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$LiNbO_3/Si_3N_4$-Bilayer Vertical Coupler for Integrated Photonics

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Abstract: The design of a $LiNbO_3/Si_3N_4$-bilayer vertical coupler is proposed based on adiabatic transition from a thick-Si_3N_4 strip waveguide to a LiNbO3/thin-Si_3N_4 striploaded hybrid waveguide having a gross coupling loss of ~0.08 dB.

1. Introduction

Heterogeneous integration of $LiNbO_3$ on Si_3N_4 provides efficient modulation and second-order nonlinearity to ultra-low-loss photonic integrated circuits [1,2]. $LiNbO_3$ is difficult to etch so striploading the $LiNbO_3$ with Si_3N_4 to create a waveguide (Fig. 1(d-iv)) can be an attractive way of realizing the platform. However, due to the lower refractive index of Si_3N_4 (~1.99) with respect to $LiNbO_3$ (~2.21) it is not possible to confine the light in the Si_3N_4 when the $LiNbO_3$ film is present which means that adiabatic tapers and low loss transitions between areas with and without $LiNbO_3$ is challenging [3,4]. In this paper, we propose the design of a vertical mode converter where a $LiNbO_3$ thin film is wafer bonded on two stacked layers of stoichiometric Si_3N_4. Simulation results show that, the vertical mode transition can be achieved with a loss as low as ~0.04 dB.

2. $LiNbO_3/Si_3N_4$-Bilayer Structure

The wafer structure investigated is shown in Fig 1(a) and is realized by wafer bonding a 300 nm $LiNbO_3$ thin film on a two-layer Si_3N_4 wafer. After chemical mechanical polishing (CMP), the thickness of this SiO_2 bonding layer becomes 100 nm. Both the Si_3N_4 layers are deposited using the low-pressure chemical vapor deposition (LPCVD) technique. The bottom Si_3N_4 (740 nm) layer is thicker than the top Si_3N_4 (200 nm) layer and suitable for nonlinear photonics [5]. A 300 nm SiO_2 layer deposited by LPCVD separates these two Si_3N_4 layers. The bottom Si_3N_4 layer is used to fabricate the strip waveguide whereas the top Si_3N_4 layer and the wafer bonded $LiNbO_3$ layer together creates a striploaded waveguide (Fig 1(a-iv)).

The coupler can be divided into 4 sections along the propagation direction. Fig. 1(c) shows the lateral view of a single side of the coupler. Section-1 consists of only the thick-Si_3N_4 strip waveguide. Section-2 minimizes the reflection between the pure Si_3N_4 area and the hybrid strip-loaded geometry, and relaxes the alignment requirements between the bonded $LiNbO_3$ film and the bilayer Si_3N_4 structure. Section-3 is the actual vertical coupler where the mode transition occurs. Section-4 is the $LiNbO_3$ on thin-Si_3N_4 striploaded waveguide.

3. Mode Transition Mechanism & Simulation Results

The optical mode in the thick-Si_3N_4 strip waveguide (Section-1) is shown in Fig. 1(d-i). While propagating from the Section-1 to Section-2 a very small portion of optical field is exposed to the $LiNbO_3$ thin film which is visible from both the mode field shown in Fig. 1(d-ii) and the field profile along the propagation direction shown in Fig. 1(c-i). The amount of field leakage to $LiNbO_3$ in Section-2 is so small that the power loss for mode transition from Fig. 1(d-i) to Fig. 1(d-ii) is almost negligible. The vertical adiabatic transition of the mode occurs in Section-3. The width of the thick-Si_3N_4 strip waveguide is 2 μm which is linearly tapered down to 200 nm whereas the width of the thin-Si_3N_4 is fixed to 1.5 μm. Fig. 1(b) depicts the top view of the coupler where the taper can be easily seen. From Fig. 1(f) it is clear that, when the width of the thick-Si_3N_4 narrows down to ~1.4 μm the effective index of the thick- Si_3N_4 strip waveguide (with $LiNbO_3$ misalignment) matches with the mode of the $LiNbO_3$/thin-Si_3N_4 stripload hybrid structure. In Fig. 1(d-iii) the optical field distribution of the mode is shown. The thick-Si_3N_4 strip waveguide is further narrowed down to 200 nm to fully transfer the mode to the $LiNbO_3$/thin-Si_3N_4 hybrid structure. The mode field looks like Fig 1(d-iv) when the optical field propagates to the end of the taper (starting point of Section-4). Fig. 1(c-ii) shows the smooth transition of the mode from the thick-Si_3N_4 layer to the $LiNbO_3$/thin-Si_3N_4 hybrid structure. A length sweep was performed for the taper (Section-3) which is shown in Fig. 1(e). The optical loss for a taper length of 700 μm is ~0.04 dB.

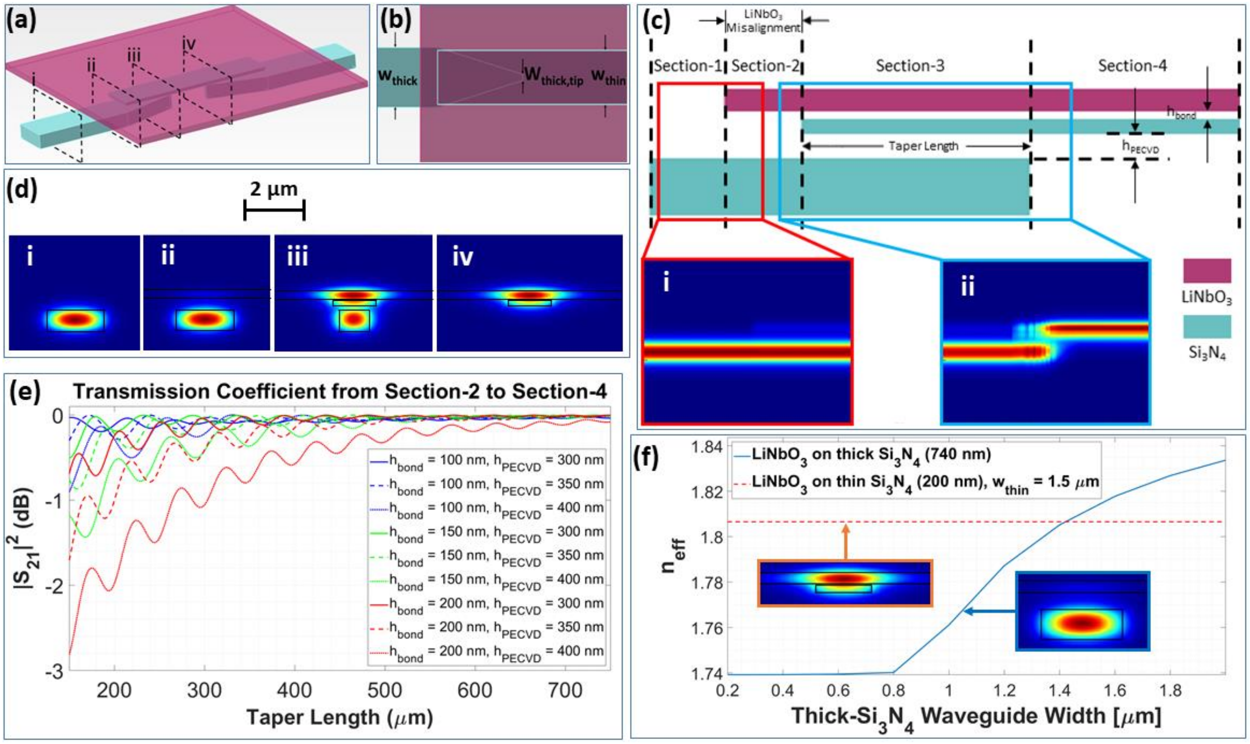

Fig. 1: (a) 3D image & (b) top view of the vertical coupler. (c) Lateral view of the coupler. Inset (i) & (ii) shows the lateral electric field distribution when the light enters from Section-1 to Section-2 & Section-2 to Section-3 respectively. (d) Mode field at different positions of the coupler (i, ii, iii & iv). (e) Transmission coefficients of a single side of the coupler for different coupling lengths and different SiO_2 thicknesses. (f) Effective index matching condition.

4. Tolerance to Fabrication Imperfections

The performance of the coupler was investigated as function of the fabrication uncertainty of the polished layers, i.e. the distance between the two Si_3N_4 layers and the top Si_3N_4 and $LiNbO_3$. Results are shown in Fig. 1(e) and shows a 0.11 dB tolerance of 100 nm for both layers.

5. Summary

We designed an ultra-low loss $LiNbO_3$/Si_3N_4-Bilayer Vertical Coupler which does not require etching of $LiNbO_3$. A total coupling loss of ~0.08 dB for a taper length of 700 µm was calculated from the simulations.

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