

Monolithically integrated 850-nm VCSEL / Electro-Absorption Modulator structures grown by MBE

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Abstract — We present a work on the design and the fabrication by Molecular Beam Epitaxy of a monolithic vertically integrated VCSEL and Electro-Absorption modulator (EAM). This complex optical multilayer stack combines two optical cavities, between which the coupling strength requires to be precisely controlled. Indeed, the final performances of the EAM-VCSEL device, in terms of frequency modulation response, is closely correlated to this coupling, in addition to the wavelength detuning between each cavity resonances and respectively the VCSEL gain and EAM multi-quantum wells absorption spectra. Our work will give clear insights on the required accuracy for the epitaxy of such EAM-VCSEL structures and on the in-situ measurement methods to implement to reach the best performances.

Keywords—EAM-VCSEL; in-situ measurements;

The increasing optical data traffic demand is driven by more and more applications, and the datacenter bottleneck should be able to satisfy the demands of high bandwidth and energy effectiveness and saving. Until now the massive use of VCSEL sources have allowed to sustain the bandwidth requirements based on their good efficiency, a moderate production price and the integration capabilities to silicon photonics¹. Nevertheless, it can also be noted that the intrinsic limits for the modulation of the standard direct-modulated VCSEL scheme are being reached for -3dB modulation bandwidth of approximately 30GHz². More complex modulation formats have been introduced to go beyond this limit at the price of more complex systems. To improve the modulation bandwidth of VCSELs, several new approaches have been proposed such as transverse-coupled cavities³, Photonic crystal structures⁴, birefringence splitting⁵ or electro-optic⁶ and electro-absorption modulation⁷.

The latter approach consists in combining the continuous wave emission of a VCSEL and an EAM, making possible to modulate the VCSEL output light power at frequencies as high as 100 GHz by modulating the EAM voltage⁸. To maximize these modulation bandwidth capabilities, one may tune accurately the coupling strength between the VCSEL and the EAM (Figure 1), including the field effect on the absorption tail, thus implying a high degree of accuracy on the thicknesses and properties of the layers of the whole stack (Bragg mirrors, cavities, QW).

We will present a study on the design of the monolithic EAM-VCSEL structures for high frequency modulation, the *in-situ* measurement methods that we used in real time during the MBE growth (Figure 2), and the resulting optical properties of the device (Figure 3). Based on this study, we will be able to define the MBE growth constraints for fabricating optimized EAM-VCSEL structures. As shown on Figure 1 and 3, a deviation of -3nm on the EAM cavity thickness enables to switch the coupling strength from strong (red) to moderate (blue), hence improving the modulation response of the EAM-VCSEL for a given field-induced absorption contrast in the EAM⁸. The combined use of several *in-situ* real-time monitoring measurements (reflectometry, surface roughness and wafer curvature) appears then to be absolutely necessary to achieve the targeted performance for such EAM-VCSEL devices.

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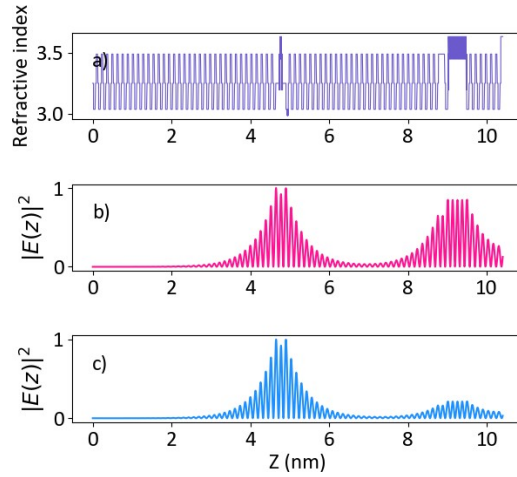


Figure 1: a) Refractive index profile of the EAM-VCSEL ; Optical power distribution in the case of b) strong coupling (red) and c) moderate coupling (blue) along the EAM-VCSEL

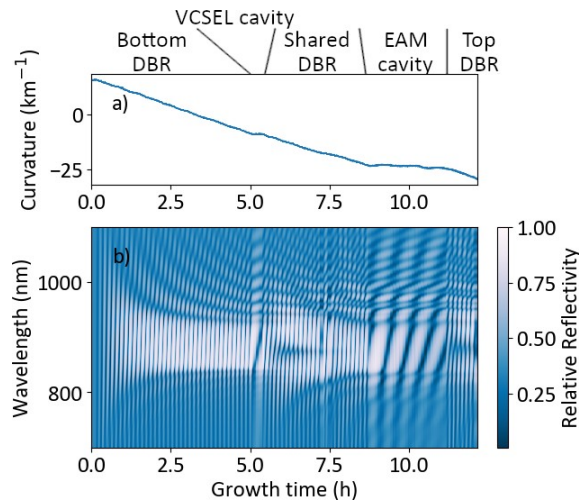


Figure 2: a) Wafer curvature and b) In-situ reflectometry of the EAM-VCSEL during the epitaxy

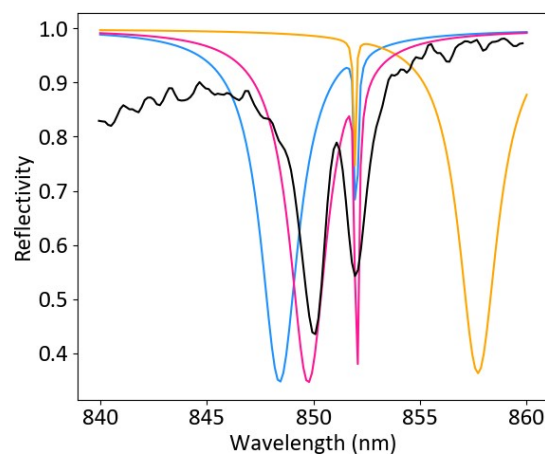


Figure 3: Room-temperature post-growth FTIR reflectivity measurement of the grown EAM-VCSEL structure (black); Numerical calculation of the reflectivity in the case of strong coupling (red), moderate coupling (blue), and overcoupling (orange). The wavelength shifts from strong to moderate coupling curves correspond to a deviation of -3 nm on the EAM cavity thickness, and +7.5nm from strong to overcoupled