First Demonstration of an E2 Class Downstream Link for 50Gb/s PON at 1342nm

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Abstract *A 1342nm EML with an external SOA has enabled the 20km, 50Gb/s downstream link for ITU-T, 50G-PON to be demonstrated for the first time. Using a 25G-class receiver and real-time equalisation, an OMA sensitivity of -24dBm and a link budget of 35.6dB were measured.*

Introduction

FTTH networks using PON (Passive Optical Network) technology have been widely deployed across the world. To date, Gigabit class PON has been the prevalent technology deployed i.e. EPON[1] and GPON[2]. In recent years, 10 Gigabit PONs (10G-EPON[3] and XGS-PON[4]) have seen a significant growth in deployment as an evolution from the earlier PON generations. In both the IEEE and ITU-T, the next generation of PON systems are being defined using 25Gb/s[5] and 50Gb/s[6] line rates respectively. In both cases a downstream wavelength band at 1342±2nm is allocated by these standards groups. To date, there have been theoretical studies and some limited proof of concept demonstrations showing the feasibility of a 50Gb/s PON downstream link [7], [8].

During the development of the IEEE 25Gb/s PON line rate project[5] the use of lower bandwidth transceiver components was proposed and both PAM-4 and electrical duobinary modulation studied. Such ideas have been comprehensively reviewed in[9]. In a similar way, there is an interest in utilising low bandwidth optical components to implement 50G-PON in order to reduce costs and exploit the advances in digital signal processing (DSP) and forward error correction (FEC). To achieve better receiver (Rx) sensitivity, and hence meet the high PON link budget, non-return-to-zero (NRZ) on-off-keying has been selected by the ITU-T for 50G-PON. However, using NRZ modulation presents the challenge of limited dispersion tolerance of ~37.5ps/nm[10].

In[10], the authors emulated a 20km, 1342nm, 50G-PON NRZ downstream link using a 1550nm electro-absorption modulated laser (EML) operating over 5km fibre to give an equivalent accumulated dispersion of 85ps/nm. This demonstration showed how both Rx-side equalisation and advanced FEC (hard or soft-decision low-density parity check, LDPC) can be used to support 50G-PON downstream transmission over a 29dB optical distribution network (ODN) with 20km fibre. A higher loss budget (33dB) has been reported with an SOA-PIN Rx in a dispersion-free link at 1314nm [11].

In this paper, we report for the first time real-time 50G PON downstream transmission in the ITU-T standardised wavelength band of 1342±2nm using a 25G-class EML boosted by a semiconductor optical amplifier (SOA). A simple real-time pre-equaliser (5-tap FIR filter with 2 precursors) is used to partially compensate for the limited modulation bandwidth of the EML. At the Rx side, a 25G-class avalanche photodiode (APD) is used along with built-in FFE (feed-forward equaliser) implemented within the error detector in real-time. A back-to-back (b2b) optical modulation amplitude (OMA) Rx sensitivity of -24dBm (10^{-2} BER) is achieved at 50Gb/s NRZ, despite the bandwidth limitations. We additionally show, over a 20km fibre ODN, a record loss budget of 35.6dB at the standardised 50G-PON downstream wavelength using a simple APD Rx. Thus, demonstrating the technical feasibility of the highest ITU-T budget class (E2=35dB) for 50G-PON.

Device description

The electro-absorption modulated laser (EML) was fabricated using butt-joint technology to separately optimize the vertical structures of the distributed feedback laser (DFB) and the electro-absorption modulator (EAM) sections. After defining the gratings with e-beam lithography, the waveguides are etched and laterally buried into Fe-doped InP, before depositing a p-doped InP thick cladding. To reduce modulator capacitance and electrically isolate laser and modulator sections, high energy H+ ions are implanted into p-doped InP which becomes electrically isolating. This semi-insulated buried heterostructures

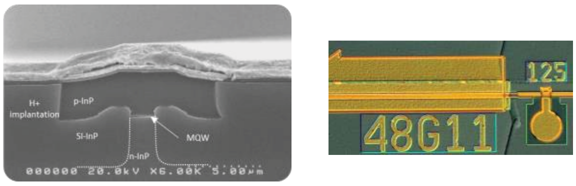

Fig. 1: SEM and microscopic images of the device

(SIBH) technology has the advantages of low leakage current for the DFB, low capacitance for the EAM, circular optical mode for high coupling efficiency, low series resistance, and efficient thermal dissipation[12]. After dicing and applying high reflectivity/anti-reflection (HR/AR) coatings, the EML was mounted on a submount where the EAM is connected to a 50Ω termination in parallel for impedance matching purposes. The DFB and EAM sections have lengths of 400 and 125μm, respectively. A scanning electron microscope (SEM) cross-section image and a microscopic picture (top left) of the device are shown in Fig. 1.

The EML output power as a function of EAM bias is shown in Fig. 2 for different laser currents (I) at 25°C. Static extinction ratios (ER) of up to 10dB can be attained. A laser current I=100mA and an EAM bias of -1.0V at 25°C were chosen as the operating point in order to optimise the modulated signal quality and its dynamic ER. At these operating conditions, the EML frequency response exhibits a 3dB bandwidth of 25GHz, as shown in the inset of Fig. 2.

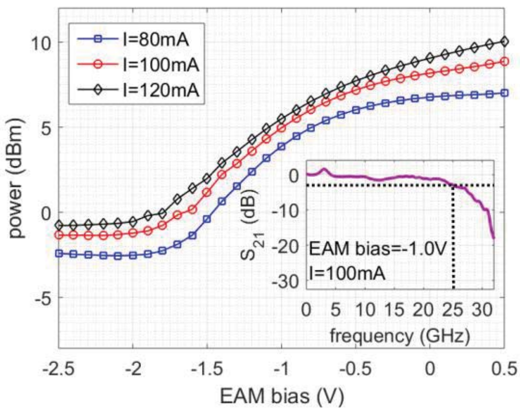

Fig. 2: Power vs. EAM bias. Inset: EML frequency response at selected operating conditions

Experimental results

The experimental setup is shown in Fig. 3. A bit pattern generator (BPG) with built-in real-time equalisation (RT EQ) is used at the transmitter side. A PRBS 31 is generated and real-time equalised using a 5-tap FIR filter with 2-precursors, to pre-compensate the EML bandwidth limitation, and the resulting signal is used to directly modulate the EML. The FIR tap weights are optimized to get the maximum eye-aperture in b2b. In order to increase the link

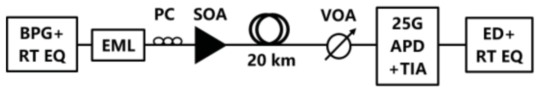

Fig. 3: Experimental set-up

budget, an SOA is used. A polarization controller (PC) at the SOA input maximises the output power. The SOA is operated at an injection current of 200mA, providing an optical gain of 12.4dB, resulting in a launch power of +11dBm. After the SOA, the signal is transmitted through 20km of single mode fibre (G.652). A variable optical attenuator (VOA) is used to control the power received by a 25G Ge-Si APD Rx. The Rx module is adapted to enhance the performance of a 25G APD applied to 50Gb/s reception with subsequent equalisation. BER measurements are performed using an error detector (ED) with built-in RT EQ. The receive side equalisation consists of a 6-tap FFE with 2-precursors. To ensure it is predominantly compensating the Rx bandwidth limitation we used a set and forget approach for the Rx-side tap coefficients i.e. the coefficients were optimised for b2b and then kept constant.

Firstly, we measured the instantaneous frequency of the modulated signal before and after the SOA. Fig. 4 shows the obtained curves along with their corresponding power waveforms. The measured time span is the same in both cases and corresponds to an optical pulse consisting of a few consecutive 1s from the PRBS. The instantaneous frequency was measured by filtering the optical signal throughout its whole frequency span using a tuneable optical bandpass filter, similar to the experiment in[13]. Besides the expected transient chirp, a small adiabatic component is also observed, which we attribute to residual feedback from the EML output facet back into the DFB section. From the instantaneous frequency curve, we estimated a positive chirp value of 0.4 for the EML (before SOA).

Interestingly, the chirp becomes negative after propagation through the SOA due to carrier depletion which results from operating the SOA in the saturated regime[14]. Indeed, at the specified operating point, the gain compression in the SOA reaches 1.5dB as can be observed in the gain vs. output power curve of the inset in Fig. 5, which also depicts the modulated optical spectra before and after the SOA at the emission wavelength of 1341.4nm, as measured with a resolution of 50pm.

Without the SOA, an OMA sensitivity of -24.4dBm (at 10^{-2} BER) is measured in b2b, as seen in the BER curves of Fig. 6. An optical path penalty (OPP) of 1dB is incurred after we launch into 20km fibre. This relatively low OPP is enabled by the small chirp factor of the EML. We expect even lower OPP could be obtained by optimising the tap coefficients when transmitting over fibre.

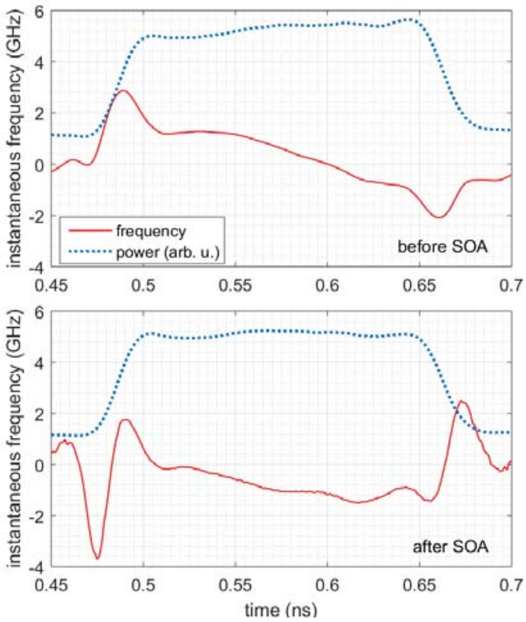

Fig. 4: Instantaneous frequency before and after the SOA along with corresponding power waveforms

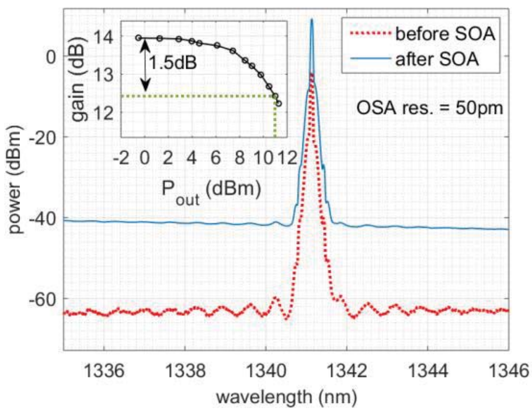

Fig. 5: Modulated optical spectra before and after the SOA. Inset: saturated gain curve of the SOA and operating point

With the SOA we obtained an OMA sensitivity of -24dBm. The optical eyes before and after the SOA have ER of 6dB and 5.8dB and are depicted as insets in Fig. 6. The SOA introduces a 0.4dB OMA penalty in the Rx sensitivity in b2b which is attributed to the slightly higher patterning on the transmitted 1s owing to gain saturation.

For reference, the same Tx and Rx combination (without SOA) was measured at 25Gb/s in b2b. This BER measurement is also shown in Fig.6. It is notable that we observe a mere 1.3dB penalty for 50Gb/s in b2b (without SOA) compared to 25Gb/s.

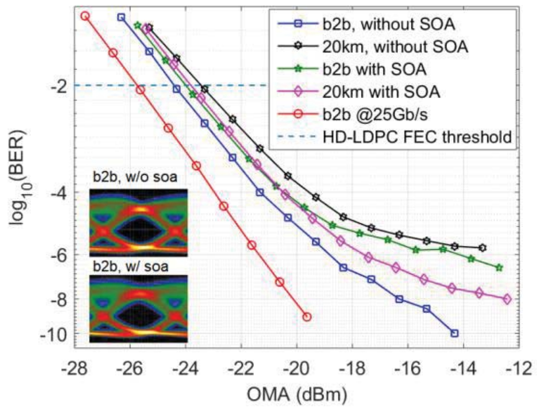

Fig. 6: BER curves for different transmission conditions and optical eye diagrams in b2b before and after the SOA

After 20km, and with the SOA, we measured the OMA Rx sensitivity as -23.8dBm. The OPP is now as low as 0.2dB. The OPP reduction is a result of the negative chirp acquired from the SOA. Despite the high launch power of +11dBm, we observed no degradation due to fibre non-linearity in these experiments. Considering an +11.8dBm launched OMA, an optical power budget of 35.6dB was achieved with 20 km fibre showing that the highest ITU-T PON budget class (E2=35dB) is feasible with an HD LDPC FEC threshold of 10^{-2} BER.

We expect that even higher link budget could be achieved with future optimisation of the Rx to enable some reasonable system margin. This current prototype Rx module exhibits about 3dB worse sensitivity at 25Gb/s than commercially available 25G APDs (e.g. -29dBm OMA sensitivity at 10^{-2} BER).

Conclusions

A 25G EML device emitting in the ITU-T standardised downstream wavelength band of 1342±2nm has been used to demonstrate a 50G-PON link for the first time. A b2b OMA sensitivity of -24dBm (at the HD-LDPC FEC limit of 10^{-2} BER) was measured using 25G-Class optical Rx components and real-time equalisation. A record 50G-PON link budget of 35.6dB over a 20km fibre at 1341.4nm was demonstrated with the aid of an SOA at the Tx. An OPP as low as 0.2dB was observed owing to the negative chirp induced by the SOA. This demonstrates the technical feasibility of achieving the highest ITU-T PON budget class E2 (35dB). We anticipate further improvement of the link performance by enhancing the equalisation, optimising the receiver, and considering the trade-off between Tx launch power and ER.

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