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High speed electroabsorption modulator in the generic photonic integration platform

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We are developing multi-channel transmitter circuits with electro-absorption modulators (EAMs) in the COBRA generic integration platform. In order to connect the EAMs to the off-chip RF-drivers, we need to route high-frequency signals on-chip. In this work we present the current status and development of such transmission lines for the COBRA platform. We examine a number of different cross sections to minimize the microwave loss and match the characteristic impedance of the lines and the modulator, while retaining compatibility with the existing fabrication process. The structure of the probing pads, needed for wire bonding, is taken into account as well.

Introduction

Photonic integrated circuits (PICs) play an indispensable role in the advancement of high speed communication devices, offering high capacity links on a small footprint. These densely packed circuits allow for many different components to be placed on a single chip, exploiting various functionalities of the designed structures. Low power consumption is certainly one of the main advantages, but also one of the main issues to be taken care of, as the high density of components causes dissipation of more power per unit area.

In order to make the most out of the integration process a small set of basic components such as passive waveguides, phase modulators and semiconductor optical amplifiers has been developed in a generic integration technology [1]. Integrated transmitters and receivers take a central part in an optical telecommunication link, where a constant demand for higher capacity comes into play, and PICs are shown to be a good solution.

The highest number of channels and data rate per channel in a wavelength division multiplexing (WDM) transmitter on a single chip so far reported is 40-channels, each capable of operating at 57 Gbit/s [2]. Direct modulation of the laser introduces chirp, which impairs a long distance transmission. Therefore the external modulation using electro-refraction (ER) or electro-absorption modulation (EAM) is used. Since the number of channels on a single chip is high, the optical, electrical and thermal crosstalk of the components are the main difficulties in realizing such a circuit.

The component which greatly determines the bandwidth of the system is the modulator. Electro-absorption modulators are a convenient choice for use in compact PICs, because of their small footprint and low bias voltage. The aim of our research is to integrate the EAM as another building block inside the COBRA generic process, allowing not only for realization of high speed WDM transmitters, but also other devices.

Electro-absorption modulator

The mechanism employed in a multiple quantum well (MQW) EAM is the intensity modulation of the optical carrier, by utilizing the quantum-confined Stark effect. In this work, the laser active region is used for the EAM cross section, shown in Figure 1. The modulator consists of a multimode waveguide, containing MQWs. At the input, the modulator is coupled either to a single mode fibre pigtailed to a laser or to an integrated laser, thus exciting only the fundamental mode. In order to achieve high confinement of the propagating mode, the trenches are etched to a depth below the QWs. This will contribute to a high extinction ratio, which is dependent on the confinement factor Γ of the optical field within the absorption region, the band-edge, the absorption coefficient α and the length L of the modulator section. Modifying these parameters is the key for optimizing the optical performance of the EAM.

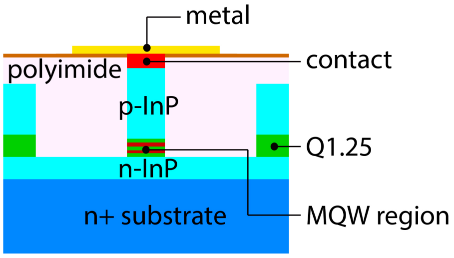


Figure 1: A cross section of an EAM.

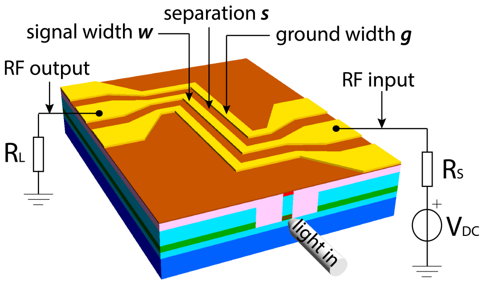


Figure 2: Illustrated view of an EA modulator.

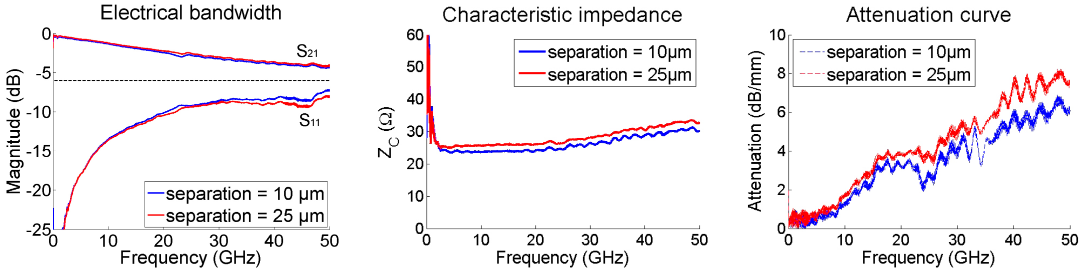
Applying an electric field onto the modulator tunes the band-edge, causing a red shift of the absorption curve by approximately 5 nm/V in InP and changing the intensity of the transmitted laser radiation. We operate the laser at a longer wavelength, typically 30-60 nm detuned from the exciton peak of the modulator, making the EAM almost transparent for the incoming laser radiation when no field is applied, and absorbing when applying an external field.

When it comes to optimizing the electrical performance of the EAM, the design of the metal pad on top of the structure is vital. In reaching high speeds of the EA modulator we need to take care of the bandwidth limiting factors, such as microwave attenuation and impedance mismatch. Velocity mismatch in this case is not a critical parameter if the metal pad is as short as the EAM, which is usually small compared to the radio-frequency (RF) wavelength. Here we will focus on optimizing the cross section of the structure in order to lower the attenuation and the impedance mismatch of the RF line.

Experimental characterization

A starting point for this work relies on previous measurements of transmission lines (TL) for the ER modulators in the COBRA process [3]. The cross section of the characterized structure is similar to the one shown in Figure 1, where the ERM is 200 µm long, and has a bulk quaternary core instead of MQWs. To avoid the impedance mismatch at the input and at the output we use GSG (ground-signal-ground) probes, which serve as a 50 Ω matching resistance (R_S and R_L in Figure 2). Metal pads for driving the modulator have a microstrip transmission line structure. By optimizing the signal width w, the ground width g and their separation s (Figure 2), we can obtain the high bandwidth of the modulator.

The measured electrical 6 dB bandwidth of the ERM presented in Figure 3(a), serves as an indication of the optical 3 dB bandwidth. We can observe that the measured bandwidth is higher than 50 GHz, where S_{21} stays above the electrical limit in the whole measured frequency range, while S_{11} is below -7 dB. Among the different signal and ground widths tested, the best results are obtained for $w = 10\,\mu\text{m}$ and $g = 12.5\,\mu\text{m}$ [3]. Varying the separation between the signal and the ground line, we present two of the best achieved results in Figures 3(a), (b) and (c).



(a) (b) (c)

Figure 3: (a) S-parameters for a $200\,\mu\text{m}$ *long ERM. The width of the signal line* $w = 10\,\mu\text{m}$*, ground line* $g = 12.5\,\mu\text{m}$ *and the separation between them is varied. Extracted characteristic impedance (b) and the attenuation (c) of the ERM.*

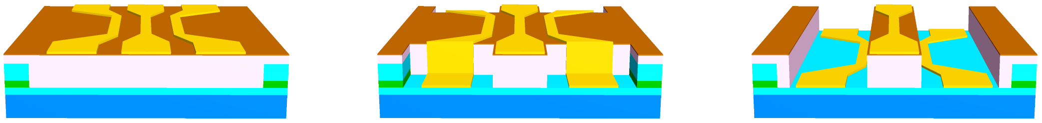
The measured characteristic impedance Z_C of the structure is shown in Figure 3(b) and stays in the range $24 - 34\ \Omega$ in the measured frequency range. As we use $50\ \Omega$ input and output probes, in order to avoid the impedance mismatch the structure should be optimized to have a higher Z_C, presented in the next section. The attenuation of the voltage is extracted from the measured S-parameters and shown in Figure 3(c). As we can see from this figure, for a presented $200\,\mu\text{m}$ long ER modulator at a highest measured frequency, the attenuation is equal to 1.6 dB. Due of the short length of the section the attenuation is not high. However, when designing a long transmission line which would connect the modulator on chip with the off-chip RF-drivers, the attenuation plays an important role in realizing a high bandwidth, and needs to be minimized.

Transmission line design

We investigate different transmission line designs and different cross sections for EA modulator, illustrated in Figure 4, in order to achieve a high speed transmission. We started the optimization of the RF field propagation by replacing a highly doped p-InP with polyimide (Figure 4(a)) to reduce the attenuation of the propagating field. Another advantage is that the characteristic impedance Z_C is inversely proportional to the dielectric permittivity ε, thus the lower ε of polyimide will increase Z_C, and consequently minimize the impedance mismatch.

On-chip probing requires a large area of signal and ground pads, which results in their increased capacitance. As before, removing the lossy layers down to n-InP under the ground pads will lower their capacitance (Figure 4(b)). The structure depicted in Figure 4(c) is expected to have the best behaviour as all the lossy layers have been removed and the capacitance of the pads is minimized. In this case however, the available metal is not optimized for contacting the n-InP, which may impact the performance.

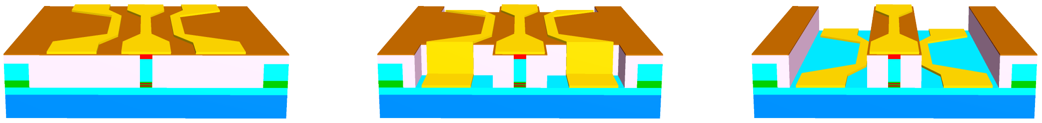
The EAM cross section is illustrated in Figures 4(d)-(f). Lower capacitance of the pads by placing them on the n-InP and the removal of the highly lossy p-InP should



(a) *TL on polyimide*

(b) *TL on polyimide, pads on n-InP*

(c) *TL: S-line on polyimide, G-line on n-InP*



(d) *Modulator on polyimide*

(e) *Modulator on polyimide, pads on n-InP*

(f) *S-line on top of the modulator, G-line on n-InP*

Figure 4: Various cross sections of transmission lines and modulators for reaching high bandwidth.

contribute to a higher bandwidth of the device. A design with the proposed variations has been included in a generic foundry run and will be validated once the fabrication cycle is finished.

The motivation to have a fully operational WDM transmitter ready for submounting and wire-bonding, imposes many different requirements such as optimization of electrical crosstalk between the channels. A combination of the presented cross sections will be used to test the crosstalk behaviour between the modulators, where the transmission line goes from one side of the chip to the other, allowing for efficient wire bonding and later packaging of the whole transmitter circuit. Low electrical crosstalk between the ER modulators has been demonstrated in the COBRA process [4]. For separation larger than 80 μm the crosstalk value stays below -20 dB up to high frequencies. Therefore, in the test structure two EA modulators are 100 μm spaced to avoid high crosstalk effect and allow for densely spaced EAMs.

Conclusion

We have presented our work on different designs of transmission lines and predictions for high-bandwith electro-absorption modulators in the COBRA generic integration platform. To minimize the microwave attenuation and the impedance mismatch of the electrical wave in the TL, various cross sections are taken into account. The measured electrical 6 dB bandwidth of the EO modulator larger than 50 GHz, serves as an indication for the bandwidth of the EA modulator. Future measurements of the presented structures will be performed, in order to verify this work.

References

[1] M. Smit *et al.*, ”An introduction to InP-based generic integration technology”, *Journal Semicond. Sci. Technology*, vol. 29, no. 8, pp. 1-41, 2014.

[2] J. Summers *et al.*, ”40 Channels x 57 Gb/s Monolithically Integrated InP-Based Coherent Photonic Transmitter”, in *Proceedings of European Conference on Optical Communication*, Cannes, France, 2014.

[3] W. Yao, G. Gilardi, M. K. Smit and M. J. Wale, ”Microwave Modeling and Analysis of an InP based Phase Shifter from a Generic Foundry Process”, *Proceedings of the 18th Annual Symposium of the IEEE Photonics Society Benelux Chapter*, pp. 151-154, 2013.

[4] W. Yao, G. Gilardi, N. Calabretta, M. K. Smit and M. J. Wale, ”Experimental and numerical study of electrical crosstalk in photonic integrated circuits”, *Journal of Lightwave Technology*, vol. 33, no. 4, pp. 934-942, 2015.