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Full C-band Tunable MEMS-VCSEL for Next Generation G.metro Mobile Front- and Backhauling

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Abstract: We report full C-band tunable, 10 Gbit/s capability, directly modulated MEMS-VCSEL for next generation converged mobile fronthaul and backhaul applications. Bit error rates below 10^{-9} were achieved over up to 40 km SSMF.

OCIS codes: (060.0060) Fiber optics and optical communications, (060.2330) Fiber optics communications, (060.4510) Optical communications

1. Introduction

Mobile network operators deploy more and more cells to cope with the tremendous increase of mobile traffic demands [1]. In order to facilitate the emerging wireless technologies such as cooperative multi-point (CoMP), network functions tend to be consolidated and centralized, leading to the split of radio frequency (RF) signal generation and processing in centralized base band units (BBUs) in the central office (CO), while the remote radio heads (RRHs) only convert the baseband to RF. However, this split imposes a stringent bandwidth and latency requirements on the mobile fronthaul (MFH), which is the transport link between BBUs and RRHs [2]. A cost-efficient solution to the MFH is the wavelength division multiplex (WDM) passive optical network (PON). The standardization group ITU-T SG15/Q6 is currently defining a unified network serving MFH and mobile backhaul in the recommendation draft G.metro. The key feature of this WDM-PON system is a centralized wavelength locker enabling autonomous wavelength tuning of the tunable laser in the tail-end equipment (TEE) at the RRH side. [3]

Yet the biggest challenge up to now is the lack of low-cost wideband tunable lasers for 10G transmission. We propose and believe that micro-electro-mechanical systems (MEMS) vertical surface emitting laser (VCSEL) is very promising for the low-cost, 10Gbps transmission over relevant reach, and offers simplicity for wideband autonomous tuning.

In this paper, we present for the first time a WDM-PON transmission, based on a wideband tunable MEMS-VCSEL, and operating at 10 Gbit/s over up to 40 km. Details of the packaged MEMS-VCSEL are also presented. Results show that MEMS-VCSEL based WDM-PON is a viable solution to cope with the pressing MFH needs.

2. Tunable WDM PON system concept

A key element of G.metro WDM-PON is the wideband tunable laser for the tail-end equipment. The laser should have a tuning range of (at least) the C-band and the capability for 10 Gbit/s transmission over relevant reach. To achieve lowest cost, the laser should not be calibrated on a per-sample base as this is a time-consuming process and, therefore, costly.

The WDM-PON concept is shown in Fig. 1. It features autonomous wavelength tuning using a centralized wavelength locker. This centralized locker replaces per-transmitter wavelength control in the TEEs and is shared by all TEEs, which further reduces cost. [4]

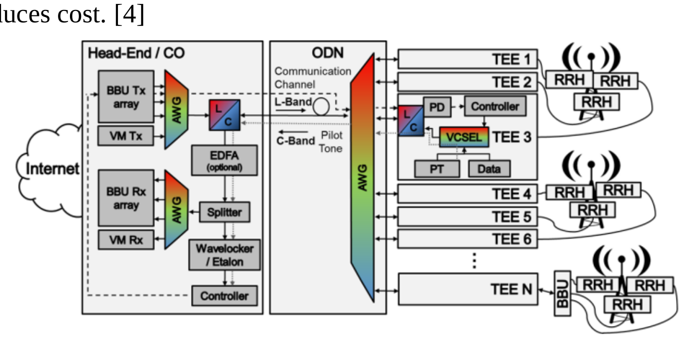

Fig. 1: System concept for converged mobile MFH and MBH. BBU: Base Band Unit; VM: Virtual Machine; TEE: Tail-End Equipment; PT: Pilot Tone: RRH: Radio Remote Head

MFH is mostly based on the Common Public Radio Interface (CPRI) protocol. In contrast, mobile backhaul (MBH) uses the Ethernet protocol. The system must therefore be protocol agnostic. [5]

The optical distribution network (ODN) can be based on a tree or dropline architecture. The wavelength multiplexing (MUX) and de-MUX in the tree architecture are based on arrayed waveguide gratings (AWG). If the feeder fiber is much longer than the drop fibers, the differential end-to-end reach in most cases is small, e.g., <5 km. Then, a single dispersion compensating fiber (DCF) in the head-end allows optimization of the chromatic dispersion (CD) for all channels. Droplines use optical add/drop multiplexers in several locations. Now, the differential reach can be as long as the system specifications, i.e., 20 km for MFH. Since both architectures need to be supported, this results in the requirement for a single DCF, which needs optimization over the complete range of relevant reach.

3. 10 Gbit/s Widely Tunable VCSEL

The transmission experiment is based on a single-mode widely tunable 1.55 µm VCSEL. It has been packaged as a transmitter optical subassembly with a standard LC connector (LC TOSA, Fig. 2) and can be assembled inside standardized small form factor pluggable (SFP) optical modules. The tunable laser diode is based on a long wavelength Indium Phosphide (InP) Buried Tunnel Junction (BTJ) VCSEL and features a MEMS top mirror. A cross section of this VCSEL design is illustrated in Fig. 3. Details about the device structure and manufacturing can be found in [6-8].

Fig. 2: LC TOSA

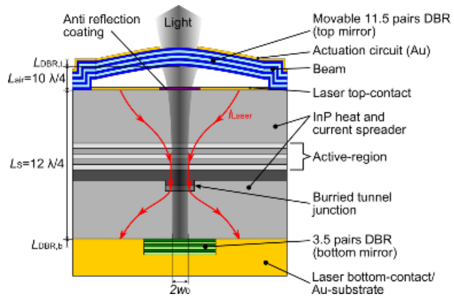

Fig. 3: MEMS VCSEL cross section

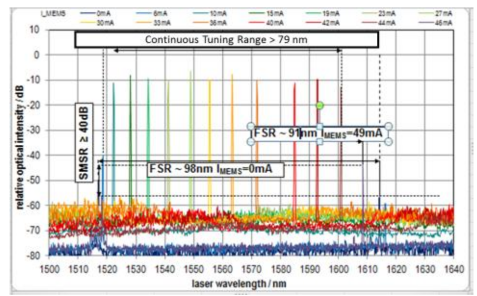

Fig. 4: MEMS-VCSEL tuning range

The small air gap between the surface of the base VCSEL and the MEMS can be controlled thermo-electrically. The change in air gap leads to mode-hop free tuning of the laser wavelength. The tunable VCSEL deployed for this experiment has a maximum tuning range from 1517 nm to 1608 nm (Fig. 4) and a peak optical power of 1.2 mW (fiber coupled). For the transmission tests, the tuning range has been limited from 1530 nm to 1592 nm to compensate a decrease of the optical power at the boundaries of the tuning range. In the future, the design will be optimized to enable the use for both C- and L-band applications with one laser.

Several components and functions are integrated inside a small TO-46 based LC TOSA package. These include a thermoelectric cooler, a thermistor and a monitoring diode. Only one control signal is required to tune the laser without mode hops across the full tuning range. In total, only 8 pins are required for the described functionality.

4. Experimental evaluation and results

In the experiments, we focused on the upstream application for MFH and MBH and therefore, a limited reach of up to 40 km. Fig. 5 shows the experimental setup. A bit error rate tester (BERT) generated a 2^{31}-1 bit long pseudo-random bit stream (PRBS 31) which was directly modulated on the MEMS-VCSEL bias current at 10.3125 Gbit/s. The bias current and modulation amplitude was kept constant for all measurements at 22 mA and 1 V, respectively. The signal was launched into a standard single mode fiber (SSMF) via an AWG used as multiplexer and was transmitted over up to 40 km. At the head-end, the dispersion was compensated by a DCF matched to 40 km for all transmission lengths. The G.metro standard considers an optional Erbium-doped fiber amplifier (EDFA) in upstream direction to lower the requirements on the tail-end tunable transmitter. The cost of EDFA and DCF can be shared between all subscribers and therefore, still supports the low cost approach. The dispersion compensated and amplified signal was demultiplexed by an AWG and finally launched into an SFP receiver on an evaluation board via a variable optical attenuator (VOA). The opto-electrically converted signal was connected back to the BERT to evaluate the BER.

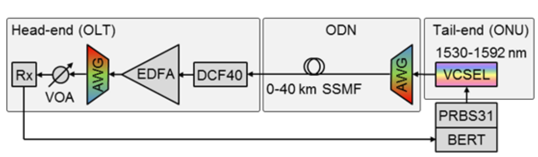

Fig. 5: Experimental setup

Fig. 6 shows the BER as a function of the received power for back-to-back (B2B) without DCF for a wavelength range of more than 60 nm. The B2B measurements show a wavelength-dependent receiver sensitivity, due to the varied extinction ratio (ER) at the different wavelength, as observed from the eye-diagram insets. However, this wavelength dependency can be minimized by optimizing the laser parameters for each wavelength. For a system evaluation representing the practical application, we kept both the bias current and modulation amplitude constant.

Fig. 7 shows the transmission results for SSMF transmission over 0-40 km with a constant dispersion compensation matched to 40 km SSMF without EDFA and AWGs (solid lines). A transmission length of 0 km means that the signal was launched directly into the DCF. Given the BERs of 10^{-9}, the receiver sensitivities after 40 km SSMF transmission are similar to the B2B case. This is expected due to the DCF matched to 40 km. For transmission lengths between 0 km and 30 km the receiver sensitivity varies less than 1 dB for the same wavelength. The dashed lines in Fig. 7 show the measurements with EDFA and one pair of AWGs. The performances of all measured wavelength do not show any significant additional impairments up to 30 km SSMF transmission length.

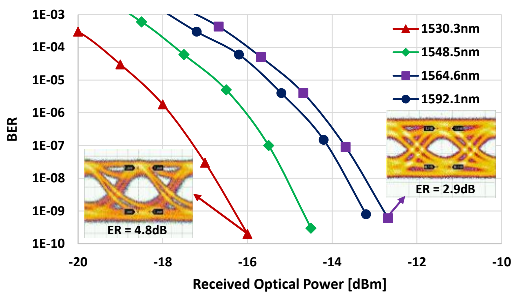

Fig. 6: Back-to-back BER performance vs. received power for various wavelengths (insets: measured eye-diagrams)

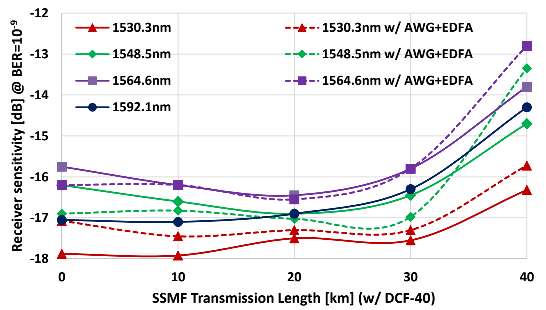

Fig. 7: Sensitivity vs. SSMF transmission length for various wavelengths and DCF matched to 40 km SSMF

For G.metro MFH applications, the differential reach is limited to 20 km. This leads to a system optimization of the DCF. From Fig. 7, it can be seen that the smallest deviation of the receiver sensitivity for a 20-km transmission range is between 10 km and 30 km. This means that the optimum DCF should be matched to 30 km SSMF. The receiver sensitivity varies within 1.75 dB over the whole tuning range and all transmission reaches. This is a sufficient result considering that the laser settings are kept constant for all wavelengths and transmission lengths. However, other applications, like MBH and enterprise access, require longer differential reaches, which is also possible with slightly increased penalties.

5. Conclusions

Up to now, low cost wideband tunable laser sources were the bottleneck of the G.metro system and therefore, the concept was not competitive enough for wide deployment. This paper provides the first experimental demonstration of a system based on MEMS-VCSELs which overcome this bottleneck. We demonstrate, for the first time, bit error free transmission of 10 Gbit/s direct modulation over 40 km SSMF for the tuning range of more than 60 nm. This is more than suitable for the proposed converged MFH and MBH network application utilizing the G.metro novel WDM-PON system and extends the system application to converged MFH, MBH, and enterprise access with differential reaches of up to 40 km.

6. Acknowledgements

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7. References

[1] T. Pfeiffer, "Next Generation Mobile Fronthaul Architectures," Proc. OFC, M2J.7, Los Angeles (2015).
[2] M. H. Eiselt et al., "Remotely Controllable WDM-PON Technology for Wireless Fronthaul / Backhaul Application," Proc. OECC, ThA3, Niigata (2016).
[3] K. Grobe et al., "Access Networks Based on Tunable Lasers," J. Light. Technol. Vol. 32, 2815–2823 (2014).
[4] S. Pachnicke et al., "Novel WDM-PON System with Shared Wavelength Locking and Full C-Band Tunability," Proc. ITG Symp. Photonic Networks, Leipzig (2014).
[5] C. Wagner et al., "Wavelength-Agnostic WDM-PON System," Proc. ICTON, Tu.D2.3, Trento (2016).
[6] R. Shau et al., "Long-wavelength InP-based VCSELs with Buried Tunnel Junction: Properties and Applications," Proceedings of SPIE, Surface-Emitting Lasers VIII, 5364, 1 (2004).
[7] S. Paul et al., "Ultra wide mode-hop free tuning around 1550 nm telecom wavelength using high-speed MEMS-VCSELs," J3, 20th Microoptics Conference, Fukuoka (2015).
[8] S. Paul et al., "High speed surface micromachined MEMS tunable VCSEL for telecom wavelengths," CLEO (2015)