Reactive Ion Etching on $(Yb,Nb):RbTiOPO_4/RbTiOPO_4$ epitaxial layers for the fabrication of Y-splitters and Mach-Zehnder Interferometers

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1. Introduction

Rubidium titanyl phosphate $RbTiOPO_4$ (RTP) belongs to a highly diverse and versatile structural family and because of its large non-linear optical coefficients, wide transparency, high laser damage threshold, high chemical stability and low dielectric constants, this material is highly attractive for electro-optic applications such as modulators and Q-switches [1]. RTP has a similar non-linear optical coefficient to KTP but, unlike KTP, it can be doped with Yb^{3+} ions to obtain a high enough concentration to allow efficient laser action [2]. Because of all these interesting properties, RTP is a strong candidate as a platform material for integrated photonics. Reactive ion etching (RIE) is a commonly used method in etching of semiconductors, but there is little literature available on the plasma-based etching of RTP. Moreover, single-mode rib waveguides have been successfully fabricated in (Yb,Nb):RTP by RIE [3]. In this work, $(Yb,Nb):RbTiOPO_4/RbTiOPO_4$ (001) epitaxial layers have been structured by RIE by using a combination of Ar and SF_6 gases. The refractive index contrasts between the $(Yb,Nb):RbTiOPO_4$ layer and the $RbTiOPO_4$ substrate at 1.55 microns have been measured.

2. Experimental details

RTP single crystals were grown by the top seeded solution growth-slow cooling (TSSG) technique to obtain thin plates of (001) oriented substrates. These substrates are well polished in order to have a smooth interface when epitaxial layers are grown over them. Liquid Phase Epitaxy (LPE) was used to obtain (Yb,Nb):RTP/RTP(001) in a well-isolated cylindrical vertical furnace with practically zero thermal gradient. Refractive indexes of the epitaxial layer and the substrate have been measured at 1550 nm with prism coupler method. After obtaining 6-7microns of epitaxial layer, a metal layer was deposited on it which acts as a hard mask during reactive ion etching. Different metal layers, for instance Al, Ti, Cr, Ni were tried to test their adhesion on the RTP and their performance as a metal mask. Channels designs were transferred by the help of conventional photolithography and the sample was etched with metal etchant to remove the unwanted parts of the metal mask. Finally**,** the samples with hard metal mask were put in a RIE Plasmalab 80Plus to etch. The process used was 250 W, 40 mTorr pressure and a gas combination of Ar (10 sccm) and SF_6 (10 sccm), which was optimized in a previous work [3]. The dimensions of the designed structures were channels with widths from 6 to 9 microns and 5 microns depth. These dimensions were chosen in order to support a fundamental mode at wavelengths near 1520 nm. A thin layer of RTP was grown using the LPE technique at the end of fabrication process to act as a cladding for better light confinement, and also serves to lower the propagation losses.

3. Results and discussion

Using the TSSG technique, we have obtained very high quality crystals with approx. 17x18x18 mm^3 dimensions without any cracks and inclusions. The same is applicable for epitaxial layers grown with the LPE technique. Figures 1a) and 1b) show the RTP crystal and as grown (Yb,Nb):RTP/RTP epitaxial layer. The refractive index contrasts between the epitaxy and the substrate ($\Delta n_i = n_{i,epi} - n_{i,sub}$ being i=x,y and z) are: $\Delta n_x = -0.004$, $\Delta n_y = 0.0003$ and $\Delta n_z = 0.005$ allowing only monomode propagation in the TM polarization by choosing the appropriate channel waveguide dimensions. We have evaluated the Ti, Ni, Al and Cr elements as possible candidates for the metal mask by checking the adhesion of these metals to the RTP surface. The topography of the metal layer, analysed by AFM technique, showed average *rms* roughness of: 2.8 nm, 2.6 nm and 14 nm for Ti, Ni and Al layers, respectively. The adhesion and durability of the metal layer on RTP surface, was checked by several tape test, and Aluminium shows the better adhesion. With RIE, a maximum etch rate of 8.5 nm/min for the epitaxial layer was obtained, and the deepest etch achieved was 2.8 μm. Figure 2a) shows an ESEM image of a part of the MZI design etched on an epitaxial layer. The Liquid phase epitaxial growth of cladding shows a clear interface of growth, as shown in figure 2b).Optical waveguiding in the fundamental mode at a wavelength of 1520 nm was observed in the above mentioned MZI and Y-splitter rib waveguides with an etch depth of 2.8 μm.

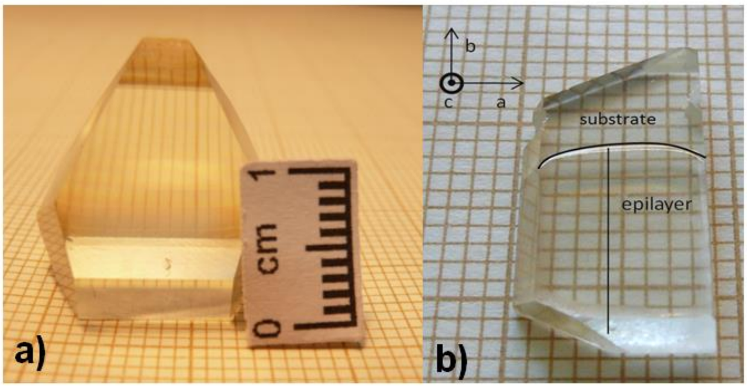

Fig.1: a) RTP single crystal, b) as grown (Yb,Nb):RTP/RTP epitaxial layer.

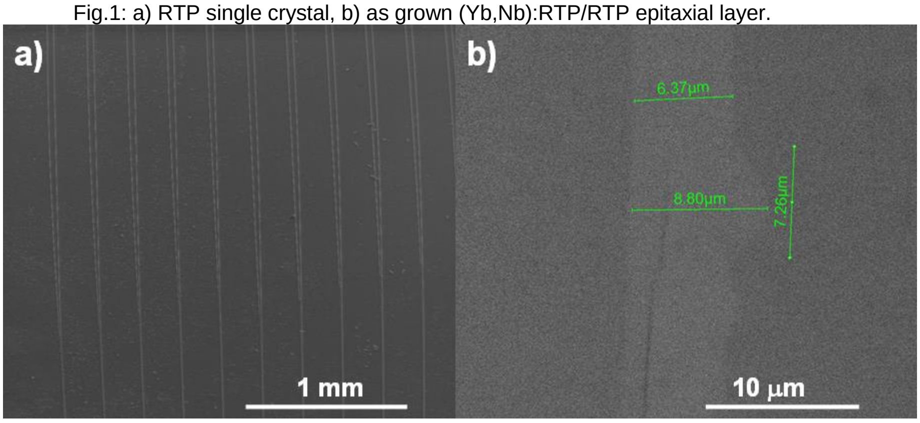

Fig. 2: a) ESEM image of the input section of MZI fabricated on (Yb, Nb): RTP/RTP; b) cross sectional view of MZI.

4. Conclusions

Reactive ion etching was used to fabricate Y-splitters and MZIs on (Yb,Nb):RTP/RTP(001) samples. The maximum etch rate that we achieved with epitaxial layer was 8.5 nm/min and the maximum channel depth obtained was 2.8 microns. A thin cladding layer was grown over the channels for better confinement. These devices were designed to support fundamental mode of 1520 nm and the MZIs are expected to operate as modulators by using the E-O coefficient of RTP. Further investigation on this is in progress.

5. Acknowledgments

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