calls for device output powers more than 12dBm if typical fiber coupling losses are considered. Several devices may be acknowledged as potential transmitters for 50G-PON. For instance, directly modulated lasers are well-known for providing high output power. However, their application in next generation PONs is debatable since they show presence of significant chirp and chromatic dispersion at 50Gb/s for transmission distances over 20km. On the contrary, externally modulated lasers (EMLs) may show low chirp but obtaining high output power of more than 12dBm is quite challenging due to modulator insertion losses and to modulator saturation.

To the best of our knowledge, simple devices that are capable to fulfil all demands of 50G-PON do not exist yet. For example, in [3] the EML operating at 1342nm had to be complemented by an external semiconductor optical amplifier (SOA). Few alternative approaches are proposed to reach high-power EMLs: the D-EML combining laser direct modulation and electro-absorption modulator (EAM) with the need of a second HF driver [4], or the EML with an integrated SOA [5]. But these solutions add complexity and are still limited to about 9dBm modulated power.

In this paper we present, for the first time, a simple EML that can deliver a record 13dBm facet average modulated power and 6dB dynamic ER at 50Gb/s, either for 1342nm or 1358nm applications. We have studied different wavelength detuning between modulator absorption peak and emitting wavelength ($\Delta\lambda$) for further optimization.

EML design and fabrication

The EML is fabricated using our standard process described in [6]. The top view image of a chip and its SEM cross-section can be seen on Fig. 1. The EML comprises a 100µm-long EAM, a 400µm-long distributed feedback (DFB) laser, an exponential taper, and a 25µm-long window section without waveguide. The total length of the device is 645µm. Thanks to the taper low divergence 17°×17° output optical field is achieved, hence, only low coupling losses of about 2.0-2.3dB are observed. The window region is included to minimize back reflections from output facet.

Laser and modulator phosphorus-based multi-quantum wells (MQWs) structures are grown by Gas Source Molecular Beam Epitaxy (GSMBE), with butt-joint technology, enabling to

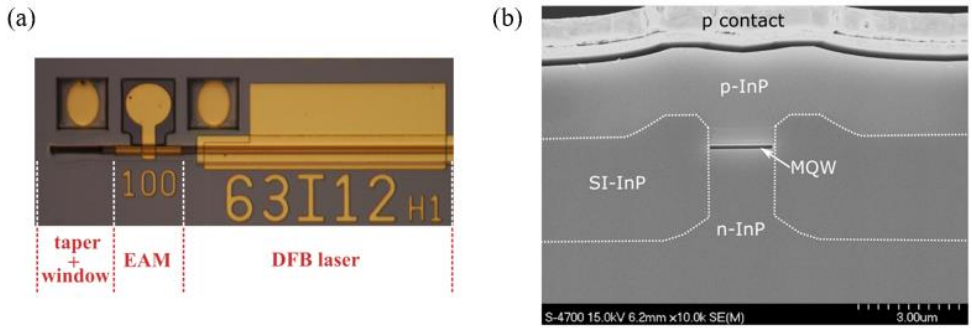

Fig. 1: (a) Optical microscope image of a chip; (b) SEM image of chip cross section.

independently tune both structures (MQW stack, bandgap energy, doping profile). To form the waveguide, we use a semi-insulated buried heterostructures (SIBH) technology, which is well known for providing high modulation speed, efficient thermal dissipation, low series resistance, and a quasi-circular optical mode.

The laser section MQW stack, doping profile and DFB grating strength are optimized to deliver high output power. The modulator MQW stack is designed to provide 15% optical confinement in the MQW, which, in our case, ensures sufficient extinction. Besides, the modulator section length is chosen to be 100µm that seems to be a near-optimal length for 50Gb/s operation: it provides high-enough electro-optical bandwidth, and it favours low modulator saturation level, when correct laser-modulator detuning $\Delta\lambda$ is applied.

The determination of a correct laser-modulator detuning $\Delta\lambda$ appears to be a critical point for PON application. A large $\Delta\lambda$ reduces the insertion losses and prevents modulator saturation as a large electrical field has to be applied in the QWs. However, increasing $\Delta\lambda$ leads to the requirement of using higher peak-to-peak modulation voltage (Vpp) in order to achieve necessary level of ER. To assist low Vpp even at large $\Delta\lambda$ the EAM section must provide steep extinction curve.

Therefore, our EAM section, material wise, is carefully designed to obtain the optimum performance trade-off. For instance, our modulator MQW stack is tailored to minimize the thickness of the undoped material for the purpose of increasing electrical field applied to MQW for a given voltage between EAM electrodes. Also, the top p-cladding layers are grown by GSMBE instead of the more usual Metal-Organic Vapor Phase Epitaxy (MOVPE). In GSMBE Zinc dopant is replaced by Beryllium dopant, which exhibits much less diffusion into the underneath layers. Thus, the modulator active zone remains perfectly undoped leading to a more efficient and homogeneous application of the electrical field over the MQW region.

EML performances

Different DFB gratings have been defined on the same wafer using electron-beam lithography to cover the two 50G-PON downstream wavelengths. A fine scan around central wavelengths (1342nm and 1358nm) allows to determine the optimum laser-modulator detuning $\Delta\lambda$ for the PON application. The full wavelength span is more than 20nm.

Fig. 2 presents static performances of fabricated EMLs when chip temperature is 45°C. Fig. 2(a) shows the optical spectra of ten selected EMLs. The side mode suppression ratio remains beyond 40dB even at high DFB injection currents. All studied chips (covering full studied

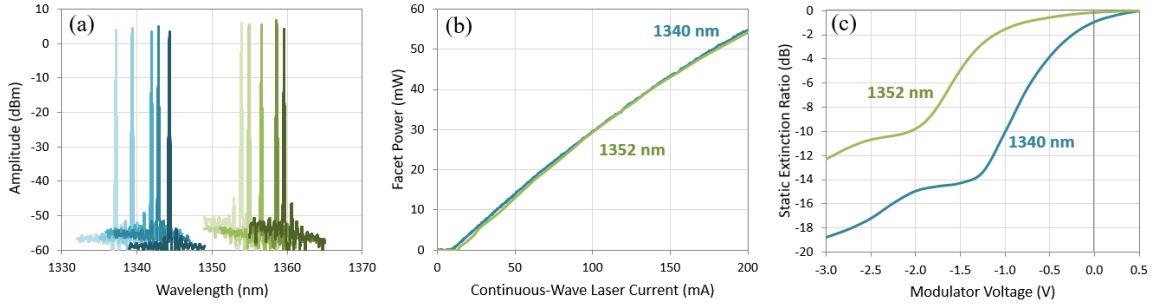

Fig. 2: Static performance at 45°C chip temperature: (a) optical spectra for different detunings $\Delta\lambda$; (b) output facet power versus laser current (continuous wave), EAM section is not connected; (c) static extinction ratio of 100µm EAM section for standard and increased $\Delta\lambda$, laser current is 150mA.

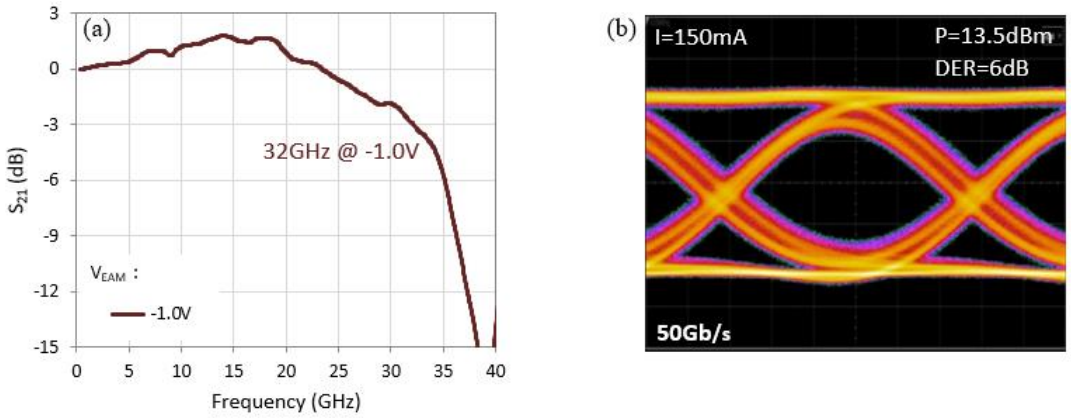

Fig. 3: Dynamic characteristics of a device at 45°C chip temperature: (a) S21 curve at -1V EAM bias and laser current 150mA; (b) 1352nm EML 50 Gb/s NRZ eye diagram for laser current 150 mA.

wavelength range) possess very similar light-current (LI) characteristics: the threshold current is below 20mA, and the output facet power is ~44mW at 150 mA. As an example, Fig. 2(b) illustrates two LI curves for chips lasing at 1340nm and 1352nm. Fig. 2(c) shows the modulator static ER. Introduced laser emission at 1340nm corresponds to the typical value of $\Delta\lambda$ that is used for our standard EML design, and it is characterised by very low (about -1dB) insertion loss at 0V and steep extinction of 14dB at -1.3V. This design allows to have high output power and low peak-to-peak modulation voltage Vpp. Although to reach record high output power of more than 12dBm the laser current should be increased, which may lead to the modulator saturation, when photogenerated holes accumulate in the MQW and screen the electrical field. Such field screening, in its turn, contributes to a closure of the eye diagram. This effect may be delayed when increasing $\Delta\lambda$ by 12nm (1352nm laser emission wavelength). In the case of larger $\Delta\lambda$ the extinction curve shifts to the left towards more negative voltages. Usually, this will lead to significant increment of Vpp value and/or ER degradation. Nevertheless, thanks to our design aiming at maximizing voltage efficiency on the modulator MQW, the ER curve remains quite steep and still provides about 10dB extinction at -2V.

The EML emitting at 1352nm and offering optimum detuning $\Delta\lambda$ was mounted on a carrier with 50Ω resistance parallel to EAM for HF matching purposes. Fig. 3(a) reports the 3dB optical bandwidth of 32GHz when the EAM bias voltage is set to -1.0V. The eye diagram for NRZ 50Gb/s presented on the Fig. 3(b) is measured at 45°C chip temperature and laser current of 150mA, without the use of any digital signal processing (DSP). The modulator voltage is applied via a bias T, added with an amplified modulation, with an estimated amplitude Vpp around 2.5V. In these conditions we obtain an outstanding >13dBm average output facet power, without any saturation of the EAM section and a large 6dB dynamic ER.

Conclusions

We have presented EMLs emitting in the range from 1340nm to 1360nm for 50G-PON applications. By optimizing the modulator design and the fabrication technology we achieve increment of voltage application efficiency on the MQW. Choosing an increased laser-modulator detuning $\Delta\lambda$ we have demonstrated a record facet modulated output power of >13dBm and dynamic ER of 6dB at 50Gb/s NRZ. This EML design may enable the use of unamplified transmitters with a small footprint and low power consumption for meeting the high loss budget requirements in 50G-PON.

Our design and fabrication rules may be also expanded to other wavelength ranges. For example, to the band C where they can be applied to 1577nm high power EMLs.

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