Teflon buffer layer for planarization of $LiNbO_3$ ridge modulators

Davide Janner[1], Miguel García-Granda[1], Domenico Tulli[1], Valerio Pruneri[1,2]
1.ICFO – Institut de Ciències Fotòniques. Mediterranean Technology Park. 08860 Castelldefels (Barcelona) Spain
2 ICREA Institució Catalana de Recerca i Estudia Avançats. Barcelona, Spain

1. 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.

2. 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 SiO2, which is a great advantage for high bandwidth devices [6]. The proposed cross section is sketched in figure 1.

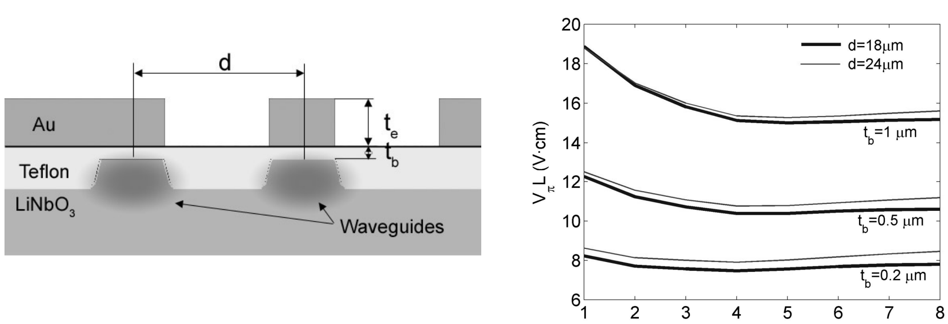

Fig. 1: Left: Proposed cross-section of planarized ridge modulator. Right: Calculated values of driving voltage-length product as function of ridge height, with buffer thickness and waveguide distance as parameters.

The main parameters ($V_\pi L$, effective microwave index n_{eff}^{MW}, and characteristic impedance Z) were calculated for the proposed structure.
The results for $V_\pi L$ are shown in figure 1. 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. From the calculations of n_{eff}^{MW} we 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 te=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.

3. Fabrication

In order to fabricate the waveguides, the proton exchange technique is used. In this technique, the substrate is immersed in a molten mixture of benzoic acid and lithium benzoate giving place to a local replacement of Li^+ ions from the crystal by H^+ ions from the melt. In this way, a layer of about 5 μm depth beneath the surface suffers an increase in refractive index, which will create the guiding effect of light in the vertical direction.
The confinement of light in the lateral directions is created by the ridge structure. The fabrication of the ridges is carried out by a wet etching technique based on an HF, HNO_3 and ethanol mixture after the fabrication of a Cr mask on the sample surface in which the waveguides design is patterned. This fabrication process produces smooth ridge walls and low optical loss. After the ridges are fabricated, diluted Teflon AF is spun on the samples at 2500 rpm and then baked at 180ºC. Figure 2 shows a SEM image of an etched ridge coated by a Teflon AF layer with a thickness of 4 μm above the ridge top. As it can be seen, the upper surface is relatively flat, without being affected by the ridge shape. 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 on the right hand side of figure 2.

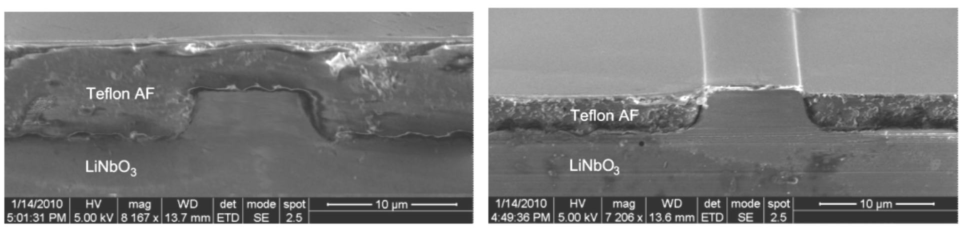

Fig. 2: Left: Ridge fabricated on $LiNbO_3$ coated with a Teflon AF layer in which the thickness of the layer above the ridge top is 4 μm. Rigth: Ridge with thinned Teflon AF layer with a thickness of 0.6 μm.

After the planarization, the modulator electrodes must be fabricated on top of the Teflon AF layer. In principle, this can be an additional problem, as the adhesion of metals on top of Teflon layers is rather bad. However, we apply a fluorocarbon etching process in which a sodium compound in the etchant solution reacts with the polymer to form a reactive film on top of its surface. In this way, the surface allows the adhesion of evaporated metal layers and the further process of electrode growth by electroplating.

6. Conclusions

A new fabrication process of $LiNbO_3$ ridge modulators with a Teflon AF planarization layer is presented. The proposed modulators with this design show improved characteristics with respect to current commercial and experimental devices. The controlled planarization of the Teflon AF layer by different means and the evaluation of the fabricated devices is currently ongoing.

References

[1] G. Poberaj, M. Koechlin, F. Sulser, A. Guarino, J. Hajfler, P.Günter, “Ion-sliced lithium niobate thin films for active photonic devices,” Opt. Mater., vol. 31, no. 7, pp. 1054–1058, 2009

[2] F. Lucchi, D. Janner, M. Belmonte, S. Balsamo, M. Villa, S. Giurgola, P. Vergani, V. Pruneri, “Very low voltage single drive domain inverted $LiNbO_3$ integrated electro-optic modulator,” Opt. Exp., vol. 15, no. 17, pp. 10739–10743, 2007.

[3] M. Roussey, M. P. Bernal, N. Courjal, D. V. Labeke, F. I. Baida, “Electro-optic effect exaltation on lithium niobate photonic crystals due to slow photons,” Appl. Phys. Lett., vol. 89, pp. 241110-1–241110-3, 2006

[4] W. K. Burns, M. M. Howerton, R. P. Moeller, R. Krähenbühl, R. W. McElhanon, and A. S. Greenblatt, “Low drive voltage, broad-band LiNbO modulators with and without etched ridges,” J. Lightw. Technol., vol. 17, no. 12, pp. 2551–2555, 1999.

[5] M. García-Granda, H. Hu, J. Rodríguez-García, W. Sohler, “Design and Fabrication of Novel Ridge Guide Modulators in Lithium Niobate,”, J. Lightw. Technol., vol. 27, no.24, pp. 5690-5697, 2009.

[6] P.R. Resnick, W. H. Buck, Fluoropolymers 2-Properties,. Springer US, 2006, pp.25–33.