Integrated $LiNbO_3$ ridge modulators planarized by using a Teflon buffer layer

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***Abstract*—Novel electro-optical ridge-guide modulators in $LiNbO_3$ are proposed. Spun Teflon AF polymer is used as buffer and planarization layer, improving modulator performance and fabrication process. Simulation results show low driving voltage (< 8 V•cm) for nearly velocity and impedance matched devices. Electro-optical characterization will be presented at the conference.**

Modulators, lithium niobate, ridge waveguides, Teflon.

I. INTRODUCTION

External modulators based on lithium niobate ($LiNbO_3$) are nowadays key components for high-bit-rate optical communication systems. Current commercial devices offer a modulation bandwidth (Δf) exceeding 40 GHz combined with a low driving voltage (V_π) in the range of 4 to 5 V, with a voltage-length product ($V_\pi L$) of the order of 12 to 15 V•cm.

Many technological approaches have been made in order to improve modulator performance. For example, thin sheet designs, [1], ferroelectric domain inversion [2], or even photonic crystal structures [3]. However, one of the most promising structures is the ridge waveguide modulator. These devices are able to shrink the size of optical modes so that the overlap of applied electric field and optical fields is maximized. Ridge structures also provide a lower effective index of the modulating microwave with thinner buffer layers, which means that the bandwidth of the devices is larger, while having low driving voltage.

High-bandwidth devices with $V_\pi L$ in the range of 8 to 9 V·cm have been demonstrated [4] based on $LiNbO_3$ ridge waveguides coated with SiO_2 buffer layer. However, a drawback of these structures is the need to deal with the different levels of the ridge structure, which make the fabrication process more sensitive and complicated. This can also result in additional electrical losses.

In this work we propose a novel combination of ridge waveguides in $LiNbO_3$ with Teflon AF as buffer and planarization layer. For the first time, we show that Teflon can be deposited via straightforward spin-coating on ridge waveguides, leading to a top planarized surface. The resulting surface morphology allows the further fabrication of electrode structures.

II. DEVICE DESIGN

Our proposed device is based on recently developed ridge waveguide modulators, in which a high-confinement, complete-ridge interferometer is made by means of a wet etching process [5]. Teflon AF, used as buffer layer material provides a good confinement of light, as its refractive index at 1.55 μm wavelength is 1.3 whereas that of SiO_2 is 1.44. Its lower dielectric constant (ε=1.9) in comparison with SiO_2 (3.9) also makes it a better choice in order to achieve velocity matching. Moreover, it has been measured that the dielectric losses of Teflon AF at high frequency are lower than those of SiO_2, which is a great advantage for high bandwidth devices [6]. The proposed cross section is sketched in figure 1.

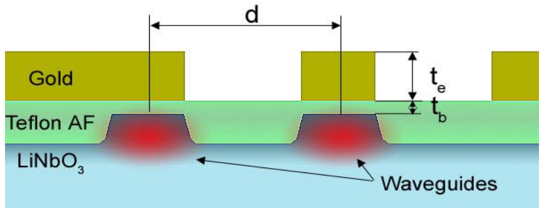

Figure 1. Cross section of proposed modulator.

In order to evaluate the performance of these modulators, their main parameters ($V_\pi L$, effective microwave index n_{eff}^{MW}, and characteristic impedance Z) were calculated.

Selected results are shown in figure 2. In figure 2(a) we can see how the $V_\pi L$ evolves as function of the ridge height (h) with the buffer layer thickness on top of the ridges (t_b) and the separation between waveguide centers (d) as parameters. As expected, the lower t_b is, the lower the driving voltage becomes. We also indentify the range of h beyond 3 μm as the one that provides a lower value of $V_\pi L$. Values even below 8 V·cm are found for t_b = 0.2 μm. In figure 2 (b), characteristic impedance and microwave effective index are shown for devices with t_b=0.2μm, with the distance between waveguides and the electrode thickness (t_e) as parameters. We can see that velocity matching condition (n_{eff}^{MW}=2.14) can be obtained with this buffer thickness for different configurations. For example, with d=24μm and t_e=8μm, a nearly velocity and impedance matched design can be made with a ridge height between 4 and 7 µm. This devices yields a $V_{\pi}L$ of 8 V·cm.

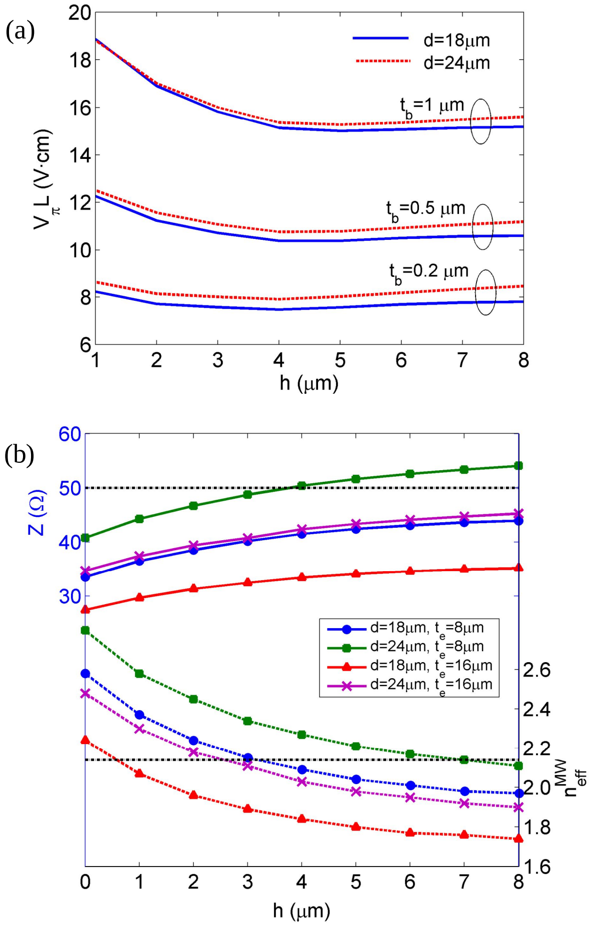

Figure 2. Calculated driving voltage-length product (a) and characteristic impedance and effective index of modulating microwave (b). In (b) all the results are for t_b=0.2 µm. The impedance matching (Z=50Ω) and velocity matching n_{eff}^{MW}=2.14 conditions are shown by horizontal dashed lines.

III. Fabrication

The fabrication of the ridge interferometers is carried out by a wet etching technique based on an HF, HNO_3 and ethanol mixture, which provides smooth ridge walls. The guiding in the vertical direction is obtained by the proton exchange technique. After the ridges are fabricated, diluted Teflon AF is spun on the samples at 2500 rpm and then baked at 180ºC. Figure 3 shows a SEM image of an etched ridge coated by a Teflon AF layer with a thickness of 4 µm above the ridge top. In order to reduce the thickness and planarize the surface of the deposited layer, different processes are being developed, such as fine mechanical polishing as well as oxygen plasma etching. A thinned layer can be shown in the lower picture of figure 3.

In order to fabricate the electrodes on top of the planarized Teflon AF layer, a fluorocarbon surface treatment to improve adhesion is used (Tetra-etch). In this way, a reactive film is created on the Teflon surface making possible to deposit thin metal layers as well as photoresist. Finally, the electrodes are fabricated on top of the buffer via electroplating. In figure 4, an example of an electrode and impedance-matching transition is shown on top of a planar Teflon AF layer.

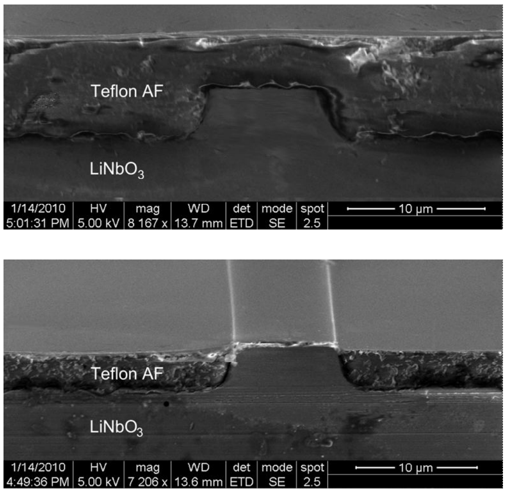

Figure 3. $LiNbO_3$ ridges covered by Teflon AF layers with a thickness above the ridge top of 4µm (upper) and 0.6µm (lower).

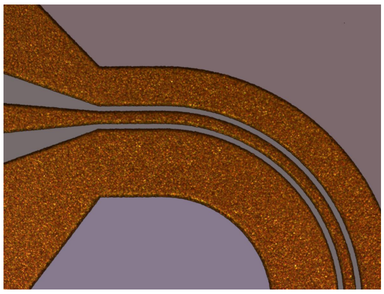

Figure 4. Electroplated electrode and tapered transition grown on top of a planar Teflon AF later.

Currently, the electro-optical characterization of the devices is being carried out and the results will be presented at the conference.

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