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## **Integrated InP membrane light sources for analog CMOS photonic transmitters**

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*InP membrane disc lasers have been considered as light sources for off chip data communication for logic microprocessors or for all optical logic devices such as gates and flip-flops. However, another family of CMOS devices can benefit greatly from integration of on chip light sources, mixed-signal and analog CMOS. In this paper we discuss recent results in the application of disc lasers for analog signal transmission such as radio over fiber. Large analog modulation bandwidth is demonstrated, and transmission of 64 and 256 QAM signals on a 5GHz RF carrier is successfully demonstrated with low EVM performance penalty*

### **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 centers, hospitals, etc., it is difficult to cover a whole building with a single, large, high-capacity wireless network. Limited coverage of wireless network in a large building environment can be solved by Radio-over-Fiber (RoF) technology, which transmits radio signals to remote antenna stations via optical fiber with low propagation losses and large bandwidth. By using RoF technology, radio pico-cells can be deployed in each room, allowing for better bandwidth allocation and improved QoS (Quality of Service) 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 demonstration of RoF pico-cell 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, the VCSELs have not been integrated with the electronic driving circuits onto a single monolithic integrated circuit, implying that required circuitry of a pico-cell 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 CMOS analog chip to deliver a monolithic RoF optical transmitter on a chip, which is both compact in size and energy efficient. In this paper, 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 an analog 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 11GHz, which can be increased by employing injection locking to as much as 15GHz. Additionally, we successfully transmit 64 & 256QAM, 20M Symbols/s at 5GHz data signal with 3.6% and 4.2% error-vector magnitude (EVM) penalty respectively compared with 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]. In Figure 1 we show the measured L-I & V-I curves for the device. For the particular disc laser used in this experiment, clockwise (CW) lasing dominates over counter CW-lasing. This unidirectional behavior, which is not common to all disc lasers [9], is important when modulating the bias current, as switching in lasing direction may interfere with analog operation. The output power fluctuates with the sweep in current injection due to changes in feedback phase and mode competition, but remains higher than  $5\mu\text{W}$  for most currents above 2mA. For currents around 2mA, the laser lased in single mode around a wavelength of 1597nm and with a side mode suppression ratio larger than 30dB.

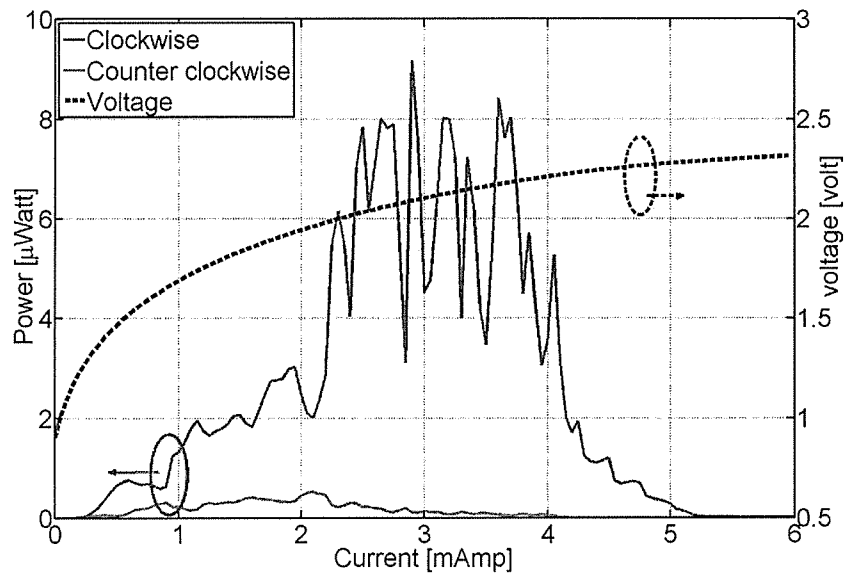


Figure 1: L-I & V-I curves of microdisc laser

### Analog small signal characteristics

To evaluate the performance of the disc structure as a directly modulated laser for analog radio signals, the frequency response (Electrical to Optical transfer function) was measured using a 20GHz light wave component analyzer. The disc was biased at 2.16mA ( $\sim 7$  times threshold), and the RF output power of the analyzer, set to 0dBm, was coupled to the bias current using a bias-T. As can be seen in Figure 2 (Left), for a small signal sinusoidal RF modulation the disc exhibits an impressive 3dB bandwidth of 11GHz, which covers the frequency bands of conventional wireless services such as

GSM, CDMA, Wi-Fi, Wi-Max. etc. Recently we have used injection locking to significantly enhance the modulation bandwidth of directly modulated disc lasers. In Figure 2 (right) we show the analog bandwidth measured with a 67GHz component analyzer with and without injection locking for a disc laser measuring 10 $\mu$ m and biased at 0.8mAmps (two times threshold). The bandwidth is almost doubled to reach 15GHz.

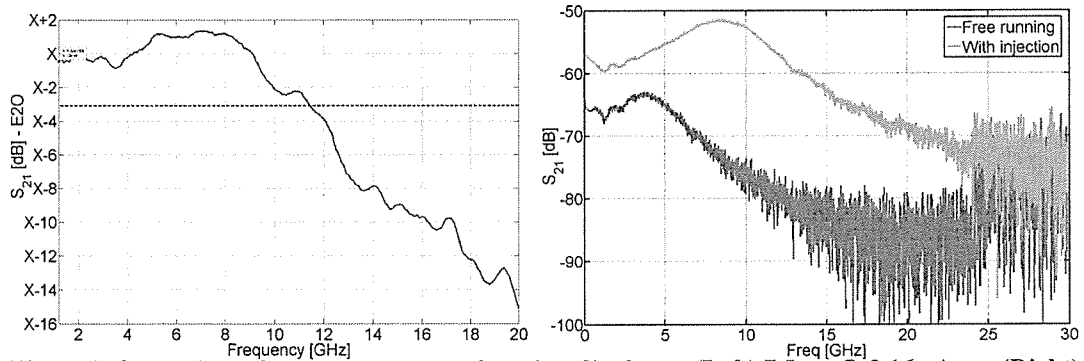


Figure 2: Small signal frequency response for microdisc laser; (Left) 7.5 $\mu$ m @ 2.16mAmp, (Right) 10 $\mu$ m @ 0.8mAmp

### Quadrature Amplitude Modulation (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, 20M Symbols/s data signals at 5GHz RF carrier were used for modulation. The micro disc laser was biased at 2.16mA with an RF power of -10dBm (70mVolts!). Then, the directly modulated optical signal is coupled to the optical fiber, detected by a conventional photodiode with 12GHz RF signal bandwidth and finally analyzed using a 40GHz Vector Signal Analyzer. As shown in Fig. 3, the SNR of the received RF signals is reduced by around 15dB, the EVM penalty is around 3.7% compared to the electrical back-to-back case, and the absolute EVM is 4.66%. The performance degradation comes from the low output optical power which translates into low modulation efficiency (due to the dependency of electrical losses on the optical power).

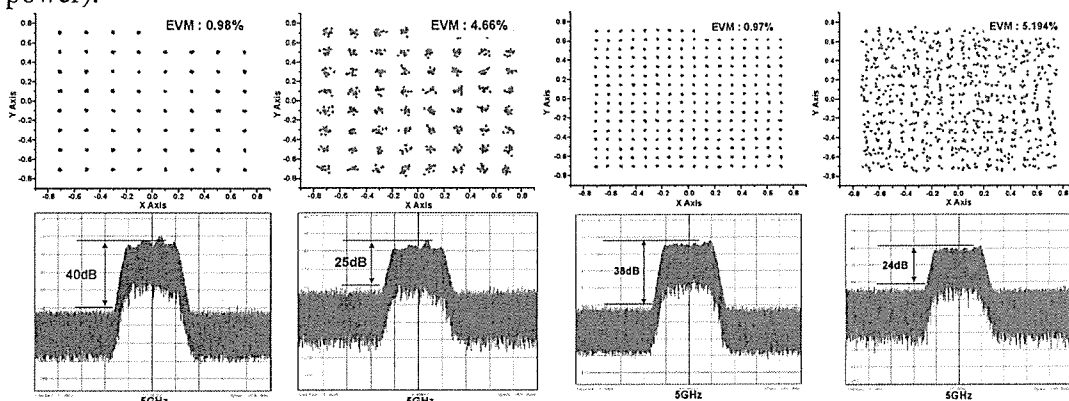


Figure 3: (Top) The constellation of 64/256-QAM signals in electrical back-to-back (1st and 3rd from the right) and direct modulation case with the microdisc laser (2nd and 4th from the right); (Bottom) recorded RF spectrum of signals showing in the constellations

As can be seen in Fig. 1, although the L-I curve is not linear, the laser shows reasonable performance for the small modulation analog 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 QAM order to 256-QAM, with same symbol rate and RF carrier, has resulted in slightly poorer SNR and an EVM penalty of around 4.2% compared to the electrical back-to-back case, or an absolute EVM of 5.194%, which is again within the required 5.6% of the Wi-Fi standard

## Conclusion

We have evaluated the analog modulation performance of an InP-based micro disc laser heterogeneously integrated with SOI to examine its applicability as an integrated on-chip transmitter for analog communication signals. The laser displays impressive frequency response with a 3 dB modulation bandwidth of 11GHz, which can be further enhanced to achieve 15GHz with the help of injection locking. In addition, we have successfully transmitted radio signals with 64-QAM and 256-QAM, 20M Symbols/s at 5GHz with 3.7% and 4.2% EVM penalty respectively, compared to electrical back-to-back case. Therefore, we believe that micro disc lasers are very promising candidates as integrated low power optical transmitters for RoF system application.

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