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# Epitaxial LiNbO3 growth and layer transfer for thin-film electro-optic modulator realization

*Grégoire Larger*[*] [1, 2], *Jerôme Hauden*[2], *Aurore Ecarnot*[2], *Anne-Laure Pointel*[2], *Vincent Astié*[3], *Ausrine Bartasyte*[1,4]

[1]Département Temps-Fréquence, FEMTO-ST, Besançon, France
[2]R&I, Exail Photonics, Besançon, France
[3]Annealsys, Montpellier, France
[4]Institut Universitaire de France

**Abstract.** The aim of the PhD project is to develop a new trend in modulation system for Exail company: thin film (<1 µm) lithium niobate (LN) electro-optic modulator. It exhibits better performance in term of bandwidth, power consumption and footprint than legacy ones [1-3]. This PhD is a cooperation between Exail photonics which is world-renowned for the performances of their electro-optic modulators and FEMTO-ST institute which can offer the possibility to grow stoichiometric LN thin film by means of direct liquid injection metalorganic chemical vapor deposition (DLI-MOCVD). This cooperation opens the possibility to obtain industrialization of optical device based on CVD LN stoichiometric layers which allow to have enhanced performances such as higher electro-optic coefficient than that of congruent compositions of commercial single crystals. Thus, all steps from MOCVD layer deposition to modulator realization can be done here in Besançon.

## 1 Waveguide and layer stack design

In order to benefit from highest electro-optic performances and to be compatible with layer transfer one stack of layers has been identified (**Fig.1**). We elaborate the following flow-chart:

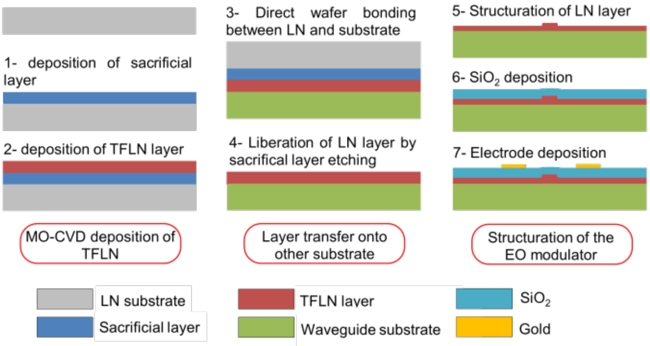

**Fig. 1.** Flow-chart of PhD project

We need first to go through MOCVD deposition on LN X-cut substrate to ensure epitaxial growth. Then we need to transfer the deposited LN X-cut layer onto a substrate with better electric performances (Si or quartz). To do so molecular wafer bonding between deposited LN layer and Si substrate is done and then we do a wet etching of sacrificial layer to liberate LN layer from LN substrate. Thus, deposited thin film LN layer is transferred onto another substrate. Finally, we can structure the electro-optic modulator from the thin-film deposited LN layer.

### 1.1 BPM simulation

Simulations with BPM algorithm have been made to apprehend light behavior in structure where dimensions are lower than light wavelength. Influences of all waveguide parameters (width, thickness, roughness…) have been estimated and their values have been set to ensure single mode propagation, low propagation loss, adequate mode size for injection (**Fig.2**) …

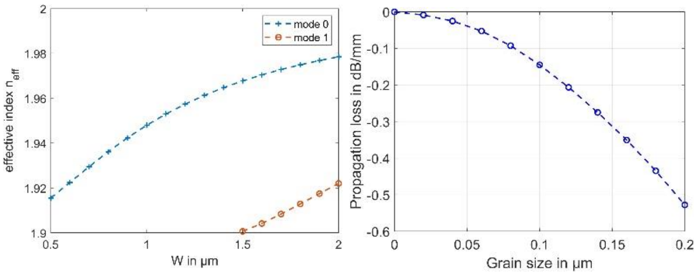

**Fig. 2.** Effective index evolution with respect to rib width W (left) and propagation loss estimation with respect to roughness dimension (right)

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[*] Corresponding author: gregoire.larger@exail.com

### 1.2 Liberation's layer identification

In order to ensure epitaxial growth of the deposited LN layer on top of the sacrificial layer, we should find a sacrificial layer which can have a similar crystal structure than LN one. This sacrificial layer should be easily removed with wet etchant solution which is not attacking LN layer. $LaNiO_3$ material has been identified as it has similar crystal structure, low lattice mismatch and similar position of dense plane (**Fig.3**). Thus, it is possible to grow single crystal LN X-cut on top of $LaNiO_3$ X-cut (top, **Fig. 4**).

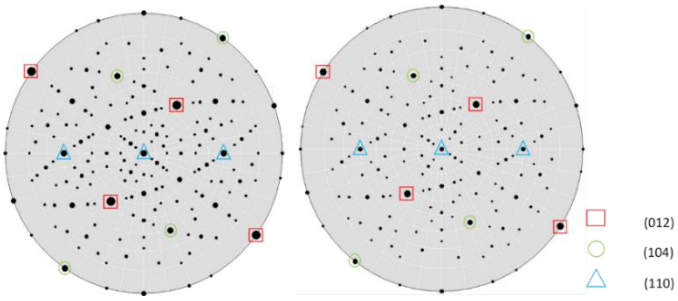

**Fig. 3.** Stereographic projection of (110) $LaNiO_3$ (left) and (110) $LiNbO_3$ (right) crystal structure and location of dense planes (red squares).

## 2 Experimental works

### 2.1. MOCVD deposition

X-cut $LaNiO_3$ has been epitaxially grown on X-LN (top, **Fig.4**). CVD growth conditions are investigated to optimize the epitaxial quality and to reduce surface roughness of the LN layer by controlling atoms kinetics on substrate surface [4] (bottom, **Fig.4**) to provide the film quality in terms of grain size, density, and in-plane orientation offering the best optical performance.

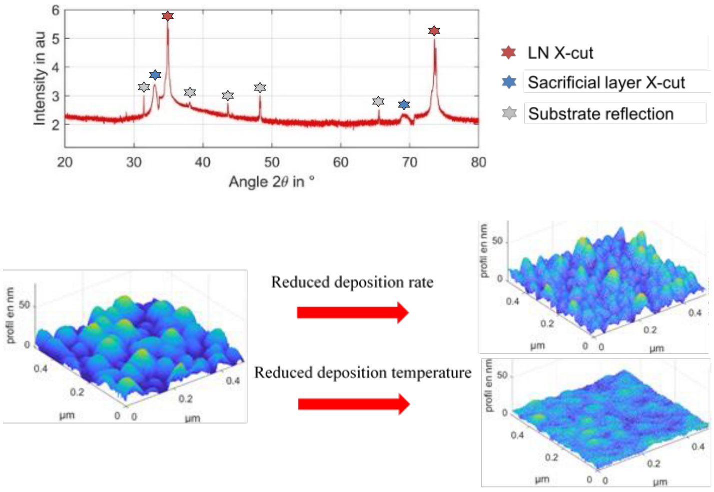

**Fig. 4.** Θ/2Θ XRD pattern of (110) $LaNiO_3$ layer on (110) LN substrate (top) and AFM images of $LaNiO_3$ surface showing grain size and roughness change with respect to CVD deposition conditions (bottom).

### 2.2 Layer transfer

Layer transfer process also includes a molecular wafer bonding of oxidized Si wafer and LN wafer with CVD deposited layers. And then wet etching of the sacrificial layer is done to liberate the bonded stack from host LN wafer (**Fig.1**). Encouraging results have already been obtained with molecular bonding of Si-LN wafers and sacrificial $LaNiO_3$ layer etching showing that layer transfer can be obtained on 1 cm² sample (**Fig.5**). Up scaling of transfer process to 4" wafers is in progress.

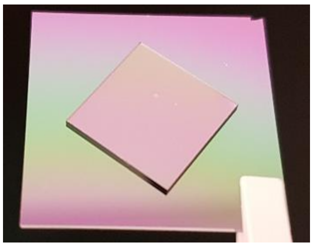

**Fig. 5.** Molecular wafer bonding between LN X-cut and oxidized Si samples

### 2.3 LN etching

Cost effective and low-loss etching of thin-film LN is challenging as even low wall's roughness of the waveguide can generate a huge amount of loss (**Fig.2**). We developed a process with reactive ion etching where smooth rib is obtained (**Fig.6**), devices are currently under test.

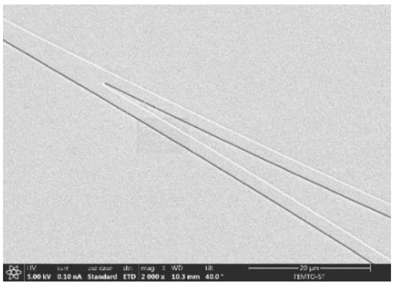

**Fig. 6.** SEM picture Y-junction of etched LN waveguide

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