A Single InP Membrane Disc Cavity for Both Transmission and Detection of 10Gb/s Signals in On Chip Interconnects

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Abstract *We give proof of concept demonstrations for the use of a single InP membrane disc structure as both a directly modulated light source and photo-detector using a 2^7-1 PRBS sequence at rates up to 10Gb/s.*

Introduction

Photonics has been suggested as a replacement for electronic interconnects as they may hold several major advantages over traditional CMOS interconnects. First, small size photonic transmitters and receivers can operate at a speed that is an order of magnitude faster compared to their electronic counter parts. Second, photonic transmission lines or waveguides do not exhibit the capacitive effects of metallic transmission lines, and can therefore offer very low attenuation and almost unlimited bandwidth through high bit-rate modulation and wavelength division multiplexing[1]. Finally, photonics offers an improved bandwidth-distance product which may result in lower energy consumption per bit which is crucial for scaling CPU performance.

For reasons of compatibility silicon is a most obvious choice for photonic interconnecting waveguides[2], yet being an in-direct band-gap material its light emitting properties are very poor. While extensive research work has been carried out on silicon on insulator modulators[3,4], these assume an off-chip light source which is power hungry and still needs low loss coupling solutions to SOI waveguides. Alternatively, bonding of thin membrane of InP on SOI has proven to be a viable solution for laser sources. These however, have not been proven to support high speed (>3Gb/s) direct modulation and thus still require an integrated modulator[5]. For detection, high-speed Germanium doped Silicon[6] as well as InP membrane photo-detectors[7] have been reported upon. Of all the above technological advancement, there is still no solution which relies upon a coherent single integration platform. Even disc laser and photo-detectors based on InP membranes have been fabricated using different epitaxially grown layer structures and have to be processed separately making for an overly complicated solution.

In this paper we suggest to use a single InP membrane disc as both a directly modulated transmitter, under forward bias and as a resonant detector under negative bias. The operation of this device at speeds up to 10Gb/s is demonstrated by tracing the time response of the disc to a PRBS sequence of the order of 2^7-1 and measuring the electrical to optical and optical to electrical transfer functions for the same device as a transmitter and receiver respectively.

Device structure and characterization

The microdisc is etched in a thin InP-based membrane, which contains 3 compressively strained InAsP quantum wells with a thickness of 6 nm in 15 nm Q1.2 barrier layers. The InP-based membrane is bonded on top of SOI with a thin layer of Benzocyclobutene (BCB). The oxide layer contains a silicon wire waveguide with a 500 nm width and a thickness of 220 nm. The laser mode is evanescently coupled to this waveguide. Electrical injection is possible via a top metal contact in the center of the disc and a bottom metal contact buried under the BCB, which curves around the perimeter of the disc. In Figure 1 we show the measured L-I & V-I curves for the device (top) together with the optical spectrum under forward bias (bottom). Note that the disc laser favors the clockwise lasing mode for all biasing conditions, so that the disc operates in fact as a unidirectional device. The output power fluctuates with the sweep in current injection due to changes in feedback phase and mode competition, but remains higher than 5µWatt for most currents above 2mAmps.

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Transmitter operation

The performance of the disc structure as a directly modulated laser was characterized using both a network analyzer and a high speed pattern generator with a sampling digital oscilloscope for capturing the modulated data.

For the transfer function measurements a 20GHz lightwave component analyzer was used with inbuilt and pre-calibrated optical receiver. The disc was biased at 2.14mAmps, and the

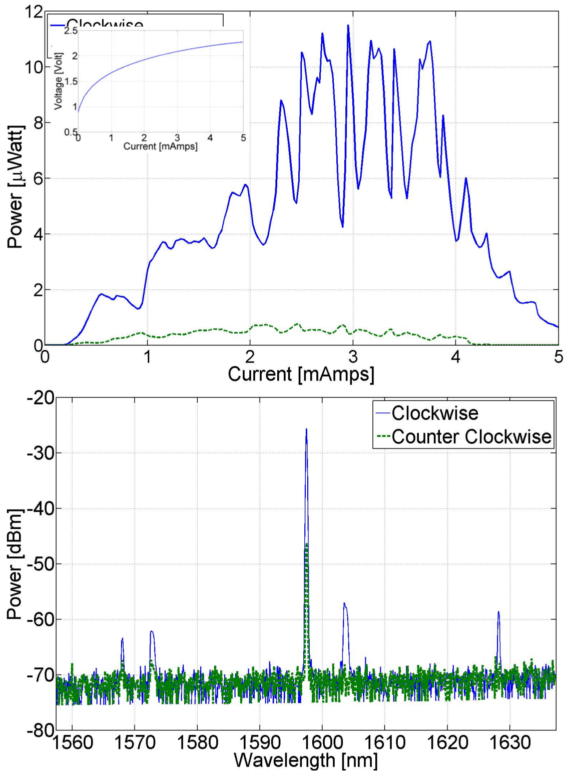


Fig. 1: (top) L-I laser curve (Inset V-I); (bottom) Optical spectrum for both lasing directions at modulation biasing point

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 (top), for a small signal sinusoidal RF modulation the disc exhibits an impressive 11GHz 3dB bandwidth. This however is not readily observable when looking at characterization done using a PRBS high speed data sequence.

For establishing the response to digital modulation a pulse pattern generator (PPG) with a PRBS of 2^7-1 at 5 and 10 Gb/s modulation speeds was employed. The disc was biased with a DC current of 3.65mA (2.186Volts) and an RF Vp-p swing of 0.55volts. The optically modulated signal, who's spectrum can be seen in Figure 1, was amplified using an L-band amplifier, then filtered with a Fabry-Perot tunable filter with a free spectral range (FSR) of 76.8nm and a width at half maximum (FWHM) of 0.21nm. The need to use optical amplification in order to obtain sufficient power to allow for photo-detection is in this case mainly the result of 6-8dB fiber to silicon coupling and 6dB insertion losses of the Fabri-Perot tunable filter. Estimated power in the waveguide for this device is higher than 100μWatts and could be increased by a more optimized design for such applications. Once filtered, the signal was detected using a 15GHz analog bandwidth receiver and displayed on a 100GHz bandwidth electrical sampling scope. In Figure 2, the obtained time series for both modulation rates can be seen. Although the rise and fall times of the modulation is limited to several tens of pico-seconds, still all 127 bits of the PRBS sequence can be clearly recognized in the time trace (without the help of averaging in the scope).

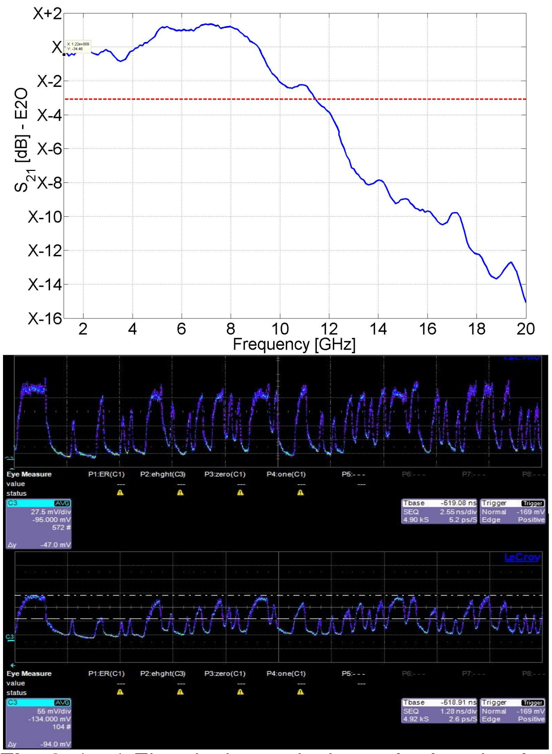


Fig. 2: (top) Electrical to optical transfer function for disc laser ; (bottom) time trace of modulated disc output at 5Gb/s and 10Gb/s

Receiver operation

Similar to the characterization of the disc as a transmitter the performance of the disc as a resonant receiver was also characterized both in the analog and digital domains.

In the analog domain the frequency response was again measured using the 20GHz component analyzer for a reverse voltage of 2.5 volts and an input optical power of ~5dBm in the waveguide. The detected electrical signal was then amplified using a broad band 20dB RF amplifier. The obtained transfer function does not show any distinct drop in response within the 20GHz bandwidth of the network analyzer used.

In the digital domain, response to a PRBS (2^7-1) sequence generated by a pattern generator and a MZM modulator at 5 and 10Gb/s was captured using a 100GHz analog bandwidth sampling scope. For these measurements the power level of the modulated signal in the silicon waveguide was lower (~ 0dbm). The reverse voltage was optimized to get the best visible transitions in the time sequence (-2 and -3.55 volts for 5 and 10 Gb/s respectively). The obtained electrical signal, measuring a few µvolts peak-to-peak was amplified using the same broad band amplifier used for the transfer function (Fig.3

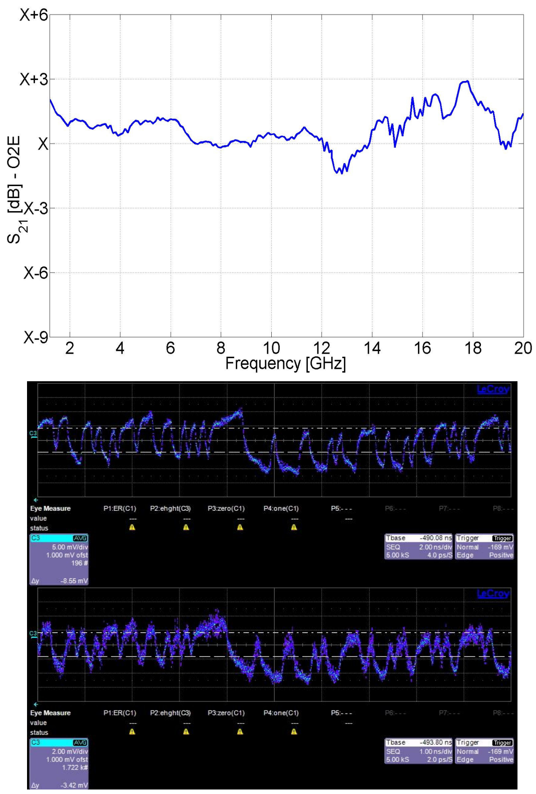


Fig. 3: (top) Optical to electrical transfer function for disc detector;(bottom) time trace of detected sequence at 5Gb/s and 10Gb/s

(top)) analysis to obtain a maximum of 25mVolt peak to peak signal. Due to the limited electrical power and noise contributions of both external RF amplifier and internal oscilloscope amplification stages the time series shown in Figure 3, are the result of averaging out the noise over 20 & 50 consecutive waveforms for 5 and 10Gb/s traces respectively.

Conclusions

We have demonstrated that an InP disc cavity bonded on top of a passive SOI circuit can function as both a fast modulated source and a resonant photo-detector. The specific design of the structure makes for limited coupling of the disc to the underlying SOI waveguide, allowing for low coupling efficiency for both transmitter and detector modes. Moreover, the number of active layers, and their position in the layer stack are not optimized for operation as a detector. Nevertheless the device has been shown to operate as a directly modulated source and a resonant photo detector at a speed of 10Gb/s by tracing the response to a PRBS time sequence. The expected operational bandwidth for the smae device was furhter charcaterized using a lightwave component analyzer showing a 3dB modulation bandwidth of 11GHz and a detection bandwidth greater then the 20GHz bandwidth of the analyzer used. Further optimization of the layer stack, bonding thickness and impedance matching are required in order to allow for reliable error-free transmission and detection. For compatibility with CMOS electronics we beleive the operating conditions can be adjusted for forward and reverse voltages of 1.5, as the disc emits ~4µWatts at that voltage and the frequency response for a -2.5 volts does not roll off within the 20GHz bandwidth available for measurements, so it is foreseable that sufficient bandwidth can be guarenteed for a -1.5volt reverese bias.

References

[1] D.A.B. Miller, IEEE Special issue on silicon Photonics, 2009

[2] I. Belz, G. Burbach, H. Vogt, I. Peter-Wedemann, and G. Zimmer, Mater. Sci. Eng. ,Vol. 34, pp. 429-433, 1989

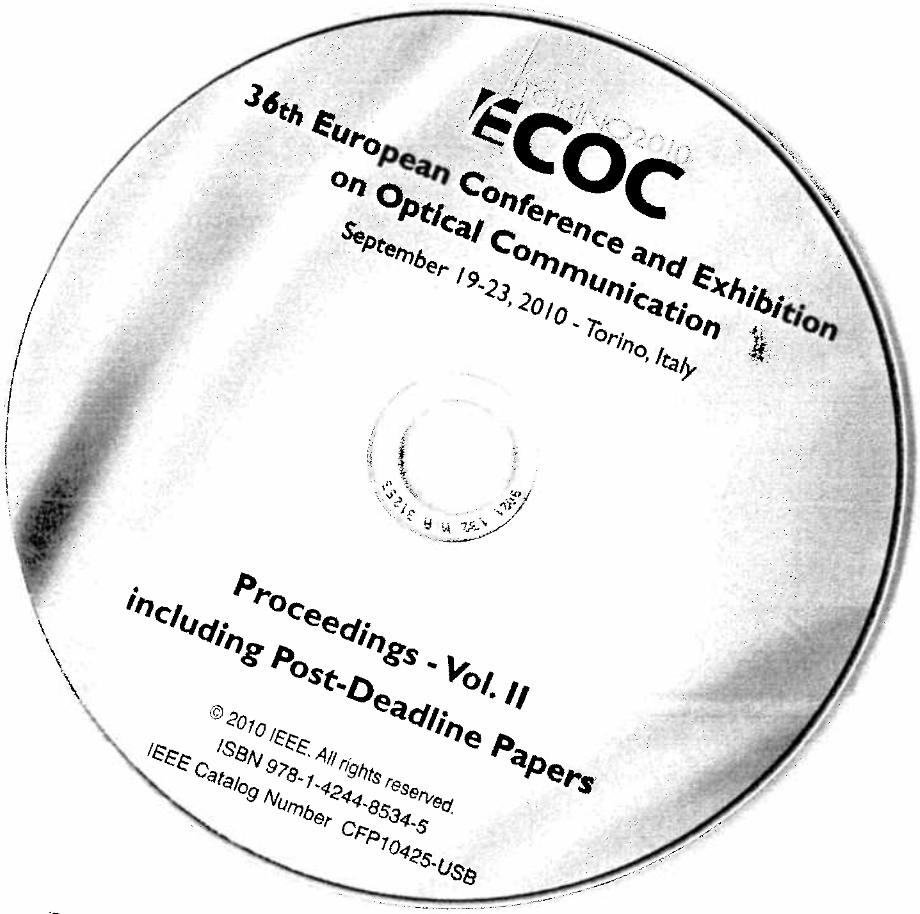
[3] J.M. Brosi, C. Koos, L.C. Andreani, M. Waldow, J. Leuthold, W. Freude, Optics Express, Vol. 16, No. 6, pp. 4177-4191, 2008

[4] M. R. Watts, D. C. Trotter, R. W. Young, A. L. Lentine, proceedings of 5^{th} International Conference on Group IV Photonics, WA2, 2008

[5] M.N. Sysak, J.O. Anthes, J.E. Bowers, O. Raday, R. Jones, Optics Express, Vol. 16, No. 17, pp. 12478-12486, 2008

[6] S. Assefa, F. Xia, Y. A. Vlasov, Nature, Vol 464, pp.80-85, 4 March 2010

[7] D. Van Thourhout, T. Spuesens L. Liu, G. Roelkens, R. Kumar, G. Morthier, P. Rojo-Romeo, F. Mandorlo, P. Régreny, O. Raz, L. Grenouillet, To be published in Special issue of the IEEE journal on Selected Topics in Quantum Electronics 2010



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