Far L-band Single Channel High Speed Downstream Transmission using Injection-locked Quantum-dash Laser for WDM-PON

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Abstract: We demonstrate an externally modulated single channel 64 Gbit/s DP-QPSK transmission based on injection-locked Fabry-Pérot broadband quantum-dash laser at far L-band ~1621 nm wavelength. A receiver sensitivity of -16.7 dBm has been observed after 10 km SMF transmission, with power penalty of ~2 dB, under the FEC threshold. We also propose that these novel quantum-dash laser diode could be a route towards next generation 100Gbit-PONs as a unified upstream and downstream transmitters.

1 INTRODUCTION

Over the next few years, mobile data traffic will increase nearly eight times globally compared to the scenario in 2015 (Cisco 2016). The relentless continuous growth at the user end demands a development of higher bandwidth and capacity applications. This will put the transmission capacity limitations in existing wavelength division multiplexing (WDM) based optical access networks in near future. To encounter the demand of broad-band services and high transmission rate per channel, next generation passive optical networks (NG-PON) like 10Gbit-PONs, 100Gbit-PONs, and 400Gbit-PONs, have been considered as a promising solution. In addition, looking down the road, the existing C–band communication window would be exhausted and hence calls for exploring far L– and U– bands for upstreaming and down streaming in NG-PON technologies, for cost effective and flexible optical systems.

Recently, an injection-locking scheme has been found to be a potential candidate for realizing next generation colorless WDM-PONs. A single channel Fabry-Perot laser diode (FP-LD) (Nguyen et al., 2010) has been demonstrated as a sustainable transmitter in multi-Gbit/s WDM-PON, however, the directly modulated transmission data rate is found to be limited to 4 Gb/s over 25 km single mode fiber (SMF) (Chi et al., 2012). On other hand, an externally modulated FP-LD laser achieved a transmission rate of 42.5 Gb/s/channel over 100 km SMF (Silva et al., 2010). Moreover, a directly modulated semiconductor optical amplifier (SOA) (Gay et al., 2014) has also been proposed by employing a comb-generator with a transmission capacity of 28 Gb/s over 100 km SMF for colorless PON. A new study has been proposed on injection-locked directly modulated weak resonant cavity FP-LD (WRC-FPLD) transmitting data at 25 Gb/s over 28 channels in near L-band (1582 nm) (Cheng et al., 2014) which is capable of ~13 nm L–band wavelength tunability via low power optical injection. WRC-FPLD would require a wideband spectrum in order to support multiple channels at the optical line terminal (OLT) and reasonable coherence for modulation bandwidth at the same time. However, these schemes limit the expansion of number of users in the optical systems because of typical narrow band nature of the FP-LDs (Xu et al., 2012). Hence, a broadband laser diode (BLD) (Lee et al., 2010), with several longitudinal modes in stimulated emission could be a possible candidate, to meet up with the future requirements. Moreover, such source also enable large scale production and deployment of

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transceivers in optical network units (ONU) and optical line terminals (OLT). Besides, most of the aforementioned work is reported on direct modulation scheme which shows trade-off between the limited bandwidth and simple device structure cost-effective PON

In this paper, we report an externally modulated 64 Gb/s single channel dual polarization quadrature phase shift keying (DP-QPSK) down transmission in the far L-band to each user based on injection-locked broadband quantum-dash (Qdash) laser as a potential WDM transmitter. This type of Qdash laser is capable of broadband stimulated emission, hence which can deploy as a transmitter in WDM-PONs. The external seeding source is placed in the OLT and could be shared among all the users for down streaming. Moreover, we also propose that the scheme could be used for up-streaming at ONUs thus able to realize next generation 100Gbit-PONs.

2 RESULTS AND DISCUSSION

The quantum-dash laser diode used in this experiment was grown on n-type InP. The active region is composed of a four stack InAs/InGaAlAs Qdash-in-a-well structure where the layers are separated by barrier layers of thickness values of 10 nm, 15 nm, and 20 nm. This intentional chirping the active region increases the inhomogeneous broadening and hence provide a broad gain profile and hence ultra-broadband lasing emission. More details of the growth and characterization of Qdash laser could be found in reference (Khan et al., 2014).

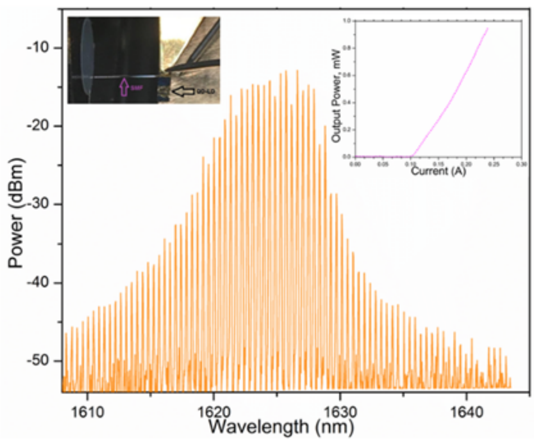


Figure 1: Free-running lasing spectra of the Qdash laser. Insets show *L-I* characteristic of a free running Qdash laser, measured at the SMF end the bare device and bare quantum dash laser.

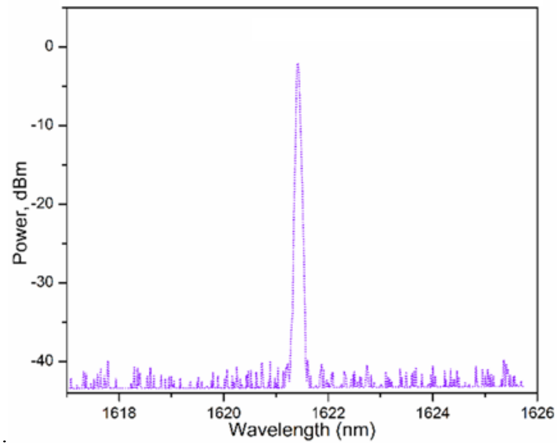


Figure 2: An injection-locked single FP mode of the broadband Qdash laser.

In this experiment, a bare 4 × 800 μm^2 ridge-waveguide Qdash laser diode is injected with a DC current of 0.24 A. The laser device was mounted on a brass base with p side up configuration. Two probes are then used where the negative one is connected to the brass base while the positive probe is placed over a gold plated clamp with the p side of the laser to safely probe the current into the laser diode. The total coupled power from the single laser facet into a lensed SMF is ~0 dBm, at a fixed temperature of 14 ºC and bias current of 0.24 A. Free running lasing spectrum of Qdash laser along with fiber end *L-I* characteristics under CW operation is shown in Fig. 1 with ~10 nm lasing bandwidth before roll off. The central lasing wavelength (calculated at the full width at half maximum) is located at ~1624 nm. The inset of fig.1 shows the lensed fiber power coupled bare Qdash laser. This degradation in the laser performance (both optical power and lasing bandwidth) under CW is attributed to the non-optimized growth of the device active region. An optimized design will enable realization of ultra-broadband lasing bandwidth of >50 nm and power > 100 mW (Khan et al., 2013). When the wavelength of the tunable master laser source was tuned to one of longitudinal mode of the Qdash laser while keeping a fixed external CW injection of 5 dBm, injection-locking occurs, as shown in setup of Fig. 2. The output spectra of the injection-locked Qdash laser is observed at the 2% output of a 2/98 coupler (CP) using optical spectrum analyzer. The measured single mode output power and side-mode suppression ratio (SMSR) are -2.5 dBm and 37 dB, respectively. Next, the tunability experiment of the injection locked Qdash laser is performed by fixing the external CW injection power at 5 dBm and varying the wavelength to lock at different modes. Fig. 3 shows the measurement results; by proper tuning in the wavelength range of 1617.5-1628.9 nm with ~1.31 nm tuning steps, tunability of ~12 nm was achieved. Moreover, short-term stability of injection-locked FP mode was also conducted and found to be stable throughout the observation time of 24 minutes. The injection locked mode was at 1619.68 nm with -5.74 dBm output power. The power fluctuation and wavelength variation of injection-locked Qdash laser are 0.56 dB and zero respectively, as shown in fig. 4. The laser source has performed well in terms of output power stability and has shown wide tuning range.

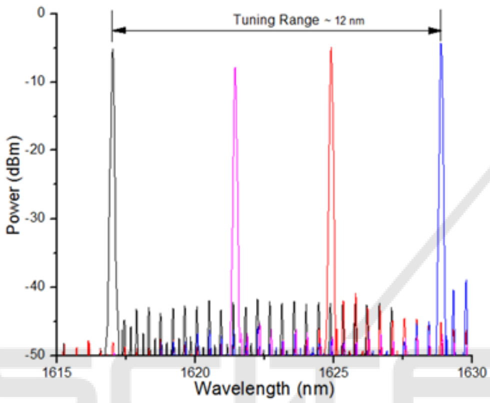


Figure 3: Output spectra of the injection-locked modes at different wavelengths in the tuning range of 1617.5-1628.9 nm with ~ 1.31 nm tuning steps, and at a fixed CW external injection of 5 dBm.

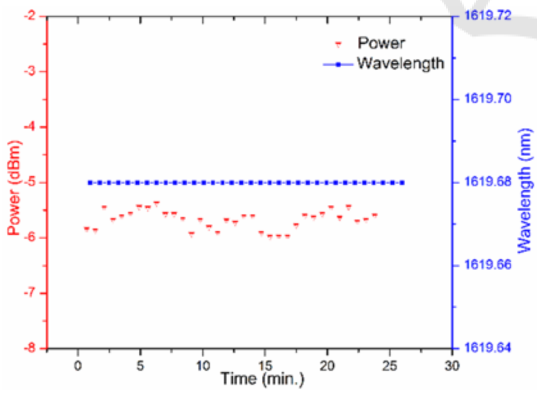


Figure 4: Stability characterization in terms of wavelength variation and output power fluctuation. Initial lasing wavelength is 1619.68 nm with -5.74 dBm output power.

The down transmission experimental setup is presented in Fig 5. The setup consisted of Qdash laser diode, TLS and an external dual polarization IQ (DP-IQ) modulator. The CW external power of TLS is fixed at 5 dBm and was injected into port 1 of the optical circulator (OC) through an isolator. The slave Qdash laser, on the other hand, was injected into port 2 using a polarization controller (PC), while the output was taken out at port 3 of the optical circulator. Isolator and PC are used to protect the TLS and improve the IL efficiency, respectively. Then, injection-locked single channel is fed to a DP-IQ modulator for DP-QPSK modulation up to 16 Gbaud data rate. Pre-processing of the signal were performed using MATLAB. A pseudo random binary sequence (PRBS) with a length of $2^{11}-1$ is mapped into 4-QPSK constellation and an 8-bit resolution arbitrary wave generator (M8195A) with a sampling rate of 65 GSa/s generates four channels multi-level signal, two channel for individual polarization. The output of four signals are driven into a quad channel amplifier having a 3-dB bandwidth of 32 GHz which can provide 20-dB gain for each channel simultaneously. Then, these signal are driven into the four RF inputs of DP-IQ modulator. For signal analysis and detection, we used Keysight optical modulation analyzer (OMA N4391A).

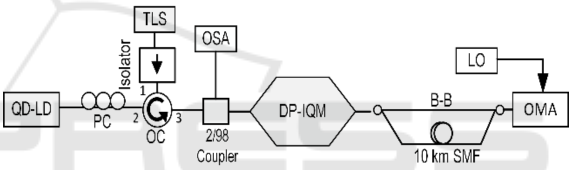


Figure 5: Experimental setup of 64 Gb/s DP-QPSK WDM transmission via injection-locked Qdash laser.

The signal transmission is characterized first in a back to-back (BtB) configuration and then over a 10 km SMF at 8 and 16 Gbaud transmission which corresponds to 32 and 64 Gb/s. Fig. 6 presents the variation of bite error rate (BER) with the received signal sensitivity. And the insets show the QPSK constellation diagram for 64 Gb/s after BtB and 10 km transmission. To achieve 3.8×10^{-3} FEC threshold, received power of -18.7 (-19.7) dBm are required for 64 (32) Gb/s in BtB case. On the other hand, a receiver sensitivity of -18.4 and -16.7 dBm is observed for 32 and 64 Gbit/s respectively, after 10 km SMF transmission, with power penalties of ~1.3 dB and ~2 dB respectively, under the FEC threshold. This might be loss incurred by the fiber due to extreme far L-band wavelength operation. In addition, any injection locked mode power variation, results from the bare Qdash laser and coupled into the lensed SMF, could also lead to receiver sensitivity fluctuations. Fig. 7 show the eye diagrams for 64 Gbit/s at -14.4 dBm and -12.5 dBm for 10 km and BTB transmissions, respectively. A clear open eye with no eye compression further affirms the potential of Qdash laser as a unified transmitter in WDM-PONs. In Table I, we summarize our experimental results in contrast to the recent literature for a single carrier L-band transmission, to the best of our knowledge. Hence, deployment of these Qdash laser diode based transmitters in OLT for down streaming as well as in ONU for 64 Gb/s upstreaming would assist a path towards next generation NG-PON.

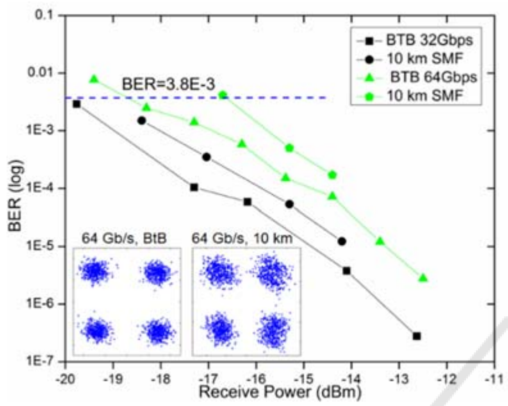
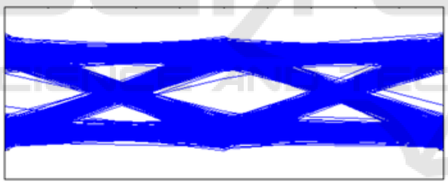
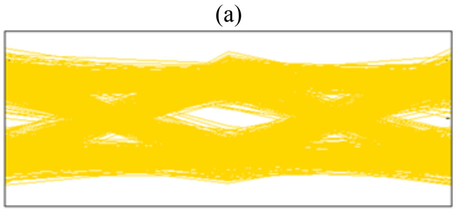


Figure 6: BER versus received optical power at 32 and 64 Gbit/s under BtB and after 10 km SMF transmission. Insets show the constellation diagrams for BtB and over 10 km for 64 Gb/s transmission.



(a)



(b)

Figure 7: Eye diagrams for 64 Gbit/s data rate for (a) BtB and, (b) over 10 km transmission.

Table 1: Comparison of a data transmission rate by a single-carrier, in L-band, available in literature.

Wavelength (nm)	Modulation scheme	Data rate (Gbit/s)	Type
1583[ü]	16-QAM	12	D
1583[ő]	16-QAM	20	D
1592[đ]	–	1.25	D
1595[ŧ]	–	1.25	D
1621[ž]	DP-QPSK	64	E

Note: ü ➔ (Li et al., 2013), ő ➔ (Cheng et al., 2014), đ ➔ (Komljenovic et al., 2014), ŧ ➔ (Lee et al., 2012), ž: ➔(This paper), D: Direct modulation, E: External modulation.

3 CONCLUSION

We have proposed an injection-locked broadband quantum-dash laser as a potential WDM transmitter for next generation passive optical networks (NG-PON). An externally modulated single channel has been transmitted at 64 Gbit/s using dual polarization modulator (DP-IQM). Experimental results showed a receiver sensitivity of -16.7 dBm under BER FEC limit after 10 km SMF transmission.

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