Arrays of surface-normal electroabsorption modulators for the generation and signal processing of microwave photonics signals

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Abstract—**The development of an array of 16 surface-normal electroabsorption modulators operating at 1550nm is presented. The modulator array is dedicated to the generation and processing of microwave photonics signals, targeting a modulation bandwidth in excess of 5GHz. The hybrid integration of the modulator arrays on carrier chips is described. Optical and microwave characterisation and modelling of the modulator array are presented.**

Keywords— electroabsorption modulator, microwave photonics, optical signal processing, phased-array antenna

I. INTRODUCTION

The demanding requirements of future radar and communication systems in terms of high-speed signal processing have fuelled the recent development of novel microwave photonics architectures and components. Amongst them, optoelectronic modulators are key devices that enable the transfer of microwave information onto an optical carrier. Surface-normal electroabsorption modulators offer several advantages compared to traditional waveguide-based modulators, including

1) Large active apertures, which enable easy coupling to optical waveguides as well as to free-space optical systems.

2) Large integration capabilities: large 1-D and 2-D arrays of modulators can be packed into very small volumes and integrated with their drive electronics.

3) Polarization insensitivity: under normal-incidence conditions, the response of electroabsorption modulators is independent of the polarization state of the incoming light.

The use of surface-normal electroabsorption modulators have been reported by several groups for optical signal processing [1, 2] and optical communication applications [3, 4]. Owing to their good modulation properties in the microwave domain [5], surface-normal electroabsorption modulators provide interesting features for microwave photonics application related to the generation or the processing of parallel signals.

In this paper, the development of a 16-modulator array to be integrated in a photonic beamformer for a K_u-band phased array antenna (see [6] for a general presentation of the architecture) is presented.

II. PRINCIPLE

A limitation of surface-normal modulators compared to waveguide-type modulators is the short interaction length between the incident light and the active medium, thus reducing the contrast ratio. Several approaches to increase modulation depth have been reported, including increasing the number of grown quantum wells (to an upper limit of a few hundreds of quantum wells set by the epitaxy technology), using optical cavities (at the expense of the optical bandwidth of the modulator), or employing advanced quantum well designs.

Our modulator design is based on InGaAs/InAlAs coupled quantum wells placed in a p-i-n structure [7]. When a bias voltage is applied across the modulator, the wavefunctions of the electrons and holes that are confined in the quantum wells are modified, which leads to a change in the absorption properties. Enhanced modulation is obtained by using a double-path structure for photon recycling: a mirror is deposit on one side of the modulator, and an anti-reflection coating on the other side.

III. PERFORMANCES OF SINGLE MODULATOR DEVICES

Single-modulator devices of different aperture sizes have been fabricated by conventional microelectronics process techniques. Constrast ratio spectra with different applied voltages are presented in Fig. 1, showing an optical bandwidth in excess of 20nm and contrast ratios up to 1.8:1 for modulators operated in transmission (single-path).

The high-frequency properties of the modulators have also been characterized, showing a 3-dB frequency bandwidth in excess of 5GHz, and excellent linear behavior. A small-circuit model has been developed to simulate the high-frequency performances of the modulator. Predictions from the model were compared to experimental results obtained from a two-probe measurement technique, a show excellent agreement.

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The model accounts for impedances from probes, transmission lines and contacts, and shows that constant drive voltage over a wide frequency range can be achieved for small-aperture devices (in excess of 20 GHz for devices with apertures smaller than 50µm).

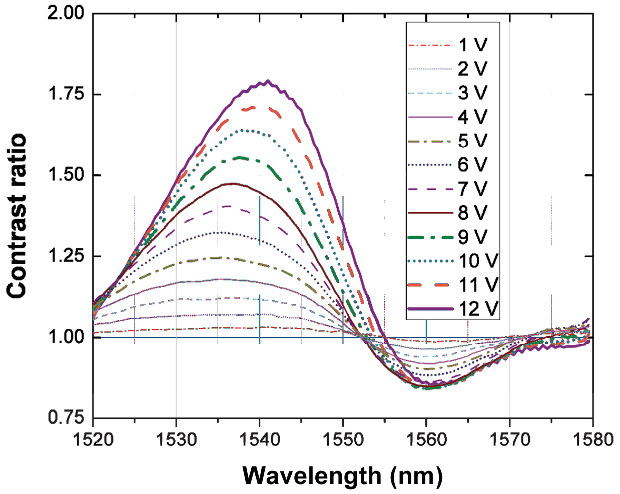

Figure 1. Constrast ratio as a function of wavelength, for different bias voltages

IV. Modulator Arrays

The generic design of a modulator array is presented in Fig. 2. The InP-based optical modulator chip is flip-chip bonding onto a carrier chip with microwave interconnects. The fabrication of such an array can be divided into three main phases:

- fabrication of optical modulator chips (wafer-level), including mesa formation, top p-contact, passivation and bottom n-contact
- fabrication of carrier chips (wafer-level)
- assembly by flip-chip bonding, substrate removal and anti-reflection coating (chip-level)

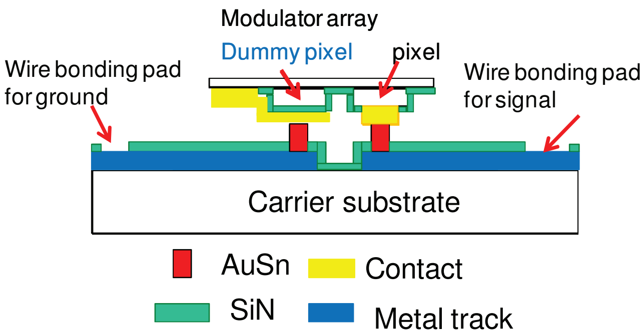

Figure 2. Sketch of the hybridized modulator array

The distance between two adjacent modulators was set to 127 µm, and their shape is circular. Different sizes of the modulator aperture, from 10µm to 50µm, were chosen in order to optimise the trade-off between speed and alignment tolerance.

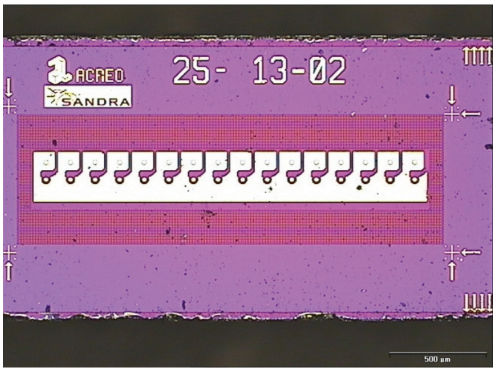

Figure 3. Photograph of a 16-modulator array

The fabrication of the modulator arrays has been successfully achieved (see Fig. 3), and their characterisation is currently being completed. Characterisation results will be presented at the conference.

V. Conclusion

The progress in the development of an array of 16 surface-normal electroabsorption hybridized to a carrier chip has been presented. The array is targeting a modulation frequency bandwidth of 5GHz. Optical and microwave modeling and characterization of the array are being developed and will be presented at the conference.

References

[1] B. Noharet and S. Junique, “Multiple quantum well spatial light modulators for correlation-based processors”, Optoelectronic Information Processing: Optics for Information Systems, Critical Reviews Vol. CR81, SPIE Press, pp. 314-334, 2001

[2] U. Arad, E. Redmard, M. Shamay, A. Averboukh, S. Levit, and Uzi Efron, "Development of a Large High-performance 2-D Array of GaAs/AlGaAs Multiple Quantum-Well Modulators", IEEE Phot. Tech. Lett. Vol. 15, pp. 1531-1533, 2003

[3] G. C. Gilbreath, W. S Rabinovich, T. J. Meehan, M. J. Vilcheck, R. Mahon, R. Burris, M. Ferraro, I. Solkolsky, J. A.Vasquez, C. S. Bovais, K. Cochrell, K. C. Goins, R. Barbehenn, D. S. Katzer, K. Ikossi-Anastasiou, and M. J. Montes, ‘‘Large-aperture multiple quantum well modulating retroreflector for free-space optical data transfer on unmanned aerial vehicles’’, Optical Engineering, vol. 40, pp. 1348-1356, 2001

[4] L. Sjöqvist, Emil Hällstig, Johan Öhgren, Lars Allard, Daniel Ågren, Stephane Junique, Qin Wang, Bertrand Noharet, David Engström and Sverker Hård, "A novel free-space retrocommunication link", Conference on Advanced Free Space Optical Communications Techniques and Technologies, Proc. SPIE Vol. 5614, 2004

[5] C. C. Barron, C. J. Mahon, B. J. Thibeault, G. Wang, W. Jiang, L. A. Coldren, and J. E. Bowers, “Millimeter-wave asymmetric Fabry–Perot modulators,” IEEE J. Quantum Electron., vol. 31, pp. 1484–1493, Aug. 1995.

[6] D. Marpaung et al., “Towards a broadband and squint-free Ku-band phased array antenna system for airborne satellite communications”, Proc. of the 5th European Conference on Antennas and Propagation (EuCAP 2011), pp. 2774-2778, 11-15 April 2011

[7] Q. Wang et al., “1550nm transmissive/reflective surface-normal electroabsorption modulator arrays”, Electron. Lett., vol. 42, no. 1, 2006