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LiNbO₃/Si₃N₄-Bilayer Vertical Coupler for Integrated Photonics

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Abstract: The design of a LiNbO₃/Si₃N₄-bilayer vertical coupler is proposed based on adiabatic transition from a thick-Si₃N₄ strip waveguide to a LiNbO₃/thin-Si₃N₄ striploded hybrid waveguide having a gross coupling loss of ~0.08 dB.

1. Introduction

Heterogeneous integration of LiNbO₃ on Si₃N₄ provides efficient modulation and second-order nonlinearity to ultra-low-loss photonic integrated circuits [1,2]. LiNbO₃ is difficult to etch so striploading the LiNbO₃ with Si₃N₄ 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 Si₃N₄ (~1.99) with respect to LiNbO₃ (~2.21) it is not possible to confine the light in the Si₃N₄ when the LiNbO₃ film is present which means that adiabatic tapers and low loss transitions between areas with and without LiNbO₃ is challenging [3,4]. In this paper, we propose the design of a vertical mode converter where a LiNbO₃ thin film is wafer bonded on two stacked layers of stoichiometric Si₃N₄. Simulation results show that, the vertical mode transition can be achieved with a loss as low as ~0.04 dB.

2. LiNbO₃/Si₃N₄-Bilayer Structure

The wafer structure investigated is shown in Fig 1(a) and is realized by wafer bonding a 300 nm LiNbO₃ thin film on a two-layer Si₃N₄ wafer. After chemical mechanical polishing (CMP), the thickness of this SiO₂ bonding layer becomes 100 nm. Both the Si₃N₄ layers are deposited using the low-pressure chemical vapor deposition (LPCVD) technique. The bottom Si₃N₄ (740 nm) layer is thicker than the top Si₃N₄ (200 nm) layer and suitable for nonlinear photonics [5]. A 300 nm SiO₂ layer deposited by LPCVD separates these two Si₃N₄ layers. The bottom Si₃N₄ layer is used to fabricate the strip waveguide whereas the top Si₃N₄ layer and the wafer bonded LiNbO₃ layer together creates a striploded 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-Si₃N₄ strip waveguide. Section-2 minimizes the reflection between the pure Si₃N₄ area and the hybrid strip-loaded geometry, and relaxes the alignment requirements between the bonded LiNbO₃ film and the bilayer Si₃N₄ structure. Section-3 is the actual vertical coupler where the mode transition occurs. Section-4 is the LiNbO₃ on thin-Si₃N₄ striploded waveguide.

3. Mode Transition Mechanism & Simulation Results

The optical mode in the thick-Si₃N₄ 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 LiNbO₃ 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 LiNbO₃ 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-Si₃N₄ strip waveguide is 2 μm which is linearly tapered down to 200 nm whereas the width of the thin-Si₃N₄ 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-Si₃N₄ narrows down to ~1.4 μm the effective index of the thick-Si₃N₄ strip waveguide (with LiNbO₃ misalignment) matches with the mode of the LiNbO₃/thin-Si₃N₄ striploded hybrid structure. In Fig. 1(d-iii) the optical field distribution of the mode is shown. The thick-Si₃N₄ strip waveguide is further narrowed down to 200 nm to fully transfer the mode to the LiNbO₃/thin-Si₃N₄ 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-Si₃N₄ layer to the LiNbO₃/thin-Si₃N₄ 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.

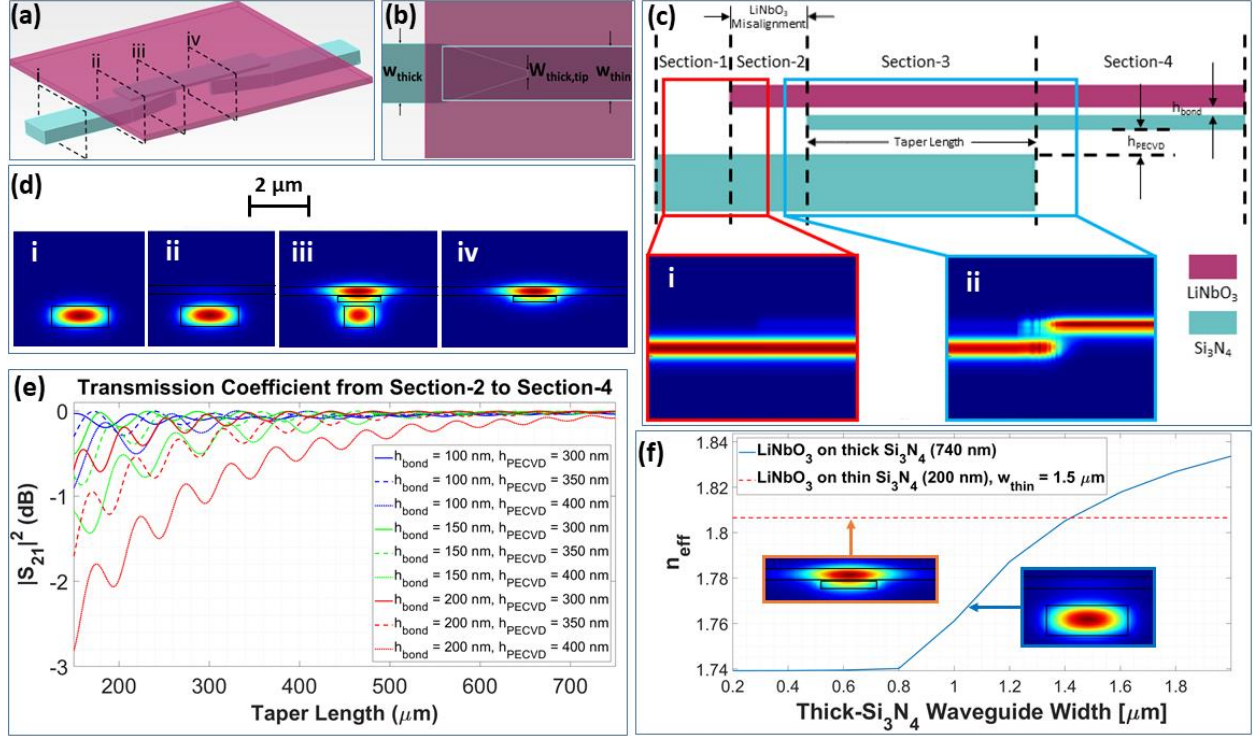


Fig. 1: (a) 3D image & (b) top view of the vertical coupler. (c) Lateral view of the coupler. Inset (i) & (ii) shows the lateral electric field distribution when the light enters from Section-1 to Section-2 & Section-2 to Section-3 respectively. (d) Mode field at different positions of the coupler (i, ii, iii & iv). (e) Transmission coefficients of a single side of the coupler for different coupling lengths and different SiO₂ 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 Si₃N₄ layers and the top Si₃N₄ and LiNbO₃. 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 LiNbO₃/Si₃N₄-Bilayer Vertical Coupler which does not require etching of LiNbO₃. A total coupling loss of ~0.08 dB for a taper length of 700 μm was calculated from the simulations.

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6. References

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