Technological bricks development for the vertical integration of a Modulator onto a VCSEL for high-speed communications

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***Abstract*— The vertical integration of a Modulator onto a mesa-structure VCSEL would allows to go beyond the physical limit of the carrier dynamics for direct modulation. However, this double mesa structure monolithically integrated requires three electrodes and a high frequency injection design optimization. This paper relates the different technological improvements to achieve the static and high frequency operation of such a device.**

I. Introduction

Vertical Cavity Surface Emitting Laser (VCSEL) are nowadays widely used in many applications such as optical mice, proximity sensor, printers, and 3D sensing like facial recognition. The first significant volume increase of this component, in the 90's with the internet expansion, was the Datacom application and still remains a significant market which is of high interest for research groups and companies. Indeed, the target of 100 Gb/s would sustain the continuous increase of the data traffic. However, if we consider only the Non Return to Zero modulation format, this goal faces the carriers dynamics limitation. One of the possible approaches to overcome this issue is to split the emission and the modulation part either with a lateral modulator [1] or with a vertical modulator. This last one could be either based on electro-refractive [2] or electro-absorption [3] phenomenon. Relaxed specification on the epitaxial growth and the lower chirp during the modulation make the absorption phenomenon more attractive. In few words, this device is based on the Quantum Confined Stark Effect (QCSE) where an electric field applied in the cavity will shift the peak absorption wavelength of the Multiple Quantum Wells and thus absorb the light emitted by the VCSEL itself.

We will focus in this paper on the technological development realized to reach such a functioning.

II. Process development for such a structure

This EAM-VCSEL component requires, as seen in Figure 1, three electrodes, backside - intermediate contact for the current injection in the VCSEL and intermediate – top contact for the voltage in the EAM structure.

Considering the dimensions the lift-off or deposition plus etching of dielectric for sidewalls passivation and metal are quite challenging. Furthermore, to ensure high frequency injection and to decreases the electrical losses in the pads, microstrip line access have been preferred to coplanar [4].

The next sections will present the lift-off improvement to realize EAM and oxide-free VCSEL and also the BCB planarization on top of the device.

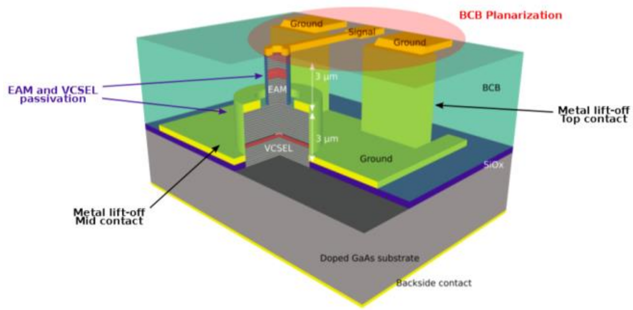

Figure 1: Technological locks for the vertical integration of an EAM onto a VCSEL

A. *Efficient self-aligned process for EAM and VCSEL*

Based on previous development about dielectric lift-off on flat surface thanks to a double resist stack, an efficient self-aligned process has been developed to ensure the realization, in one single photolithography step, of an EAM or an oxide-free VCSEL. Process step of such a process are described in Figure 2 and cross view can be seen in Figure 3, and in more details in [5] or in Appendix of [6]. A non-photosensitive resist (LOR) is used to be able to lift-off the resist even with dielectric deposition on the sidewalls of this one. Thanks to the reverse sidewalls of the LOR, it is also possible to lift off of the metal deposited further on.

The static characterization results obtained on our EAM stand-alone structures where based on this process. Furthermore, this double stack resist was used in the entire process fabrication of the EAM-VCSEL for all the SiO_2 sidewalls passivation, to avoid any wet or dry etch, and also for the metal deposition.

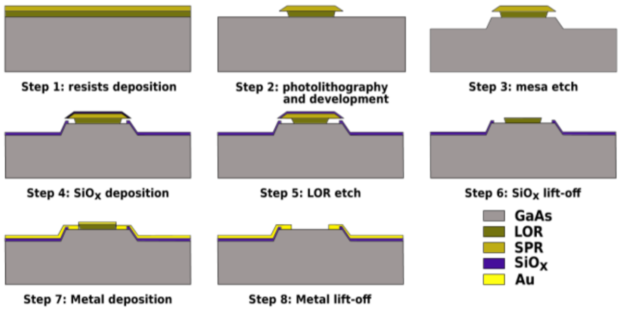

Figure 2: Self-aligned process step for EAM or oxide-free VCSEL fabrication

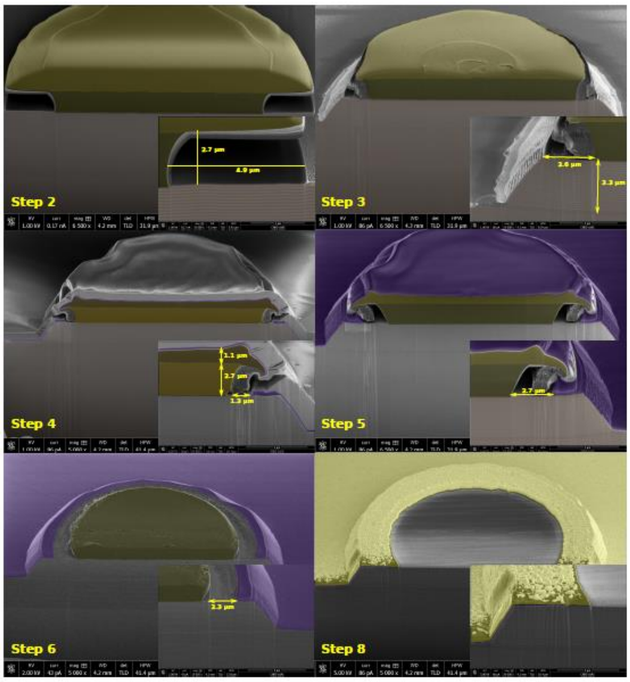

Figure 3: Focus Ion Beam Cross view of a VCSEL fabricated with one single photolithography step

B. BCB planarization

Several materials with low permittivity can be used for high frequency signal injection in a photonic device. Either a thick SiO_2 or Si_3N_4 layer, however it induces a high stress and is more complicated to structure, or more commonly with lower permittivity material, polyimides like BCB or PBO. One of the main advantages of these resists is their process deposition by spin-coating which allows a good planarization for many applications with a degree of planarization ~95%. In the case of the EAM, a perfect planarization (~100%) has to be done to avoid any leakage at the top edge of the mesa. To overcome this issue we developed a new planarization technic while using a nano-imprint tool as mechanical press which flatness the surface of the BCB before dry etching. More details about this process can be found in [6]. Final results of a VCSEL planarized with this technic is shown in **Figure 4** where we can notice that the BCB overlaps perfectly the top corners of the mesa to avoid any further metal deposition for top-contact.

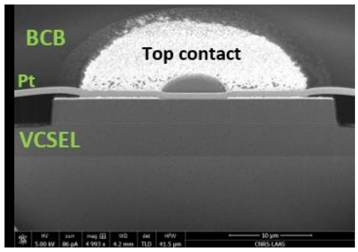

Figure 4: Cross view of a VCSEL planarized with BCB using nano-imprint tool as mechanical press

III. Conclusion

We described in this paper the two main technological developments needed for the realization of an Electro-Absorption Modulator vertically integrated on a VCSEL.

First, a self-aligned process with a double resist stack. Then, the BCB planarization with nano-imprint tool. Modulators were characterized in static with this first process, while the EAM-VCSEL benefited from both process developments and allowed the measurement of a -3dB bandwidth of 29 GHz. This value is the highest record for an EAM-VCSEL and is competing with direct modulation VCSEL state of the art. Considering that developments on the epitaxy stack layers are still possible, this device is an attractive solution for next Datacom chips.

Acknowledgment

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