A lithium niobate-Si_3N_4 platform on silicon by heterogeneous wafer bonding

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Abstract: A lithium niobate-Si_3N_4 platform on silicon is demonstrated. It combines second- and third-order nonlinearities and has low-loss waveguides with mode converters. This is a key step for integrating nonlinear materials in silicon photonics.
OCIS codes: (190.4390) Nonlinear optics, integrated optics; (130.3730) Lithium niobate; (040.6040) Silicon.

1. Introduction

Silicon (Si) is one of the most important material platforms used in photonics due to its mass-market applications in industry [1]. However, one limitation for Si and other CMOS-compatible materials (Si_3N_4, SiO_2) is that they typically do not have strong second-order nonlinearities (electro-optic effect, $\chi^{(2)}$), due to their centro-symmetric crystal structures or amorphous nature. Therefore, with the Si platform it is challenging to achieve many practically important functions, *e.g.* electro-optic modulation and three-wave mixing. In order to introduce second-order nonlinearity, here we bond lithium niobate (LN) thin film to thick Si_3N_4 waveguide. Compared to existing work of heterogeneous LN platform, our approach not only provides waveguides with lower losses [2], but also has an efficient taper for low-loss mode transition between different waveguides [3].

2. Design and fabrication

The heterogeneous platform presented here consists of two types of waveguides, both illustrated in Fig. 1. The fully cladded Si_3N_4 waveguide for $\chi^{(3)}$ nonlinear interaction is 850 nm high and ~2 μm wide to achieve anomalous group velocity dispersion around 1.55 μm [4]. Another type of waveguide is the LN-Si_3N_4 waveguide consisting of a 300-nm thick LN layer separated from a Si_3N_4 core by a 150-nm thin SiO_2 spacer. The thickness of these two layers satisfied the index-matching condition for mode transition, and the spacer aims at reducing the abrupt change of mode shape at the boundary to limit coupling loss. A linear taper of Si_3N_4 rib with a length of 500 μm is used to achieve adiabatic mode transition.

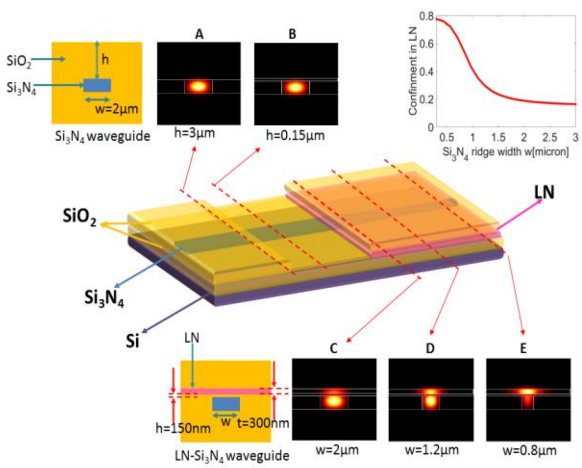

Figure 1: Cross-section schematics of waveguide and taper, and mode profile simulations.

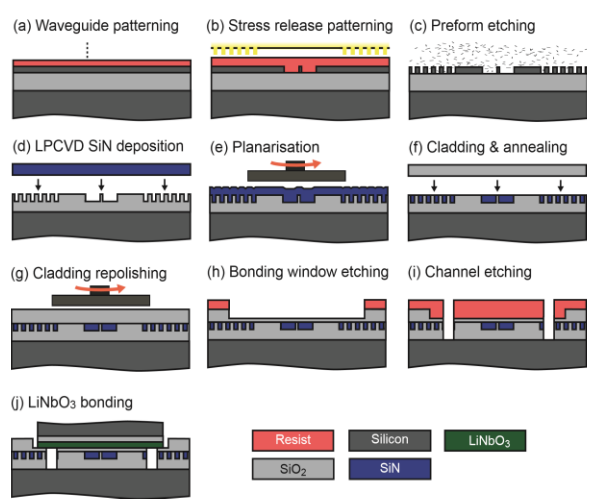

Figure 2: Processing flow.

The device processing flow is schematized in Fig. 2. The photonic Damascene process [5] is used to fabricate the Si_3N_4 waveguide devices on a Si substrate (100 mm in diameter) and provides local openings with planar surface for LN bonding. Compared to the previously used Damascene process for only Si_3N_4 waveguides [5], here in order to reduce the surface roughness in preparation for bonding, the deposited SiO_2 cladding layer is re-polished. This reduces the roughness from 5 nm to <0.3 nm. Additionally, the bonding area is opened by dry etch, leaving a thin SiO_2 layer as spacer. Vertical channels are patterned in these areas to release the gas during bonding. After Damascene process, surface plasma activation is performed and a chip (purchased from NANOLN) consisting of a 300-nm thick *x*-cut LN film on a 2-µm thick buried SiO_2 on a Si substrate is bonded onto the opened area. The bonded sample is finally annealed to enhance bonding strength.

3. Experimental results

The testing structure used here is a 1-cm long heterogeneous waveguide, with two tapers connecting the Si_3N_4 waveguides. TE polarized light is coupled in and out through Si_3N_4 waveguides. Compared to a reference structure with the same length of Si_3N_4 waveguide, the insertion loss of the heterogeneous waveguide is ~2 dB larger, as shown in Fig. 3. The simulated loss of one taper is ~0.9 dB, which matches well with the testing results. The propagation loss of the LN-Si_3N_4 waveguide is estimated to be <1 dB/cm, and such a low propagation loss is comparable with the loss of a bulk LN waveguide [6]. Small ripples are observed in the spectrum for the heterogeneous waveguide, which may be due to the taper reflections.

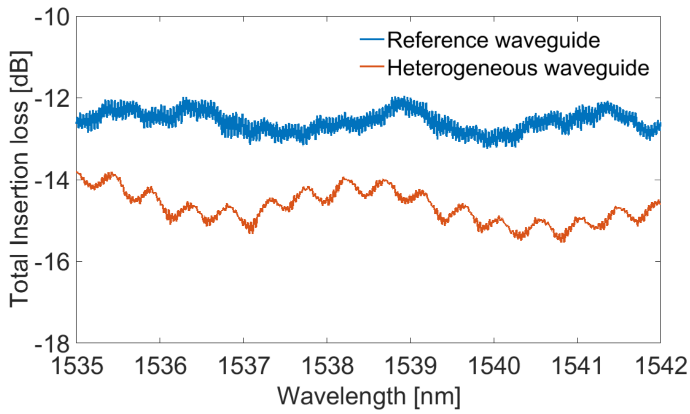

Figure 3: Spectra of total insertion loss.

4. Conclusion

A heterogeneous platform on Si is demonstrated with large $\chi^{(2)}$ and $\chi^{(3)}$ coefficients by bonding a LN film onto thick Si_3N_4. With careful design of the waveguide geometry and by using advanced fabrication techniques, high confinements and low propagation losses have been achieved both for Si_3N_4 and LN-Si_3N_4 waveguides, with low mode transition loss by using an adiabatic taper. Therefore, this platform is promising for the wide range of chip-level nonlinear applications on Si.

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5. References

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