

Analogue modulation characteristics of InP membrane microdisc laser for in-building networks

H.-D. Jung, R. Kumar, P. Regreny, H. Dorren, T. Koonen and O. Raz

Using thin membrane InP microdisc lasers heterogeneously integrated on a silicon on insulator (SOI) substrate having a broadband analogue modulation bandwidth of 11 GHz, analogue direct modulation with radio data signals (64 and 256 QAM, 20M symbols/s at 5 GHz RF carrier) is demonstrated. The demonstration shows the potential of the microdisc laser as a low-energy analogue optical transmitter with error-vector magnitude penalties of 3.6 and 4.2% for 64 and 256 QAM, respectively, and the low biasing currents for both DC (4 mW) and RF (0.1 mW) signals, which are compatible with signals and currents which can be supplied by a simple CMOS driving chip.

Introduction: The development of internet and wireless technologies for wireless LAN and cellular phones has boosted wireless communications. However, inside closed environments such as airports, convention centres, hospitals, etc., it is difficult to cover a whole building with a single, large, high-capacity wireless network. Limited coverage of a wireless network in a large building environment can be solved by radio over fibre (RoF) technology, which transmits radio signals to remote antenna stations via optical fibre with low propagation losses and large bandwidth. By using RoF technology, radio picocells can be deployed in each room, allowing for better bandwidth allocation and improved quality of service (QoS) for users in terms of available bandwidth per user and signal strength. Therefore, simplified remote antenna stations, based on RoF technology, with low cost and low power consumption are highly desirable. Most demonstrations of RoF picocell stations have focused on using vertical-cavity surface emitting lasers (VCSELs) as directly modulated light sources [1–6]. Although compact in size and relatively cheap, VCSELs have not been integrated with electronic driving circuits onto a single monolithic integrated circuit, implying that the required circuitry of a picocell station needs to include not only the RF generation and detection but also the packaged VCSEL source and VCSEL driver chips, making for a more complicated and power-hungry cell.

InP membrane disc lasers bonded on top of a silicon waveguide circuit have been suggested as potential light sources, which can be integrated on top of functional CMOS electronic chips [7]. Recently they have been shown to allow for broad bandwidth direct modulation [8] for digital communication purposes. Thus, a path has been created for the integration of the laser sources directly on top of the COMS analogue chip to deliver a monolithic RoF optical transmitter on a chip, which is both compact in size and energy efficient.

In this Letter, we give a proof-of-concept demonstration for the use of an InP membrane disc structure integrated on top of silicon-based photonic integrated circuits (PICs) as a low power broadband directly modulated light source for analogue radio signals. Such a source offers low cost, compact size, low power consumption and CMOS compatibility. The measured frequency response of the microdisc laser shows a -3 dB small signal modulation bandwidth of 11 GHz. Additionally, we successfully transmit 64 and 256 QAM, 20M symbols/s at 5 GHz data signal with 3.6 and 4.2% error-vector magnitude (EVM) penalty, respectively, compared with the electrical back-to-back case.

Device characteristic: The heterogeneously integrated microdisc laser is based on post-bonding processed InP membrane on top of an SOI waveguide circuit as described in [7]. Fig. 1 shows the measured $L-I$ and $V-I$ curves for the device while operating at 18°C . For the particular disc laser used in this experiment, the laser is operating in continuous-wave mode and the clockwise (CW) lasing dominates over the counter CW-lasing owing to larger than expected feedback from the grating couplers. This unidirectional behaviour, which is not common to all disc lasers [9], is important when modulating the bias current, as switching in lasing direction may interfere with analogue operation. The output power fluctuates with the sweep in current injection owing to changes in feedback phase and mode competition, but remains higher than $5 \mu\text{W}$ for most currents above 2 mA. For currents around

2 mA, the laser lased in singlemode around a wavelength of 1597 nm and with a sidemode suppression ratio larger than 30 dB.

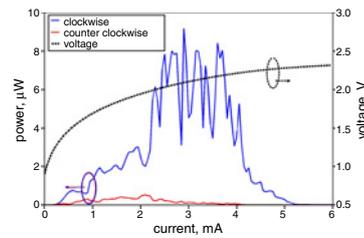


Fig. 1 $L-I$ and $V-I$ curves of microdisc laser

Analogue small signal characteristics: To evaluate the performance of the disc structure as a directly modulated laser for analogue radio signals, the frequency response (electrical to optical transfer function) was measured using a 20 GHz lightwave component analyser. The disc was biased at 2.16 mA, and the RF output power of the analyser, set to 0 dBm, was coupled to the bias current using a bias-T. As can be seen in Fig. 2, for a small signal sinusoidal RF modulation the disc exhibits an impressive 3 dB bandwidth of 11 GHz, which covers the frequency bands of conventional wireless services such as GSM, CDMA, Wi-Fi, Wi-Max, etc.

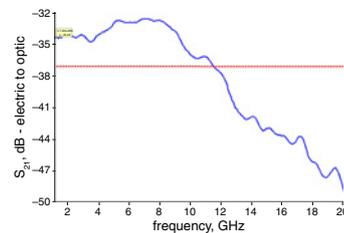


Fig. 2 Small signal frequency response for microdisc laser

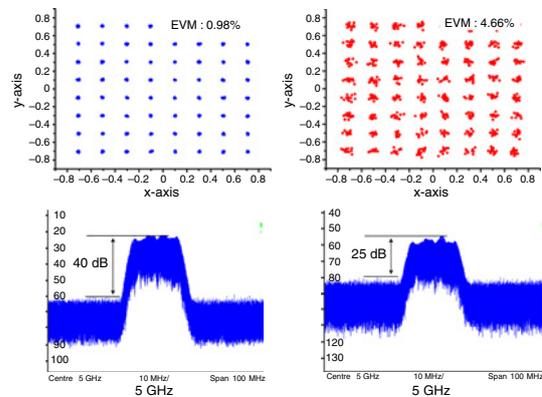


Fig. 3 Constellation and RF spectrum of 64 QAM signals in (left) electrical back-to-back, and (right) direct modulation case with microdisc laser

QAM performance: Based on the frequency response measurement, we applied radio data signals to evaluate the performance of the disc laser as a photonic QAM transmitter. As shown in the Fig. 3 (left), 64 QAM, 20 M symbols/s data signals at 5 GHz RF carrier were used for modulation. The microdisc laser was biased at 2.16 mA with an RF power of -10 dBm. Then, the directly modulated optical signal is coupled to the optical fibre, detected by a conventional photodiode with 12 GHz RF signal bandwidth and finally analysed using a 40 GHz vector signal analyser. As shown in Fig. 3 (right), the SNR of the received RF signals is reduced by around 15 dB, the EVM penalty is around 3.7% compared to the electrical back-to-back case (Fig. 3, left), and the absolute EVM is 4.66%. The performance degradation comes from the low output optical power which translates into low modulation efficiency (owing to the dependency of electrical losses on the optical power). Theoretical studies on the disc lasers show that a power level 10–15 dB higher can be expected outside the silicon chip by following several design improvements. The modulation efficiency can also be improved by increasing the RF power, but this will require a device with a smoother

L - I curve. As can be seen in Fig. 1, although the L - I curve is not linear, the laser shows reasonable performance for the small modulation analogue radio signals and performs better than the radio signal standard, i.e. the EVM is below the upper limit of Wi-Fi (IEEE 802.11a/g) of 5.6%. Increasing the QAM order to 256 QAM, with the same symbol rate and RF carrier, has resulted in slightly poorer SNR (Fig. 4, bottom right) and an EVM penalty of around 4.2% compared to the electrical back-to-back case, or an absolute EVM of 5.194% (Fig. 4, top right), which is again within the required 5.6% of the Wi-Fi standard.

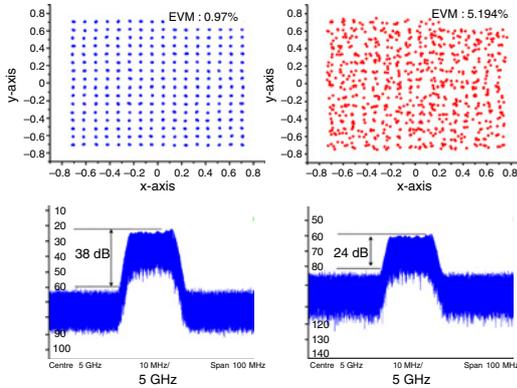


Fig. 4 Constellation and RF spectrum of 256 QAM signals in (left) electrical back-to-back, and (right) direct modulation case with microdisc laser

Conclusion: We have evaluated the analogue modulation performance of an InP-based microdisc laser heterogeneously integrated with SOI to examine its applicability as an integrated on-chip transmitter for analogue communication signals. The laser displays impressive frequency response with a 3 dB modulation bandwidth of 11 GHz. In addition, we have successfully transmitted radio signals with 64 and 256 QAM, 20 M symbols/s at 5 GHz with 3.7 and 4.2% EVM penalty, respectively, compared to the electrical back-to-back case. Therefore, we believe that microdisc lasers are very promising candidates as integrated low power optical transmitters for RoF system application.

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One or more of the Figures in this Letter are available in colour online.

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