10 Gb/s 1550 nm VCSEL transmission over 23.6 km Single Mode Fiber with no Dispersion Compensation and no Injection Locking for WDM PONs

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Abstract: We demonstrate 10Gb/s VCSEL transmission for WDM PON over 23.6km single mode fiber. Dispersion penalty is limited to 2.9dB by introducing a wavelength offset with respect to the remote array waveguide grating to reduce chirp.

OCIS codes: (140.7260) Vertical surface cavity emitting diodes

1. Introduction

Vertical Cavity Surface Emitting Lasers (VCSELs) are an attractive candidate for use in optical access networks due to their relative low cost, high bandwidth, wavelength tuneability, single mode operation at 1550 nm, and low drive currents. Chromatic dispersion, however, is a major hurdle to VCSEL transmission at 10 Gb/s bit rates and above. In previous demonstrations, for example, dispersion limited the transmission distance of free-running VCSELs with no injection locking over single mode fiber (SMF) to 10 km at 10 Gb/s [1], and 6.5 km at 20 Gb/s [2]. In this paper we demonstrate the application of an uncooled 10 Gb/s VCSEL operating at 1550 nm with no injection locking for use in a 23.6 km wavelength division multiplexing (WDM) passive optical network (PON) with no dispersion compensation. The dispersion penalty is mitigated by introducing an offset between the VCSEL wavelength and the center wavelength of the remote node (RN) array waveguide grating (AWG) in order to obtain chirp reduction. To the best of our knowledge this is the first time that SMF transmission exceeding 20 km, corresponding to typical PON reach, has been achieved without the use of injection locking [3,4] or dispersion compensating fiber [1].

2. WDM PON with VCSEL sources

The investigated VCSEL sources operating at 1550 nm are developed partly within the framework of the ‘GigaWaM’ (Gigabit Access Passive Optical Network using Wavelength Division Multiplexing) research project, which is an ICT STREP (Small or medium-scale focused research project) funded by the European Commission under the 7th Framework Programme [5]. GigaWaM is aimed at developing all necessary photonic components for a WDM PON for 64 users covering a 20 km reach, as shown in Fig.1. Special focus is placed on developing innovative new low cost components with high level of integration and hybridization in addition to novel manufacturing processes.

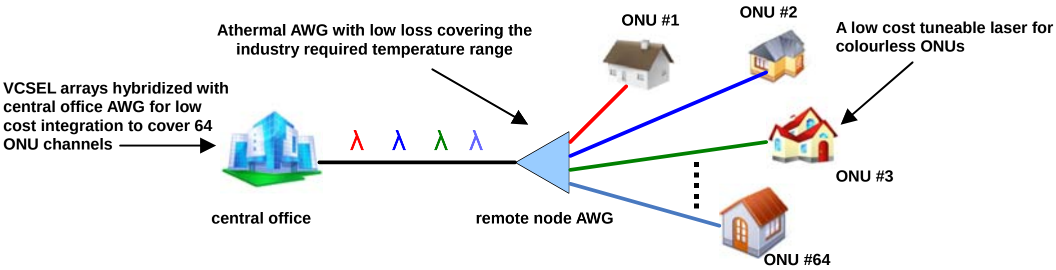

Fig.1 Schematic of the GigaWaM WDM PON network using VCSEL arrays for downstream transmission.

For capacity upgrade to 10 Gb/s of WDM VCSEL-based networks such as GigaWaM it is essential to consider simple and cost effective strategies for managing dispersion. This applies both to the use of integrated VCSEL arrays used for downstream transmission as in GigaWaM, as well as scenarios in which individual VCSELs are used at the optical network units (ONUs).

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3. Experimental setup

Figure 2(a) shows the experimental setup representing the scenario with the VCSEL in the ONU. A 1548.8 nm uncooled VCSEL biased at 11.1 mA was directly modulated at 10 Gb/s using a 2^{11}-1 non-return to zero (NRZ) pseudo random bit stream (PRBS) pattern. The VCSEL drive amplitude was around 14 mA, giving an optical output power of -0.8 dBm. An isolator with 37.6 dB isolation and 1.8 dB insertion loss was used to suppress back reflections to the VCSEL. A tuneable Gaussian filter with a 0.38 nm 3 dB bandwidth was used to represent a 100 GHz channel spacing AWG in the remote node. The inset of Fig. 2(b) shows the normalized filter transfer function. The separation from the ONU to the central office is 23.6 km of SMF with a loss of 7.4 dB. This is a realistic representation of standard access networks with around 20 km network reach, consisting only of SMF with no dispersion management. The receiver in the central office consists of an erbium doped fiber amplifier (EDFA) pre-amplifier stage, followed by a 0.95 nm 3 dB bandwidth optical filter to suppress EDFA noise, and a standard positive-intrinsic-negative (PIN) photodiode. The cost of the EDFA in such a preamplifier would be shared amongst all users in a commercial WDM PON implementation. During bit error rate (BER) measurements the optical power into the central office receiver was adjusted using a variable attenuator (Att. 1), while Att. 2 was used to fix the input optical power to the photodiode at -5 dBm at all times. All eye diagrams presented were measured directly after the photodiode.

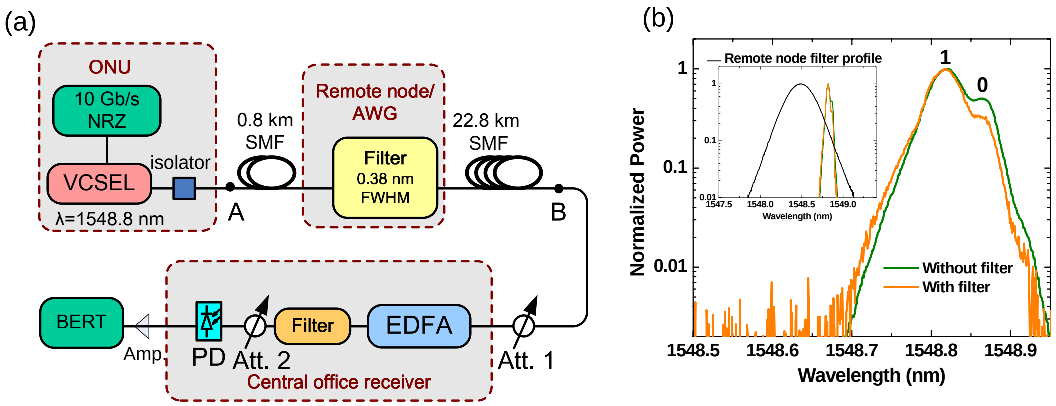

Fig.2 (a) The experimental setup for 10 Gb/s VCSEL transmission. (FWHM: full width at half maximum, Att: variable optical attenuator, PD: photodiode, Amp: electrical amplifier, BERT: Bit error rate test set) (b) Normalized optical spectra measured at the fiber output using a 0.01 nm resolution optical spectrum analyzer, both with and without the filter at the remote node.

4. Experimental results

Figure 3(a,b) show the BER measurement results and corresponding eye diagrams. The back-to-back VCSEL receiver sensitivity at a BER of 10^{-9} is -25.9 dBm. For transmission over 23.6 km of SMF with no dispersion compensation and no filtering (i.e. with the remote node in Fig. 2(a) bypassed with a patchcord), dispersion was found to completely ruin the signal. This is indicated by eye diagram (ii). When the filter representing the remote node AWG is included and tuned to an optimal offset of 336 pm relative to the VCSEL as shown in the inset of Fig. 2(b), then the dispersion is mitigated and the signal recovered. This is illustrated by open eye diagram (iii). From Fig. 2(b) it is also evident that dispersion mitigation by filtering introduces a relative increase in extinction ratio between the “0” and “1” levels, which is an indication of reduction in the signal chirp. From Fig. 3(a) the corresponding receiver sensitivity with filtering is seen to be -23.0 dBm, a penalty of 2.9 dB relative to the back-to-back case. It should be noted that this principle of dispersion mitigation by filtering can also be applied when VCSELs are used in the central office instead of the ONU. In this case the AWG at the central office which is used to couple the light into the fiber can be used to filter the chirp instead of the remote node AWG.

In a real implementation of a WDM PON the positions of the AWG channels are fixed and they cannot be tuned in wavelength to mitigate dispersion. It is however possible to tune the VCSEL to the optimum wavelength offset relative to the fixed AWG by means of adjusting the VCSEL bias. The VCSEL central wavelength and output power dependence on bias is shown in Fig. 3(c). The wavelength gradient about the operational VCSEL bias of 11.1 mA is 306 pm/mA, and the output power gradient is 0.48 dB/mA. Tuning the VCSEL wavelength to an 336 pm offset relative to the AWG for optimal dispersion mitigation as in the inset of Fig. 2(b) hence corresponds to a 1.10 mA bias adjustment, with only a 0.53 dB fluctuation in VCSEL output power.

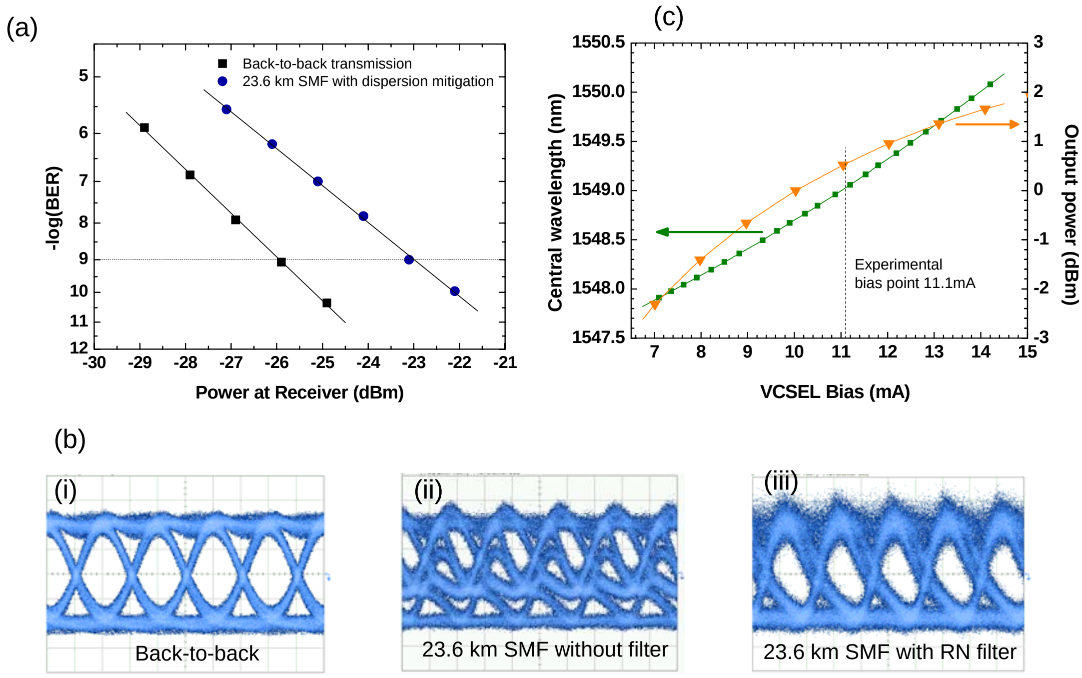

Fig.3 (a) BER measurement results for back-to-back and fiber transmission. (b) Eye diagrams corresponding to (i) back-to-back transmission, (iii) the impact of dispersion without dispersion mitigation, (iii) dispersion mitigation using the filter at the remote node. For all eye diagram scales x-axis: 50 ps/div; y-axis: 421 mV/div. (c) VCSEL wavelength and output power as a function of bias voltage.

5. Conclusions

We demonstrate dispersion mitigation of high speed VCSEL transmission in WDM PONs by exploiting chirp reduction introduced through an offset between the transmission wavelength and the central wavelength of an AWG passband. Using this approach, free-running uncooled 1550 nm VCSEL transmission at 10 Gb/s over 23.6 km of SMF is demonstrated with a dispersion penalty of only 2.9 dB relative to the back-to-back case. This simple and effective dispersion mitigation method paves the way for the use of VCSELs operating at 10 Gb/s and beyond in 20 km reach WDM PON networks, without the need for dispersion compensating fiber or injection locking.

6. References

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