Photonic Filters on the lithium-niobate-on-insulator With Ultra-High Sidelobe Suppression Ratio

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***Abstract*—We present a box-like photonic filter on the x-cut lithium-niobate-on-insulator (LNOI) platform made using cascaded six identical multimode waveguide gratings (MWGs) with a high sidelobe suppression ratio of ~60 dB and a maximum insertion-loss is 0.6dB for light in the telecom C-band near 1550nm.**

Keywords—MWG, optical filter, LNOI

I. Introduction

Lithium niobate (LN) [1] has been one of the most attractive candidates for high-speed electro-optic modulators and nonlinear wavelength conversion devices in communication systems for decades, thanks to its excellent electro-optic (EO) effect, ultra-wide transparency window (350–5000 nm), and superb nonlinear properties. Despite its great potential, LN has faced difficulty competing with other integrated photonic platforms, mainly due to LN waveguides having a low index contrast (< 0.02) and a large device footprint. In recent years, the commercial availability of lithium-niobate-on-insulator (LNOI) wafers (up to 6 inches) and the development of LN etching technology have made photonic integrated circuits based on the LNOI platform a promising solution for the next generation of photonic integrated circuits (PICs) in both the classical and quantum domains.

With the advantage of high optical confinement, low linear waveguide losses, flexible dispersion control, and large $\chi^{(2)}$ nonlinear coefficients, LNOI-based periodically poled lithium niobite (PPLN) devices have been widely used for many nonlinear optical applications, such as wavelength conversion and photon-pair generation [2, 3] . It's interesting to note that spontaneous parametric down-conversion is routinely used as a method to generate entangled photons. Previously, a thin-film periodically poled lithium niobate waveguide was designed and fabricated which generates entangled photon pairs, where the classical pump light is near 785 nm and the generated photon pairs are near 1570 nm [2] . However, to drive the entangled photon pairs, strong classical pump light is necessary [4] , and its intensity is usually much higher than the generated single-photon level entangled photon pairs, making it difficult to achieve monolithic integration of source and detectors. Therefore, it's crucial to develop high extinction on-chip filters on the LNOI platform to strongly attenuate the classical pump light.

Recently, due to the flexible wavelength selectivity, ultra-large free spectral ranges (FSRs), and box-like spectral responses of multimode waveguide gratings (MWGs), optical filters based-MWGs have been widely explored among numerous PICs platforms, such as silicon-on-insulator (SOI) [5] , silicon nitride (SiN) [6] and lithium-niobate-on-insulator (LNOI) [7] . The fact that no circulator is required to separate the incident and reflected signals with the help of mode (de)multiplexers is a significant advantage over conventional single-mode Bragg gratings. Furthermore, the structure of multimode waveguide gratings (MWGs) avoids introducing any cured design in the grating region, making it an excellent choice of optical filter on the LNOI platform without worrying about anisotropy. Previously, we have realized a high-performance optical filter with an MWG and two-mode multiplexers on the x-cut LNOI platform with flat-top responses and low excess loss [7] . However, the extinction ratios and roll-offs of the filters need furthermore improvement for integration with entangled photon pairs based on PPLN. In this paper, we demonstrate a box-like photonic filter on the x-cut lithium-niobate-on-insulator (LNOI) with an ultra-high extinction ratio (~60 dB) and for the first time by cascading the same MWGs at the drop end of the MWGs. The present optical filter shows a broad 1dB bandwidth ~13 nm with a low excess loss of ~0.6 dB.

II. Design, Fabrication and Characterization

The present optical filter on x-cut LNOI combing an asymmetric MWG with a mode (de)multiplexer based on an adiabatic dual-core taper (waveguides A and B) as shown in Fig. 1(a). Here the MWG is used to convert the optical signals carried by the forward TE_0 mode to the TE_1 mode reflected backward when operating at the Bragg wavelength λ_B according to the phase-match condition, which is given by [5]

$$\lambda_B = (n_{eff0} + n_{eff1})\Lambda \tag{1}$$

where n_{eff0} and n_{eff1} are respectively the effective indices of the TE_0 and TE_1 modes in the MWG, and Λ is the grating period. Then the mode demultiplexer converts the reflected TE_1 mode to the TE_0 mode at the drop port finally, as shown in Fig. 1(a). The waveguide perturbations were apodized with a gaussian apodization function[8] .

$$\Delta\delta = \delta exp[-b(i - N/2)^2 / N^2]\ (i = 1, \ldots, N) \tag{2}$$

where the δ is the maximum offset for the MWG; b is the apodization index and N is the total number of MWG periods. For the MWG in the device, the corrugation width (δ) is chosen 500nm for achieving broad bandwidth, the number of the grating (N) is 500, waveguide width (W) is 2μm, apodization index(b) is 10. The grating period is chosen as Λ=444nm for the corresponding central wavelengths of MWG filters is 1550nm. To achieve an ultra-high extinction ratio on-chip optical filter, six identical apodized MWGs were cascaded, in which the drop-port of one MWG was connected to the input port of the next MWG as shown in Fig. 1(b).

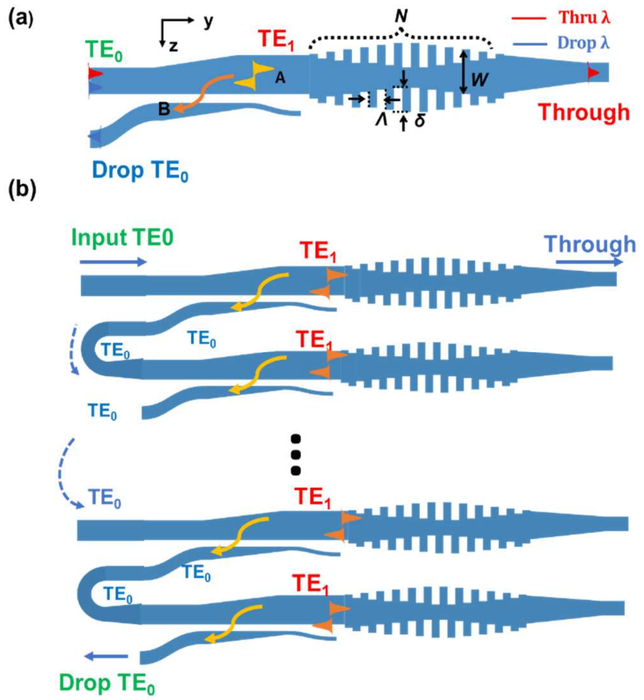

Fig. 1. Schematic configurations. (a) The proposed on-chip optical filter on x-cut LNOI. It consists of an MWG and a mode (de)multiplexers based on an adiabatic dual-core taper coupler; (b) six cascaded MWGs.

The proposed optical filter was fabricated on an x-cut LNOI wafer from NANOLN consisting of a 400 nm LN layer and a 3 μm buried SiO2 layer. The structure was patterned using electron-beam lithography (EBL) then 200nm thick LN layer was etched by Ar+ plasma to form the waveguide structure. The optical microscope and scanning electron microscope (SEM) images of the fabricated device are shown in Figure. 2(a)-(c).

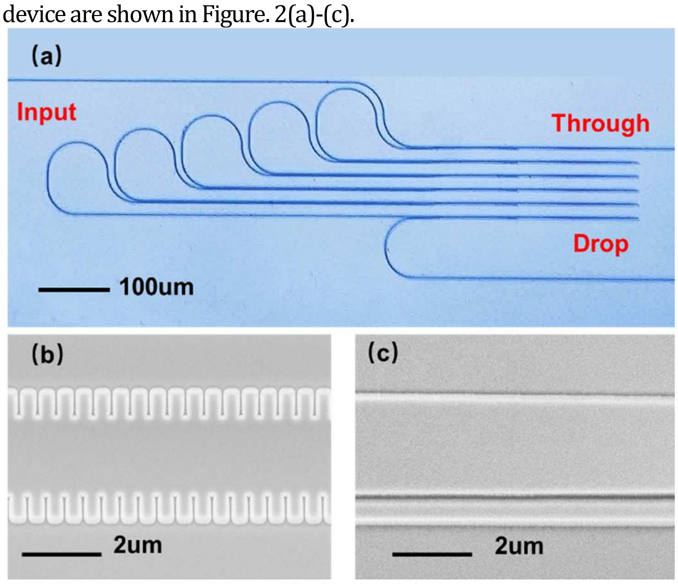

Fig. 2. (a) Microscope image of a fabricated device. Scanning electron microscope images of the part of (b) MWG;(c) mode (de)multiplexer.

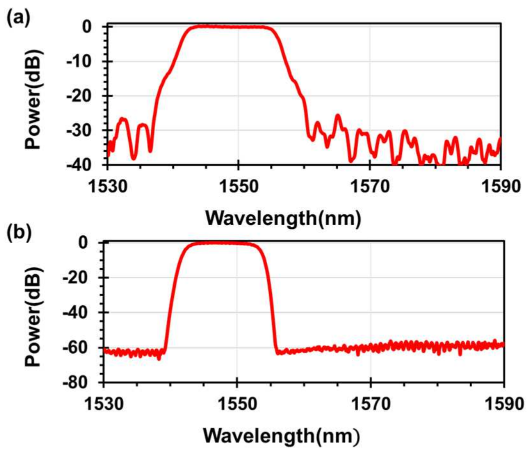

Fig. 3. Measured spectral responses at the drop port of the fabricated device based on the (a) one-MWG; (b) cascaded six MWGs.

The fabricated optical filters based-LNOI were characterized by using a broadband amplified spontaneous emission (ASE) light source and optical spectrum analyzer. The measured results were normalized with respect to the transmission of a 1000 nm-wide straight waveguide connected with grating couplers on the same chip. We obtained a flat-top response with a 1 dB bandwidth of 13nm, a sidelobe suppression ratio of 26 dB, and an excess loss of 0.05 dB at the drop-port (see Fig. 3(a)) for the device based-signal MWG, we also obtained square-shaped, drop-port response with 1 dB bandwidth >10 nm, and excess losses <0.6 dB sidelobe suppressions ~60 dB, which are limited by the dynamic range of the measurement setup.

III. Conclusion

In conclusion, we have proposed and demonstrated an ultra-high sidelobe suppression ratio optical filter on the LNOI platform for the first time by using the series-cascaded MWGs. Broadband, square-shaped, add–drop filters that have 1 dB bandwidths >10 nm, sidelobe suppression ratio~60 dB, and low excess losses <0.6 dB have been realized experimentally. The demonstrated high filtering performance and low insertion loss can potentially solve the long-standing problem of realizing sufficient on-chip filtering for fully integrated quantum photonic chips.

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