Influence of termination load placement on electro-absorption modulator performance

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In this work we investigate a module of an electro-absorption modulator (EAM) and ways to improve the electrical response in order to increase its bandwidth. The module consists of an InP-based EAM, an alumina tile with RF-lines and a PCB for the DC connections. Starting from the empirical model of the modulator, we utilize the combination of the termination load placement and design of the transmission line on the alumina in order to improve the bandwidth. The EAM is designed on an InP platform on n-substrate for further use in monolithic integrated photonic circuits for transmitters in optical telecommunications.

Introduction

The invention of the optical fiber played a major role in boosting the advancements in the field of optical communications. Furthermore, wavelength division multiplexing (WDM) scheme allowed scaling up the bandwidth of a single channel by sending more information imprinted onto a different wavelength through the same channel. Transmitter devices have advanced even more with the introduction of photonic integrated circuits (PICs) [1] [2]. Nowadays, 100G WDM integrated products are available [3] [4] [5]. The next challenge is making the transmitters more compact and energy efficient. Therefore each component on the chip has an important part.

The criteria each device on the chip needs to meet are small footprint and low drive voltage needed for their bias [6]. The modulator structure in transmitter circuits plays a key role as its bandwidth determines the capacity of the transmitter itself. An electro-absorption modulator (EAM) provides both small footprint and low bias-voltage, thus ensuring high bandwidth [7] [8]. Therefore, its potential for low energy consumption is the main motivation for their use in transmitter PICs.

By integration of photonic components, the circuit performance depends on more than the single component performance. New opportunities come with co-design of the electronics. The optimization of the electrical connectivity of the chip can be done in different ways. Various types of techniques are used when it comes to connecting the electronic driving circuitry with the photonic integrated chip [9]. The driver circuit, transmission lines for high frequency signal with negligible loss, termination load and decoupling capacitance are parts of the system needed for efficient modulator performance. Depending on where these parts are in the system, the frequency response will change. Therefore careful examination of these cases is important as a co-design.

In this work we will focus on wire-bonding technique for obtaining 25GHz bandwidth of the EAM module. The wire-bonding approach gives the flexibility of placing the driver circuit and the termination load in different locations in the system without having a design or fabrication restriction.

Electro-absorption modulator representation

In our case the electro-absorption modulator is defined as a ridge structure with a multi-quantum well (MQW) active region (Figure 1). When driven with a reverse bias voltage the MQW region exerts a quantum-confined Stark effect. A simple electrical representation of the EAM takes into account the MQW region which acts as a capacitor (C_m), while the p-InP cladding acts as a resistor (R_s). In the presence of an input light signal, a photocurrent is generated in the active region, represented with a variable resistor R_0 as it changes with the power of the incoming signal. In this work we ignore the photocurrent, therefore the series resistance and the modulator's capacitance are the two most important parameters to describe an EAM. Connecting the modulator in a fully operational circuit, a metallization pad is added to it and then wire-bonded to the electrical driving circuit. The pad lies on an insulating polymer layer and therefore acts as a capacitor (C_0).

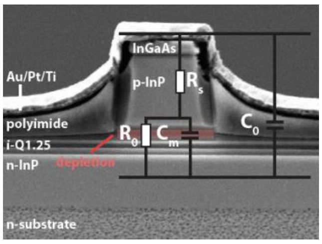

Figure 1: SEM picture of the modulator cross-section and its equivalent electrical circuit *[10]*.

Equivalent electrical circuit

In order to drive the transmitter circuit, a direct current (DC) drive source is needed for biasing the laser and a RF-source for driving the modulator structure. A scheme is shown in Figure 2 where the RF-drive is placed on the alumina (Al_2O_3) in order to support high frequencies with insignificant microwave loss. The connection between the alumina RF circuit and the modulator on the PIC is done with wire-bonds. This representation is taken into account when wire-bonding the EAM to the alumina.

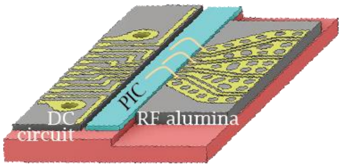

Figure 2: Transmitter module scheme from III-V Lab.

The key performance metrics for EAM operation are captured in S-parameters (electrical transmission and reflection). The transmission parameter (S_{21}) gives us information about the bandwidth of the device, whereas the reflection parameter (S_{11}) gives an indication how high the reflection in our system is. The transmission parameter alone is not sufficient, because a high reflection in the system will limit the performance and degrade the eye-diagram. In order to obtain a high bandwidth and operate at high frequencies, both parameters need to be optimized simultaneously.

The starting point is the extraction of the parameters at III-V Lab of the simplified EAM model, which we then use to optimize the rest of the circuit. The series resistance of our modulator is 17Ω and its capacitance 107pF. As the drivers used in the system are 50Ω, there is an impedance mismatch between the electronic and the photonic circuit. For this reason, the termination load equal to 50Ω is inserted, to increase the characteristic impedance seen from the driver input.

We investigate two variants, the first one where the driver and the load are placed on the same alumina and then wire-bonded to the PIC; and the second one where the driver signal is brought to the PIC by wire-bond and then another wire-bond is introduced after the PIC to the termination load on another alumina tile. The electrical scheme of the two cases is presented in Figure 2. The wire placement is controlled with a good precision and the inductance value of the wire is 0.15nH. In the second case, we also investigated another option with a transmission line on the second alumina tile to further improve the electrical response of the whole system.

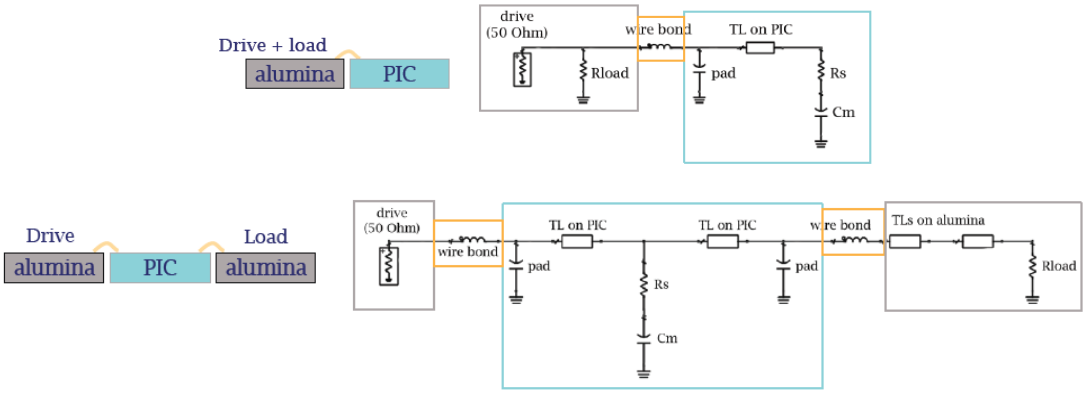

Figure 2: (top) First variant – driver signal and the termination load on the same alumina and wire-bonded to the EAM. (bottom) Second variant – driver signal fed through a wire-bond into the EAM and another wire-bond introduced leading to the termination load. Final case introduces a transmission line on the latter alumina for further improvement of the electrical response.

Simulation results

The ADS simulation tool is used to predict the response of our module. The starting point is the circuit shown in Figure 3 – top: placing the driver and the termination load on the same alumina. For this case we obtain a fairly high transmission, with a 3dB bandwidth of 35GHz, see Figure 4 (blue curve). The presence of a small resonance peak around 20GHz influences the reflection and makes it go above -10dB for frequencies above 10GHz. Ideally, the reflection parameter should stay below –15dB in the whole frequency range of interest – in our case up to 25GHz. The second case when the driver and the termination load are placed on separate alumina (Figure 2 – bottom) shows improvement in both of the S-parameters, Figure 4 (red dashed curve), however still limited in reflection for 25GHz desired bandwidth. Therefore, a third case is introduced with a transmission line on the alumina after the EAM and before the termination load. In this case, the 3dB bandwidth is higher than 40GHz and we obtain a flat reflection response up to 25GHz. The ripples present in the transmission parameter have an amplitude of around 0.5dB, which should not deteriorate the performance.

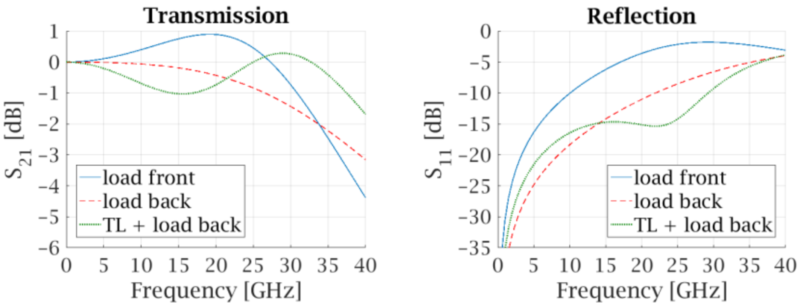

Figure 3: Simulated transmission (left) and reflection (right) parameters of the proposed EAM module.

Conclusion

We have simulated the electro-absorption modulator on InP platform placed in a module having a 25GHz bandwidth. The connection between the electronic and the photonic circuit is by wire-bonds, represented as inductive element in the circuit. The EAM is made on n-substrate, where the pad lies on polymer acting as a capacitor, and has to be large enough for connecting the modulator. Three different cases have been investigated, observing the influence of the termination load placement in the system. The best result in our case has been obtained when placing the load after the EAM structure, thus increasing the characteristic impedance of the system seen from the driver input. Compared to the case when the load is placed in front of the modulator structure, we expect to achieve an improvement in operating bandwidth of 15GHz by placing the load after the modulator, thus attaining the desired module bandwidth of 25GHz.

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References

[1] M. Smit et al, "An introduction to InP-based generic integration technology," *Journal Semiconductor Science and Technology,* no. 8, pp. 1-41, 2014.

[2] R. Nagarajan, M. Kato, J. Pleumeekers, P. Evans, S. Corzine, S. Hurtt, A. Dentai, S. Murthy, M. Missey, R. Muthiah, R. A. Salvatore, C. Joyner, R. Schneider, M. Ziari, F. Kish and D. Welch, "InP Photonic Integrated Circuits," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 16, no. 5, pp. 1113-1125, 2010.

[3] Intel. [Online]. Available: https://www.intel.com/.

[4] Luxtera. [Online]. Available: http://www.luxtera.com/.

[5] Oclaro. [Online]. Available: http://www.oclaro.com/100g-solutions/.

[6] D. A. B. Miller, "Energy consumption in optical modulators for interconnects," *Optics Express,* vol. 20, no. S2, pp. A293-A308, 2012.

[7] T. Y. a. M. T. H. Fukano, "Design and Fabrication of Low-Driving-Voltage Electroabsorption Modulators Operating at 40 Gb/s," *Journal of Lightwave Technology,* vol. 25, no. 8, pp. 1961 - 1969, 2007.

[8] W. K. e. al, "Wide Temperature Range Operation of a 1.55-μm 40-Gb/s Electroabsorption Modulator Integrated DFB Laser for Very Short-Reach Applications," *IEEE Photonics Technology Letters,* vol. 21, no. 18, pp. 1317 - 1319, 2009.

[9] W. Reinert, T. Harder, "Performace of the Stud Bump Bonding (SBB) Process in Comparison to Solder Flip Chip Technology," in *4th International Conference on Adhesive Joining and Coating Technology in Electronics Manufacturing*, 2000.

[10] W. Yao, *Towards a high-capacity multi-channel transmitter in generic photonic integration technology,* Eindhoven: Technische Universiteit Eindhoven, 2017.