Fabrication of Y-Splitters and Mach-Zehnder interferometers on (Yb, Nb):$RbTiOPO_4$/ $RbTiOPO_4$ epitaxial layers by Reactive Ion Etching and on $RbTiOPO_4$ by Cs^+ diffusion

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Abstract We present the fabrication and characterization of Y-splitters and Mach-Zehnder Interferometers by the two different techniques of reactive ion etching and ion exchange on (Yb,Nb):$RbTiOPO_4$/ $RbTiOPO_4$ and $RbTiOPO_4$, respectively. Liquid phase epitaxy was used to grow planar thin films followed by reactive ion etching for fabrication of structures over it. Cs^+ ions were used for diffusion process because they produce a significant increase in the refractive index and the ionic radius is close to the Rb^+ radius. It has been found that these structures can guide light with TM polarization at 1520 nm.

1. **Introduction:** Rubidium titanyl phosphate $RbTiOPO_4$ (RTP) belongs to a highly diverse and versatile structural family and is of interest because of its large non-linear optical coefficients, wide transparency, high laser damage threshold, high chemical stability and low dielectric constants.[1] RTP has similar non-linear optical coefficients to $KTiO(PO_4)$ (KTP) but, unlike KTP, it can be doped with Yb^{3+} to obtain a high enough concentration to allow efficient laser action.[2] Thus, 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. Recently, Cs^+ ion exchange channel waveguides on RTP have been reported.[3] Cs^+ ions were used for diffusion process because they produce a significant increase in the refractive index and the ionic radius is close to that of Rb^+. The motivation for the current work is to make use of all these excellent properties of RTP (001) to fabricate integrated EO devices such as Mach-Zehnder Interferometers (MZIs) by different techniques like RIE and Cs^+ ion difusion.

2. Experimental details: RTP single crystals were grown by the top-seeded solution growth-slow cooling (TSSG) technique. Thin plates with (001) orientation were obtained to be used as substrates for Liquid Phase Epitaxy (LPE) growth and Cs^+ diffusion. RTP single crystals are orthorhombic biaxial crystals, and the (001) plane contains the optical phase matching direction for doubling light at 1 μm. LPE was used to obtain (Yb,Nb):RTP/RTP(001) in a well-isolated cylindrical vertical furnace with practically zero thermal gradient. The refractive indexes of the epitaxial layer and the substrate have been measured at 1550 nm by the dark mode method.

<u>RIE on (Yb,Nb):$RbTiOPO_4$/$RbTiOPO_4$ epitaxial layers for the fabrication of Y-splitters and MZIs:</u> After obtaining 6-7 μm thickness epitaxial layers, a metal layer was deposited on it which acts as a hard mask during RIE. Channel designs were transferred to the mask by 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 reactive ion etched in a Plasmalab 80Plus (OIPT) to fabricate the structures. The process was carried out at 250 W, with 40 mTorr pressure and a gas combination of Ar (10 sccm) and SF_6 (10 sccm), which was optimized in previous work.[4] Etching times were in the range of 200-600 min. The width and height of the designed patterns were 6-9 μm and 5 μm, respectively, 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 the fabrication process to act as cladding for increasing light confinement, and also serves to lower the propagation losses.

Y-splitters and MZIs on $RbTiOPO_4$ by Cs^+ ion Exchange: A Ti layer was deposited on the RTP (001) substrate by sputtering. The designs of Y-splitters and MZIs of 9 mm in length and 6 μm in width along ***b*** direction were transferred onto a photoresist by photolithography. After developing the exposed part, the design was transferred to the Ti mask by etching it with H_2O_2:NH_4OH in 2:1 molar ratio. Cs^+ diffusion was carried out by immersing the sample with the Ti pattern horizontally in a crucible containing 25 g of $CsNO_3$ at 698 K for 2 h, rotating at 40 rpm.

3. Results and discussion: We have obtained very high quality crystals with dimensions close to 17x18x18 mm^3 along the **a**, **b** and **c** directions respectively, without any cracks and inclusions. The same is applicable for epitaxial layers grown by LPE. 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 1a) shows an ESEM image of a part of the MZI design etched on an epitaxial layer. The LPE growth of cladding shows a clear interface of growth, as shown in figure 1b). Optical waveguiding of the fundamental mode at 1520 nm was observed.

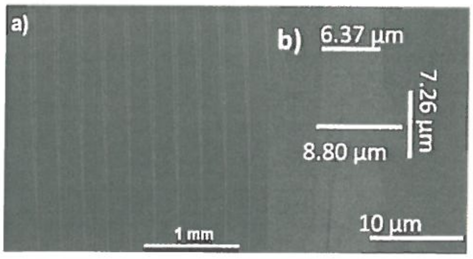

Fig. 1: a) Input section of the MZIs fabricated on (Yb,Nb):RTP/RTP; b) cross sectional view of a MZI .

In case of Cs^+ diffused channels, EPMA analysis show traces of Cs^+ along ***c*** direction to a depth of 6 μm. In all the MZIs and Y-splitters, the 1520 nm light was guided only in the TM polarization because of the existing relatively higher n_z refractive index contrast as compared to n_x and n_y . Figure 2 shows the horizontal intensity cross section (a) and the measured near field pattern (b) of the output guided modes in a 9 mm long Y-splitter. A Gaussian profile with dimensions of 15.6 μm x 9.0 μm for the left arm and 13.2 μm x 8.5 μm for the right arm in the ***b*** and ***c*** directions was measured.

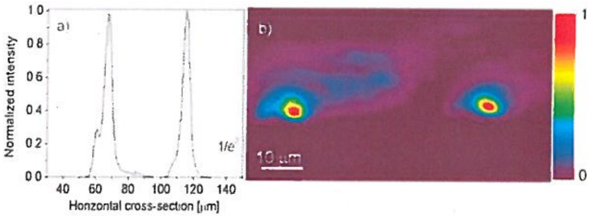

Fig. 2: a) Horizontal intensity cross section of the near field profile and b) measured near-field image, of the fundamental mode at 1520 nm wavelength of a Y-splitter.

4. Conclusion: RIE was used to fabricate Y-splitters and MZIs on (Yb,Nb):RTP/RTP(001) samples. Y-splitters and MZIs in RTP fabricated by Cs^+ ion exchange have been reported for the first time to our knowledge. Optical waveguiding was achieved at a wavelength of 1520 nm using both the RIE and Cs^+ diffusion.

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