Silicon photonics for high data rate applications -INVITED

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Abstract. The high speed conversion of signals between the optical and electrical domains is crucial for many key applications of silicon photonics. Electro-optic modulators integrated with electronic drive amplifiers are typically used to convert an electrical signal to the optical domain. Design of these individual elements is important to achieve high performance, however a true optimisation requires careful co-design of the photonic and electronic components considering the properties of each other. Here we present our recent results in this area together with a MOSCAP type modulator with the potential for high speed, high efficiency and highly linear modulation.

1 Introduction

Many applications of silicon photonics require operation in the 10's of GHz range, from data communication to radio over fibre and LIDAR. High speed modulation in silicon has been demonstrated for over a decade now [1] and typically devices demonstrated are based upon the depletion of free carriers in a waveguide based, reversed biased PN diode. Integration of such devices with the required driving electronics usually causes a degradation of the operating speed due to the parasitics from the integration process and/or the driver performance itself. In order to produce an optical signal modulated at such high frequencies and operating at low power both the design and implementation of both the modulator and drive electronics therefore require careful design. Here we present our work on the co-design and integration of a silicon photonics modulator and CMOS electronic driver using both wire bonding and flip-chip bonding approaches.

The above mentioned carrier depletion based devices typically have low modulation efficiencies owing to the limited depletion widths and tolerable doping levels. Devices require interaction lengths on the order of milimetres in order to keep to CMOS compatible driving voltages. For high speed operation on such device lengths travelling wave electrodes are required with impedance matched terminations that result in large power consumption. Another issue with depletion based devices is the linearity of the phase shift versus voltage which can have implications when producing higher order modulation formats, in radio over fibre applications and LIDAR. MOSCAP modulators which are based upon the accumulation of high densities of electrons and holes around a thin dielectric layer in the waveguide have a far superior linearity together with the potential for an order of magnitude improvement in efficiency. In this case devices lengths are in the 100's of micrometre range and can be driven as a lumped element, which typically requires a lower drive power. Here we also present our recent work on this type of modulator.

2 MOSCAP modulator

A deterring factor to the use of the MOSCAP modulator is difficulty of the fabrication as compared to the carrier depletion approach. The main challenge lies in the realisation of the thin dielectric layer in the waveguide and keeping the optical and electrical properties of the silicon either side of it sufficiently good so as to maintain a high device performance. In typical devices from the literature the dielectric layer is positioned on top of high quality single crystal silicon with polycrystalline silicon deposited on top of that. The properties of the polycrystalline silicon are however inferior optically and electrically to single crystal silicon and therefore impact the device performance.

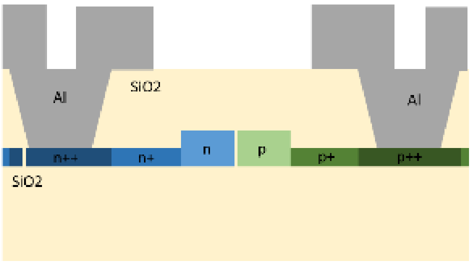

Fig. 1. Cross-section of the MOSCAP modulator

In our work the dielectric layer runs vertically in the waveguide (as shown in figure 1) and a regrowth process

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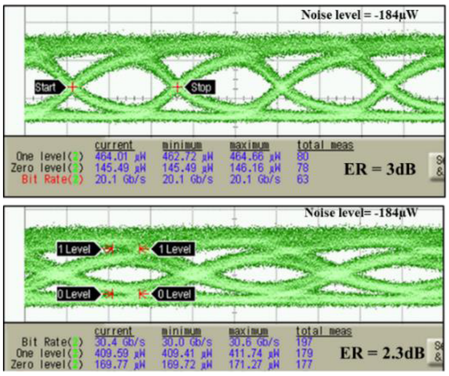
is used to transform deposited amorphous silicon into single crystal silicon. The resulting device therefore has high quality silicon on both sides of the dielectric layer. Results from a proof of concept batch of devices have demonstrated efficiencies on the order of 1.8V.cm with modulation in the 10's of Gbit/s (figure 2).



	current	minimum	maximum	total meas
One level(2)	464.01 µW	462.72 µW	464.66 µW	80
Zero level(2)	145.49 µW	145.49 µW	146.16 µW	78
Bit Rate(2)	20.1 Gb/s	20.1 Gb/s	20.1 Gb/s	63

	current	minimum	maximum	total meas
Bit Rate(2)	30.4 Gb/s	30.0 Gb/s	30.6 Gb/s	197
One level(2)	409.59 µW	409.41 µW	411.74 µW	179
Zero level(2)	169.77 µW	169.72 µW	171.27 µW	177

Fig. 2. Optical eye diagrams from the MOSCAP modulator

3 U-shape modulator and CMOS driver

Recently with have performed work on the close integration of the design of both silicon optical modulators and CMOS drive electronics to produce high performance, power efficient modulation units. One implementation of this work uses a carrier depletion based optical modulator designed in a U-shape Mach Zehnder modulator (MZM) configuration to allow access to both input and termination pads of the MZM on one side of the chip (figure 3). Both CMOS driver and MZM were designed with common-centre topology, making either wire-bonding or flip-chip bonding solutions possible. By terminating the modulator electrodes on the CMOS chip dynamic control of the termination impedance can be performed allowing fine tuning of the performance.

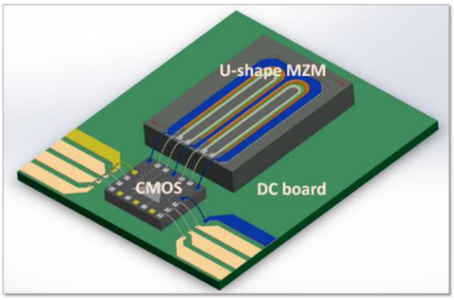


Fig. 3. Schematic of CMOS driver – U shape modulator integration with wire bonds.

In the design process the properties of the modulator and parasitics of the integration approach are incorporated into the CMOS driver design. The design of either individual component can be altered and the overall unit performance analysed in order to perform a full optimisation. Wire bond and flip-chip bond integration approaches have been followed and the results compared (figure 4) [2].

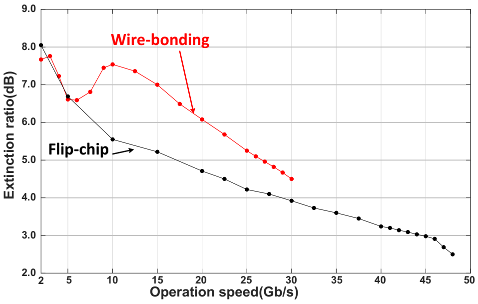


Fig. 4. Eye extinction ratio versus data rate for wire bond and flip chip bond integration approaches.

Figure 4 shows the achievable eye extinction ratio at different data rates with the two integration techniques. At lower frequencies the wire bonding approach yields a better performance in terms of extinction ratio. This is due to inductive peaking from the parasitics of the bond wires in the 10-12Gbit/s range. As the modulation rate is increased the extinction ratio of the flip-chip bonded approach roles off at a slower rate allowing modulation to 40Gbit/s. With wire bonding the eye is closed at around 25Gbit/s.

Summary

An efficient, linear optical modulator based upon the accumulation of free carriers around a thin, vertical dielectric layer in a silicon waveguide has been presented together with a modulation efficiency around 1.8V.cm and operating speed in the 10's of Gbit/s. Work around the co-design of CMOS electronic driver and silicon optical modulator has compared integration through wire bonding and flip-chip bonding. Wire bonding gives a better performance at lower data rates due to a peaking effect from the bond wires, however at data rates of 25Gbit/s and beyond the eye is closed Whereas for flip-chip integration modulation at 40Gbit/s is possible.

Acknowledgements

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