Highly Efficient and Novel Lumped Michelson Modulator using Vertical PN junction based Phase Shifter

[1]M.A. Hamdani, [1]G. Qazi, [1]S.K.Naik, [2]R.G.J. Sugesh, [3]M.A Magray
[1]Department of ECE, National Institute of Technology, Srinagar, J&K, India
[2]Department of ECE, Vellore Institute of Technology, Chennai, India
[3]Department of Physics, Central University of Kashmir, Ganderbal, J&K India.
mursal_03phd18@nitsri.net, gausia.qazi@nitsri.net, suhailkhursheed@nitsri.net, jesuwanthsugesh.rg2016@vitstudent.ac.in, Mushtaq_02phd16@nitsri.net

***Abstract*- Vertical PN depletion phase shifter based novel Common Mirror Michelson Modulator is proposed. It has a lower $V_\pi L_\pi$, higher ER for a particular value of source impedance at a given bitrate and doping than conventional PN phase shifter based modulator.**

I. Introduction

Silicon photonic transceivers with integrated optical modulators offer high integration density at high speed and low cost [1]. Resonance modulators offer compact footprint while interferometric modulators (IM) based on carrier depletion allow high speeds and broad optical bandwidths at the cost of increased device length [1]. Although, travelling wave electrode (TWE) drivers for IM allow baud rates exceeding 60G, optical and radio frequency (RF) mismatch along with RF loss increases at high frequency and device length values [2]. However, the baud rates of IM based on LiNb03 and InP are much higher at the cost of low integration density [2]. This trend makes silicon photonic IMs rely more on increasing density of integration rather than enhancement of baud rates. Recently, lumped element (LE) Mach Zehnder modulator (MZM) and Michelson Modulator (MM) design variants with and without light wave effects have been proposed [2]. The LE based MM designs are more efficient since the light moves through the phase shifters (PS) twice, halving the value of **VπLπ** compared to MZM. To date, very little work focusing on LE based silicon photonic MM designs has been reported [3].

In this work, we compare the performance of vertical (V-PN-PS) with nominal horizontal (H-PN-PS) within our novel Common Mirror Michelson Modulator (CMMM) [4].

II. H-PN- vs V-PN based Phase Shifter

The carrier depletion based H-PN and V-PN are shown in Fig 1 with n = 1e18 and p = 3.5e17. For V-PN, a larger overlap between the optical mode and the PN junction increases the value of Δneff for a given change in Vbias leading to a higher value of junction capacitance as shown in Fig 2 (a).The change of phase with respect to bias voltage is plotted as in Fig 2(b) and for a given V-bias value phase change in V-PN is almost double to that of H-PN. From the value of phase shift we evaluate the value of $V_\pi L_\pi$ (Fig 2(c) as

$$V_\pi L_\pi = \frac{\pi .\ L\ \text{V-bias}}{\Delta\varphi} \quad (1)$$

Where Δφ is phase change for a given V-bias.

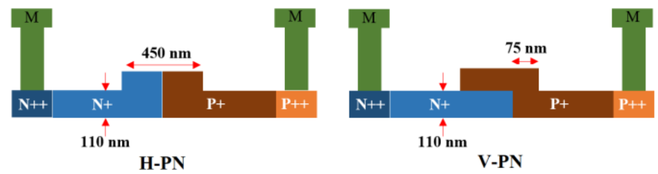

Fig 1. The schematic of H-PN and V-PN depletion diodes for phase shifters.

The PS is modelled as a RC low pass filter with a 3dB roll of frequency (Fig 2(d)) equal to.

$$F_{cutoff} = \frac{1}{2\pi\ (R_{PN})C_J(V)} \quad (2)$$

While the capacitance C_J is indicative of the effect of voltage on the depletion region, resistance R_{PN} is calculated for the entire P, N, P+, P++, N+, N++ region.

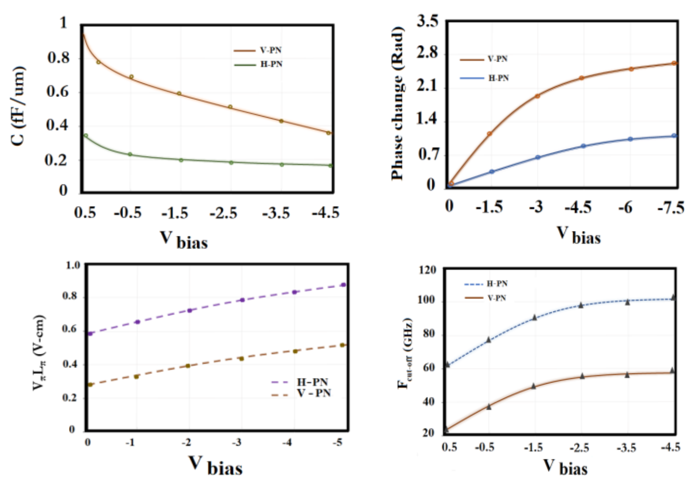

Fig 2. The variation of (a) Cj (b) Phase Change Δφ (c) $V_\pi L_\pi$ (d) F-cutoff with V-bias.

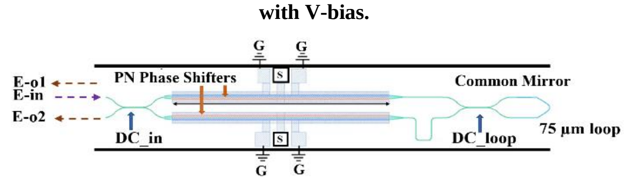

Fig 3. The schematic of proposed CMMM structure [4]

III. Novel Lumped CMMM Design

The novel CMMM structure proposed in [4] is redrawn in Fig 3. RLC circuit (Fig 4) is the lumped element model of the proposed modulator with Rb and Cj as the diode elements. The values of Csg (C - signal and ground) and L (inductance of the electrode) are independent of the doping profile of the diode based phase shifters and common mirror implementation. So we use the values extracted from experimental data on general MM design [8] such that Csg = 12.2 fF and L = 140.5 pH for reverse bias voltage of -4V.

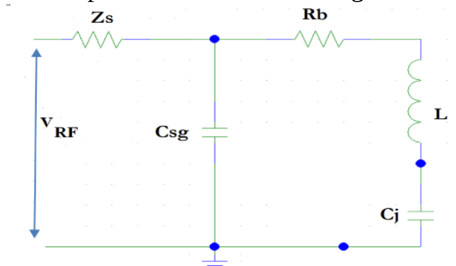

Fig 4. Small Signal model for lumped electrode based CMMM

Using the small signal AC model of Fig 4, we plot the frequency response of the modulator for the two PN variants as shown in Fig 5.

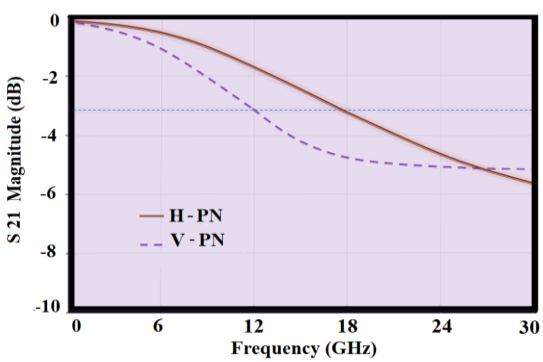

Fig 5. Electro-optic response of the lumped electrode based CMMM with HPN and VPN based diode shifters.

Next we examine the optical eye diagram at different bit rates with PRBS-31 signal pattern with 3V peak to peak without any pre-emphasis. For a source impedance of Zs = 50 Ω, clear eyes with extinction ratio (ER) upto 3.6 dB are observed for speeds upto 35 Gbps in H-PN based CMMM. The value of ER at the same bitrate of 35 Gbps increases to 4.73 if the source impedance is reduced as shown in Fig 6. For a selected source impedance of 25Ω, **V**-PN -CMMM shows a higher ER for a given bit rate even though it junction bandwidth gets lowered**.** This is due trade off of bandwidth with modulation depth. If the bit rate is increased to 50 Gbps, V-PN based CMMM shows an acceptable ER of 3.84 db (Fig 6).

IV CONCLUSION

The V-PN based CMMM shows a better $V_\pi L_\pi$ at reduced bandwidth. The ER of VPN based CMMM is higher for a given bitrate and source impedance.

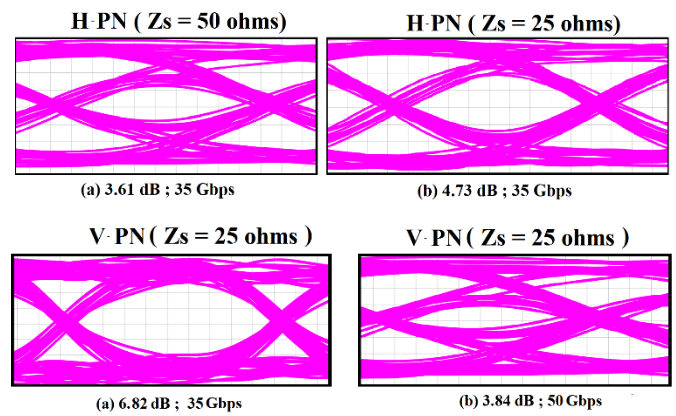

Fig 6. Optical Eye diagram for different source impedances in H-PN and VPN based CMMM.

TABLE I

Comparing the proposed ILSPN based CMMM with other interferometer based lumped silicon photonic modulators

Reference	Doping Concentration (cm^{-3})	Length (mm)	3dB Bandwidth (GHz) at (Zs=25 Ω) (V= -4V)	$V_\pi L_\pi$ (V-cm)	Extinction Ratio (dB)	Bitrate (Gbps)
[5] MZM	n = 1e18 p = 2e17	0.5	17.12	0.76	3.56	50 Gbps
[6] MZM	n = 7.9e17 p = 2.7e17	0.5	15.4	1.12	4.18	45 Gbps
[7] MZM	n = 2e18 p = 2e18	0.25	37.6	0.68	2.76	60 Gbps
[7] MZM	n = 1e18 p = 1e18	1	18.12	1.36	4.12	50 Gbps
[8] MM	n = 1e18 p = 3.5e17	0.5	13.33	0.64	3.72	45 Gbps
Proposed	n = 1e18 p = 3.5e17	0.5	12.31	0.32	3.84	50 Gbps

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