Analog Modulation Characteristics of InP Membrane Microdisc Laser for In-building Networks

Hyun-Do Jung, Rajesh Kumar, P. Regreny, Harm Dorren, Ton Koonen, Oded Raz

Abstract: Using thin membrane InP microdisc lasers heterogeneously integrated on a Silicon on Insulator (SOI) substrate having a broad band analog modulation bandwidth of 11GHz, we demonstrate analog direct modulation with radio data signals (64 and 256-QAM, 20M Symbols/sec at 5GHz RF carrier). The demonstration shows the potential of the microdisc laser as a low-energy analog optical transmitter with EVM penalties of 3.6% and 4.2% for 64-QAM and 256-QAM respectively and the low biasing currents for both DC (4mW) and RF (0.1mW) 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 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 COMS compatibility. The measured frequency response of the microdisc laser shows a -3 dB small signal modulation bandwidth of 11GHz. Additionally, we successfully transmit 64 & 256QAM, 20M Symbols/s at 5GHz data signal with 3.6% and 4.2% errorvector 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 5µW 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.

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, 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, 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.

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. 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(right), 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 (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 (due to the dependency of electrical losses on the optical power). As can be seen in Fig. 1 (top), 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 (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.

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. 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 an integrated low power optical transmitter for RoF system application.

Acknowledgment: This work is partially supported by the FP7 EU-Project 'ALPHA' and the FP7 EU-Project HISTORIC

References

1. T. Niiho et al, "Transmission performance of multichannel wireless LAN ssytem based on radio-over-fiber techniques," IEEE Trans. Microw. Theory Tech., vol. 54, no. 2, pt. 2, pp. 980-989, Feb. 2006.
2. K.-A. Persson et al, "WCDMA radio-over-fibre transmission experiment using singlemode VCSEL and multimode fibre," Electron. Lett., vol. 42, no. 6, 2006.
3. M. L. Lee et al, "850nm radio-over-fiber EVM measurements for IEEE 802.11g WLAN and cellular signal distribution," in Proc. 36th Eur. Microwave Conf., 2006, pp. 882-885.
4. A. Das et al, "Design of low-cost multimode fiber-fed indoor wireless networks," IEEE Trans. Microw. Theory Tech., vol. 54, no. 8, pp. 3426-3432, Aug. 2006.
5. R. Alemany, et al, "UMTS Radio-over-Fiber Pico-Cell Interconnection Employing Low-Cost VCSELs and Multi-Mode Fibre," proc. Of ICTON 2009, Mo.B5.4, 2009.
6. A. Ng'oma et al, "Performance of a Multi-Gb/s 60GHz Radio Over Fiber System Employing a Directly Modulated Optically Injection-Locked VCSEL," J. of Lightw. Technol., vol. 28, no. 16, pp. 2436-2444, Aug. 2010.
7. T. Spuesens et al, "Improved design of an InP-based microdisk laser heterogeneously integrated with SOI", proc. of Group IV Photonics 2009, FA3
8. O.Raz et al, "A Single InP Membrane Disc Cavity for Both Transmission and Detection of 10Gb/s Signals in On Chip Interconnects", proc. of the ECOC 2010, to be presented

9. G. Mezösi, et al, “Unidirectional Bistability in AlGaInAs Microring and Microdisk Semiconductor Lasers,” Photon. Tech. Lett., Vol. 21, no. 2, pp. 88-90 (2009).

Authors’ affiliations:

Hyun-Do Jung, Harm Dorren, Ton Koonen, Oded Raz are with the COBRA Research Institute, Eindhoven University of Technology, P.O. Box 512, 5600 MB, Eindhoven, The Netherlands - o.raz@tue.nl
Rajesh Kumar is with INTEC, Ghent University—IMEC, St-Pietersnieuwstraat 41, 9000 Ghent, Belgium
P. Regreny is with the Institut des Nanotechnologies de Lyon INL-UMR5270, CNRS, Ecole Centrale de Lyon, Ecully F-69134, France

Figure captions:

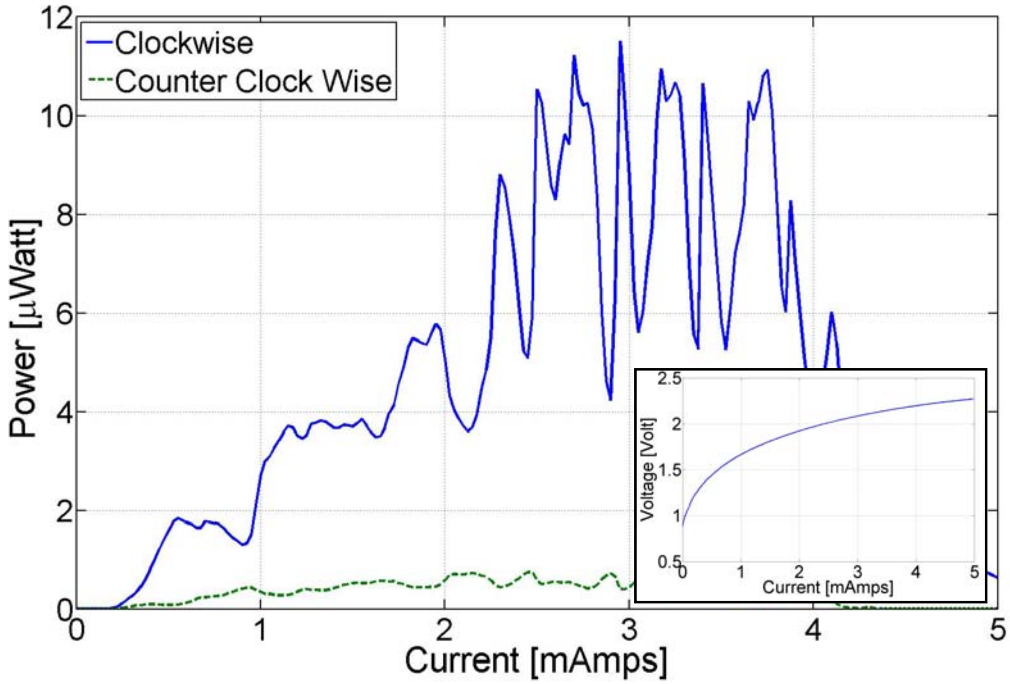
Figure 1: (Top) L-I) curve of microdisc laser (Inset: V-I), (bottom) optical spectrum for both lasing directions at modulation biasing point.

Figure 2: Small signal frequency response for microdisc laser

Figure 3: The constellation and RF spectrum of 64-QAM signals in (left) electrical back-to-back, and (right) direct modulation case with the microdisc laser

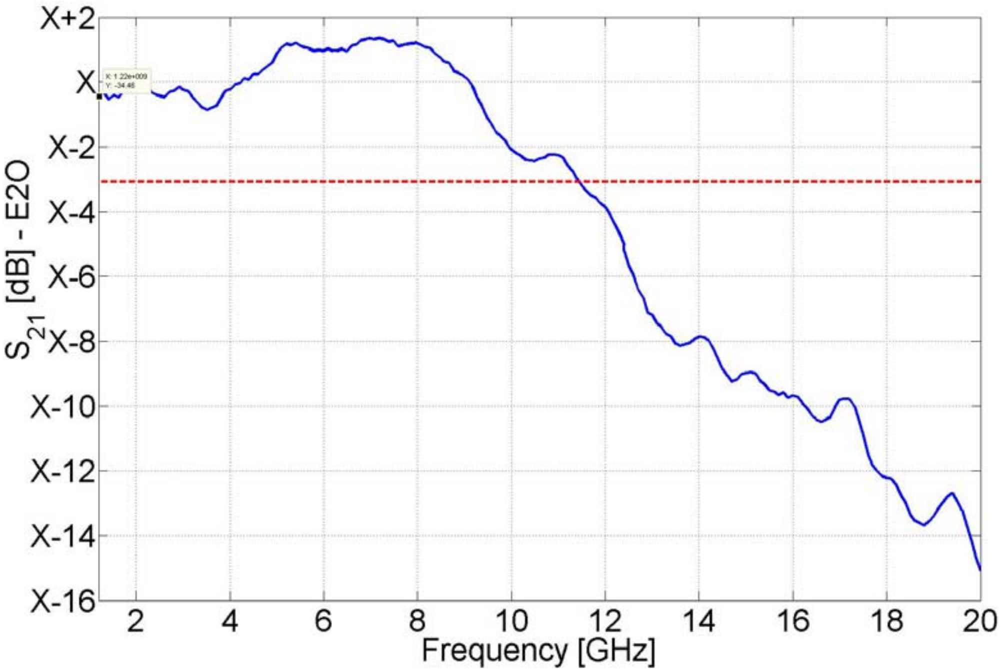
Figure 4: The constellation and RF spectrum of 256-QAM signals in (left) electrical back-to-back, and (right) direct modulation case with the microdisc laser

Figure 1



Clockwise
Counter Clock Wise
Power [μWatt]
Current [mAmps]
12
10
8
6
4
2
0
0
1
2
3
4
5
Voltage [Volt]
Current [mAmps]
2.5
2
1.5
1
0.5

Figure 2



X+2
X
X-2
X-4
X-6
X-8
X-10
X-12
X-14
X-16
2
4
6
8
10
12
14
16
18
20
Frequency [GHz]
S21 [dB] - E2O

Figure 3

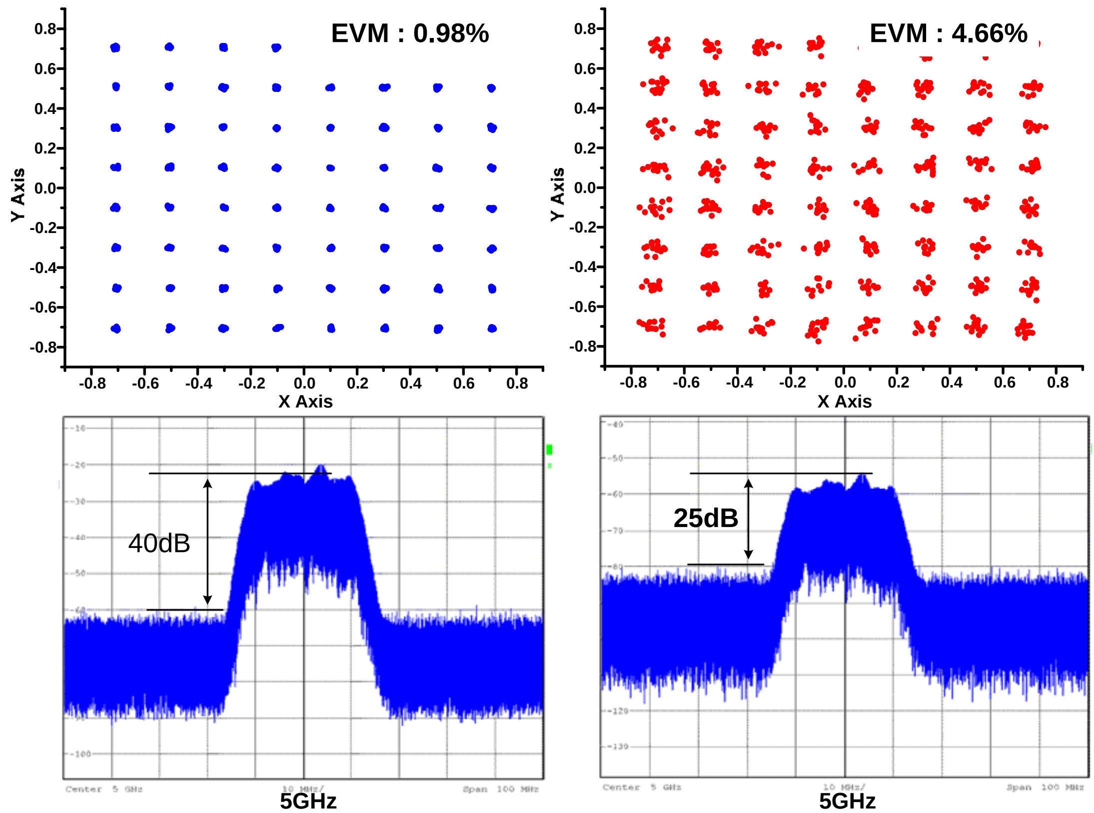

EVM : 0.98%
EVM : 4.66%
Y Axis
X Axis
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
40dB
25dB
5GHz
5GHz

Figure 4