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Monolithically Integrated Tandem Waveguide-Type Acoustooptic Frequency Shifter Driven by Surface Acoustic Waves

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***Abstract*— A monolithically integrated tandem waveguide-type acoustooptic frequency shifter driven by surface acoustic waves was fabricated on 128° Y-cut $LiNbO_3$ for an optical wavelength of 1.55 μm. A peak doubly diffraction efficiency of 63% was obtained.**

I. Introduction

A new type of laser, called the frequency-shifted feedback (FSF) laser, with unique spectral properties has been developed and has received attention owing to its potential applications[1]-[7]. The FSF operation is achieved by feedback of the first-order diffracted light of an intracavity acoustooptic frequency shifter (AOFS), and the FSF laser output consists of periodically generated chirped frequency components whose chirp rate is higher than 100 PHz/s[2].

To realize a compact and stable FSF fiber laser, we have proposed a waveguide-type AOFS driven by surface acoustic waves (SAWs) using guided-optical waves in a tapered crossed-channel proton-exchanged (PE) optical waveguide on a 128°-rotated Y-cut $LiNbO_3$ substrate for an optical wavelength of 1.55 μm[8]. An 84% diffraction efficiency was obtained for an AO interaction region length of 2 mm and a driving frequency of 200 MHz[9]. The wide frequency-shift range makes it attractive for various applications in optical measurements.

In this study, the monolithically integrated tandem AOFS driven by SAWs was fabricated and the diffraction properties were measured. Moreover, an optical frequency domain ranging using the FSF fiber laser with the tandem AOFS was demonstrated.

II. Design and Fabrication of Tandem AOFS

The overall configuration of the monolithically integrated tandem waveguide-type AOFS is shown in Fig. 1. Several waveguide-type AOFSs driven by SAWs in the tapered crossed-channel PE optical waveguide are connected in tandem on a 128°-rotated Y-cut $LiNbO_3$ substrate. The structure considered is a 2×4 optical switch consisting of one 2×2 and two 1×2 switches. The input ports of the two second 1×2 switches are connected to the two output ports of the first 2×2 switch on the same substrate. Using this structure of the tandem AOFS, the optical frequency shifts for the sum of two driving frequencies and the difference between two driving frequencies can be obtained by combining the upward and downward frequency shifts in the first and second SAWs.

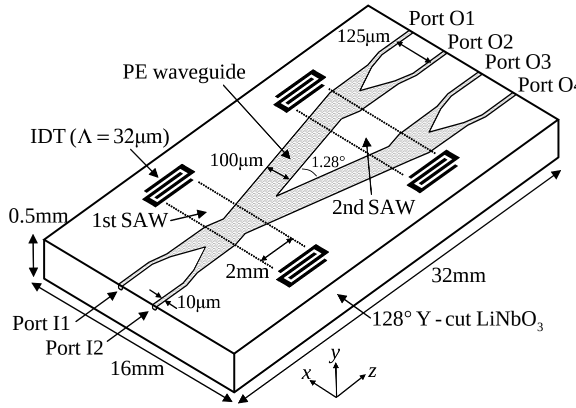

Fig. 1. Configuration of monolithically integrated tandem waveguide-type AOFS.

The waveguide shape was designed using a beam propagation method (BPM). To increase the length of the AO interaction region, the 10 μm width of the single-input four-output waveguide is increased to 100 μm using a tapered waveguide 3.3 mm long. The first and second switches are connected together with the 100-μm-wide straight waveguide.

The fabrication conditions of the proton exchanged (PE) waveguide were the same as those given in the previous paper[10]. An interdigital transducer (IDT) with a period length Λ of 32 μm and an overlap length of 2 mm was formed in both steps. The substrate size after polishing the end face was 32 mm×16 mm.

III. Measured Diffraction Properties

Diffraction properties were measured using a 1.55 μm laser diode at a driving frequency of approximately 120 MHz. The maximum values of the diffraction efficiency of 92% and 83% were obtained by the first and second SAWs, respectively. Figure 2 shows the dependences of the diffraction properties on the input voltage supplied to the second SAW at the maximum diffraction efficiency by the first SAW. The peak diffraction efficiency of 63% was obtained by driving both steps at the same frequency.

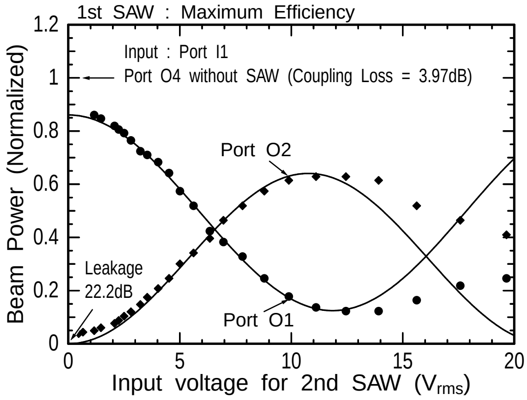

Fig. 2. Diffraction properties of tandem AOFS as function of input voltage supplied to second SAW at maximum diffraction efficiency by first SAW.

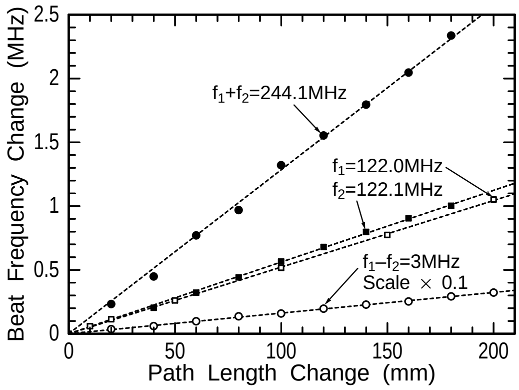

Fig. 4. Beat frequency change vs. path length change of interferometer.

IV. Optical frequency domain ranging using FSF fiber laser

The experimental setup of optical frequency domain ranging using the FSF fiber laser with the tandem AOFS is shown in Fig. 3. The tandem AOFS was incorporated into a module and optically connected to the input polarization-maintained (PM) and output single-mode fiber arrays through collimating and condensing lenses. The erbium-doped fiber (EDF) was used as a gain medium. The tandem AOFS was driven by the first and/or second SAW. The light in the cavity is frequency shifted every round trip by feeding the diffracted light of the tandem AOFS back into the EDF. The FSF fiber laser output was split into the two arms of the Mach-Zender interferometer. The adjustable path difference was obtained by including the propagation length of spatial light to one arm. The beat signal was detected with a photodetector and the beat spectrum was analyzed using an RF spectrum analyzer. Figure 4 shows the beat frequency change as a function of the path length change. The linear relationships between the beat frequency change and the path length with three slopes were obtained. One is due to the optical frequency shift of 120 MHz generated by driving only the first or second SAW. The other two slopes correspond to the optical frequency shifts for the sum of two driving frequencies (244 MHz) and the difference between two driving frequencies (3 MHz), respectively.

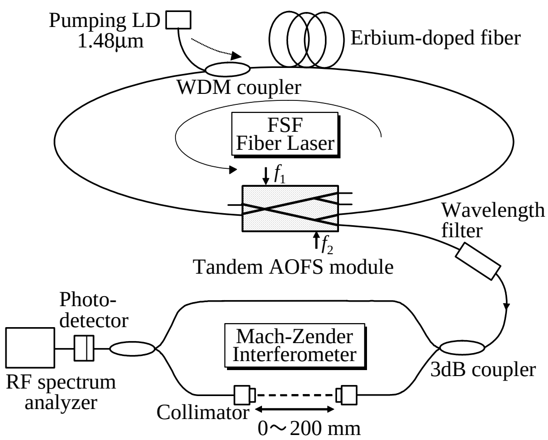

Fig. 3. Experimental setup of optical frequency domain ranging using FSF fiber laser with tandem AOFS.

V. Conclusion

A monolithically integrated tandem waveguide-type AOFS driven by SAWs was designed and fabricated for an optical wavelength of 1.55 μm. A peak diffraction efficiency of 63% was obtained by driving both steps. Moreover, the optical frequency domain ranging using the FSF fiber laser with the tandem AOFS was demonstrated.

Acknowledgment

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