A thin-film PPLN waveguide for second-harmonic generation at 2-µm

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Abstract: We present a thin-film periodically-poled lithium niobate (PPLN) wavelength converter for second-harmonic generation (SHG) and demonstrate with 2-micron light. The device is fabricated with a new developed surface-poling method and is compatible with photonic integration.

1. Introduction

PPLN waveguide is one of the most important wavelength converters in nonlinear optics and has been widely used in different applications, *e.g.* communication networks [1], quantum storage [2] and self-referencing [3]. However, previously photonic integrated PPLN devices were not available, mainly constrained by the waveguide technology and quasi-phase-matching (QPM) engineering. Recently, we demonstrated a new thin film surface poling technology for QPM on a low loss silicon nitride (SiN)-lithium niobate (LN) platform [4]. This approach is compatible with photonic integration on various material platforms. Moreover, the waveguide has a sub-micron-size waveguide core that can enhance the efficiency of the nonlinear effect. Based on this technology, we present a PPLN waveguide for SHG working at 2-µm pump light, which can be used for chip-scale self-referencing.

2. Device description

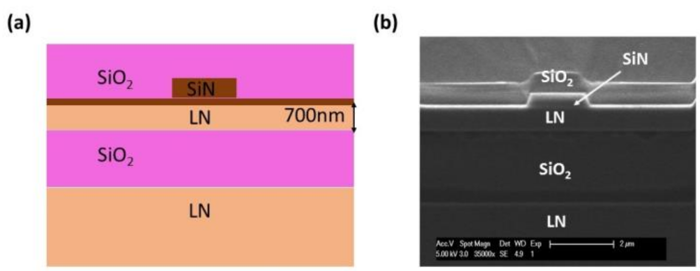

Fig. 1. Cross section (a) schematic and (b) SEM image of the waveguide.

The waveguide cross section of the wavelength converter is shown in Fig. 1. It is built on an x-cut lithium niobate on insulator (LNOI) wafer, which is commercially available from NANOLN. The LN film is 700-nm thick and on a 2-µm buried SiO_2 layer. The sub-micron thickness of LN and high index contrast between LN and SiO_2 provide a good confinement in vertical direction. In lateral direction, a SiN strip is used to guide the light. Compared to previous Ti diffused and proton exchanged LN waveguides [5], this SiN-LN ridged waveguide has a mode size that is more than one order of magnitude smaller, which enhances the non-linear effect. We chose SiN as the guiding material for low loss of the waveguide because SiN has a wide transparent window and smooth etched sidewalls, and introduces less loss compared to previous thin film LN waveguide with ridges of other materials (*e.g.* Si, Ta_2O_5). Moreover, the refractive index of SiN (1.98) is slightly smaller than the extraordinary index of LN (~2.13). Therefore, most of the power is confined in the LN core. This also reduces the loss induced by the etched sidewall. These factors lead to a low-loss platform (< 1 dB/cm for fundamental TE mode in telecom band [4]), which is comparable to the best result of previously reported bulk LN waveguide. It is thus of great benefice for non-linear applications.
The most important part of this approach is the surface poling technology we developed for LN films. Electrode teeth were deposited on *x*-cut LN films and a high voltage was applied between two electrodes. After careful optimization, this resulted in periodically inverted domain of LN between the electrodes. The traditional surface poling method suffers from the random domain growth and leakage current, reducing the poling quality. Here we

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applied multi-pulses with short duration (10 ms) to improve the generation of nucleation sites and reduce the accumulated heat caused by the leakage current. In this way, we obtained near 100 % poling yield and uniform duty cycles. Fig. 2 presents some poling results. In order to visualize the inverted domain, ion milling is used to create a cross section to expose the *z*-surface of LN. A 10-min HF etch then attacks the inverted domain and reveals the poling profile.

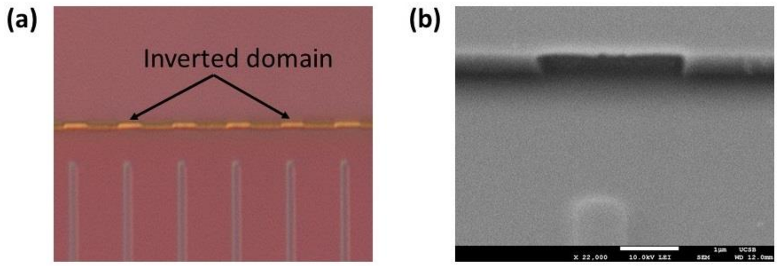

Fig. 2. (a) Top-view micrograph of inverted domains; (b) SEM image of the poling profile.

Compared to previous poling technology of bulk LN, the new method can be directly applied to thin films without limitations of substrate and the usage of backside electrodes. This leads to a much simpler fabrication process. It is also compatible with photonic integration. Since LN film has been integrated to various platforms via heterogeneous wafer bonding, it is straightforward to transfer the thin-film PPLN waveguide to them.

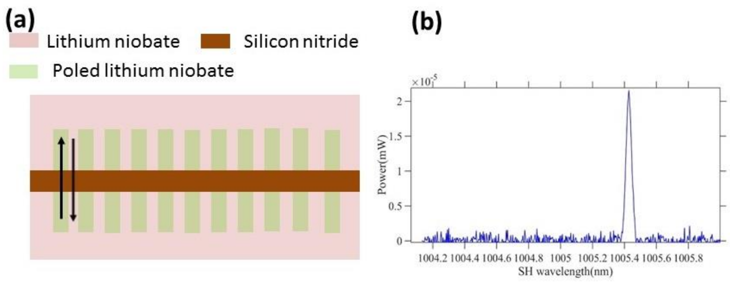

Fig. 3. (a) Top-view schematic of the PPLN waveguide; (b) Measured SH spectrum

According to the QPM condition, a PPLN waveguide working at 2-μm pump corresponds to a poling period around 7.4 μm. It is very challenging to achieve such short periods by traditional bulk poling. It is however much easier based on the surface poling method we developed. Fig. 3(b) shows the SH spectrum measured with a pump light at 2010.8 nm. This heterogeneous wavelength converter can be directly integrated with other functional devices in photonics integrated circuits (PICs), *e.g.* SiN ring resonator for self-referencing of optical frequencies [6].

In summary, we have demonstrated the first chip-scale PPLN waveguide device working around 2-μm pump wavelength for integrated non-linear optics. This technology may be the key step to integrate compact PPLN wavelength converters with record-high efficiencies in PICs for multi-applications.

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