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Polarization-reversed nonlinear optical waveguides in lithium niobate

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1. Introduction

Polarity control in $\chi^{(2)}$ materials has been appealing dramatic progress last two decades, which enables us to design intensity, spectral, and even phase profiles by polarity patterning. Electric-field poling first demonstrated by us in 1992, plays a key role in polarization reversal in ferroelectric materials such as lithium niobate. The technology opened a new horizon in applications of electro-optic/nonlinear optical devices.

2. $\chi^{(2)}$ devices by polarization reversal

(a) Mg:LN waveguide on LN platform [1]

Because of the high nonlinear coefficient d_{33} of 25pm/V, polarization-reversed Mg:LN produces extremely high normalized efficiency of 4600%/W by combining with a ridge waveguide structure. The waveguide called adhered ridge waveguide (ARW), extends interaction length with tightly confined beam size, achieving an enhancement factor of >100 [2]. The 4600%/W device yields 46% efficiency at 10 mW input power, especially being suitable for optical fiber communication operated in the power range of < 0.1W. Such a waveguide works as a parametric amplifier, producing 14.2 dB gain at 1570 nm in difference frequency generation (DFG). The high gain performance helps to build a phase-sensitive amplifier for coherent optical communication.

The $\chi^{(2)}$-based device also exhibits ultrafast response in optical sampling due to its virtual transition nature in Mg:LN ARW. Sum frequency mixing between the 640 Gbps data stream and a local clock pulse, produces the error signal for phase locking at 780 nm (Fig.1 (a)). Combination of QPM ARW with a high-speed electronic circuit realizes clock frequency extraction at 640 Gbps from ultra high-speed data signals [3].

The excellent performance also achieved parametric down conversion at low pump power for entangled photon generation. Specially designed ARW produces orthogonally-polarized photon pairs by type II interaction with d_{24} component (Fig.1 (b)), generating bright narrowband polarization-entangled photons [4].

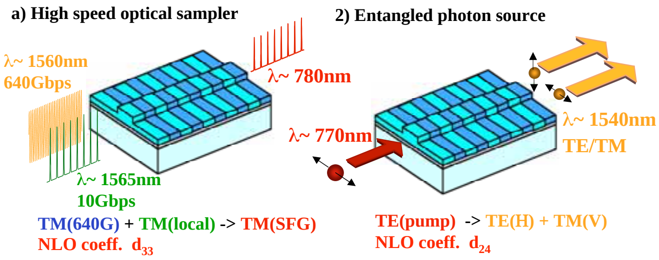

Fig.1 QPM ARW: (a) High speed optical sampler
(b) Polarization-entangled photon source

(b) Mg:LN waveguide on Si platform

Fabrication of a ridge waveguide onto the Si platform is a fascinating approach to hybrid silicon photonics for multi-function integration. Light emission and wavelength conversion are still challenge in Si due to the intrinsic material properties. Because of the centrosymmetric crystal structure of Si, it is difficult to fabricate an efficient nonlinear optical device on the Si platform. The solution we proposed is a hybrid integration with QPM ARW by building a Mg:LN block onto the Si.

We first demonstrated a Mg:LN ridge waveguide on Si with the conventional adhesion technology, as shown in Fig. 2(a). The device exhibits normalized SHG efficiency of 220%/Wcm^2 for 11mm-long interaction length, which encourages ourselves to try more sophisticated work. Nonlinear wavelength conversion between telecom bands was proved by DFG for wavelength-division multiplexing in Si-photonic optical bus system.

Our recent device is based on surface-activated bonding technology, which is adhesive-free bonded ridge waveguide (BRW). Mg:LN bonded at room temperature on Si was fabricated into a ridge waveguide in a cladless membrane structure (Fig.2 (b)). The normalized SHG efficiency of ~120%/Wcm^2 was observed at telecom wavelength.

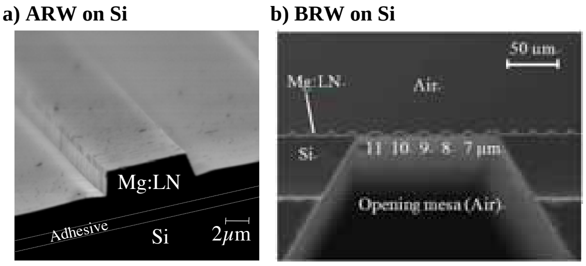

Fig.2 Mg:LN ridge waveguide on Si platform:
(a) ARW: adhered on Si (b) BRW: bonded on Si

3. Conclusions

Waveguide nonlinear optical devices become more energy-efficient and have potential applications in various fields such as optical processing/bus and quantum optics.

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