ELECTROOPTIC SSB MODULATOR / OPTICAL FREQUENCY SHIFTER BY USING PERIODICALLY DOMAIN-INVERTED STRUCTURE WITH A SPATIAL SHIFT

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Abstract

A novel guided-wave electrooptic single-sideband modulator, or optical frequency shifter by using the periodically domain-inverted structure with a spatial shift is proposed. The single-sideband modulation in the proposed device is demonstrated experimentally for the first time as far as we know.

1. Introduction

High-speed optical single-sideband (SSB) modulation and broadband optical frequency shifting are very useful for the applications in many fields, such as, optical communication systems, optical measurements, high-resolution spectroscopy, photochemistry, and so on. Several guided-wave electrooptic (EO) SSB modulators have been proposed and implemented [1]-[3]. These devices are composed of two or more EO phase modulators, and the SSB modulation is based on the mixing of the two balanced phase-modulated light beams driven by a pair of microwave signals with a phase shift of $\pi/2$.

In this report, we present the demonstration of a novel EO SSB modulator/optical frequency shifter (OFS) by means of the technique of the quasi-velocity-matching (QVM) with the domain-inverted structure of ferroelectric materials for the first time as far as we know. Utilizing the control of the phase of EO modulation by the spatial shift of the periodic domain-inversion in the QVM traveling-wave modulators, the balanced phase modulation characteristics with a $\pi/2$ modulation phase shift are obtained with only a traveling-wave Mach-Zehnder intensity modulator of the periodic domain inversion. This device can be operated as a SSB modulator/OFS by not a pair of modulation signals but only one modulation signal.

2. Operation principle

A basic structure of the proposed SSB modulator/OFS is shown in Fig. 1. Adopting the two periodically domain-inverted structures with a 1/4 period spatial shift in two parallel waveguides of the Mach-Zehnder intensity modulator, the SSB modulation is obtained around the designed modulation frequency. $LiNbO_3$

or $LiTaO_3$ are applicable as a substrate material, and high-speed modulation of ~100GHz with low operational power is possible, since it is based on the QVM traveling-wave modulator and free from the restriction of the operation frequency by the velocity mismatching [4].

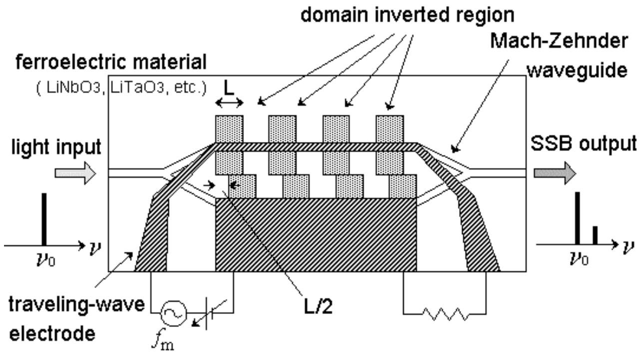

Fig. 1. The structure of the novel SSB modulator/OFS.

Figure 2 shows the comparison of the phase shift in the traveling-wave EO modulators of the periodically domain-inverted structures with a $L/2$ length spatial shift. The length L of the successive domain-inverted and non-inverted regions is derived as follows,

$$L = \frac{1}{2 f_m \left(\frac{1}{v_m} - \frac{1}{v_g} \right)} \tag{1}$$

where f_m is the designed modulation frequency, v_g is the group velocity of light, and v_m is the phase velocity of a modulation wave. By adjusting the spatial pattern of the periodic domain-inverted structure, the phase of the modulation is controlled and a $\pi/2$ phase shift of the modulation is obtained with the $L/2$ length spatial shift structure. Therefore, we can construct the SSB modulator/OFS.

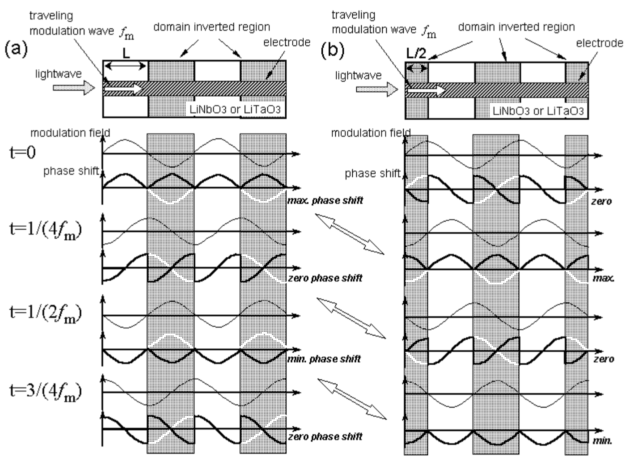

Fig. 2. The control of the phase of the modulation by the spatial pattern of the domain-inverted structure.

3. Design and fabrication

The details of the designed device and the fabrication sequences are shown in Fig. 3. First, the periodically domain-inverted structure with a spatial shift of L/2 was fabricated on a z-cut $LiTaO_3$ substrate by use of the pulse-voltage method. The period of the domain inversion was 8.2mm (L=4.1mm), which was designed for the SSB modulation/frequency shifting for the light wavelength λ~650nm and the modulation frequency f_m=15GHz. The calculated 3dB modulation bandwidth was about 4GHz around 15GHz. Next, a Mach-Zehnder optical waveguide composed of single-mode guides was fabricated on the domain-inverted substrate by the proton-exchange method. The width and the depth of the waveguide core were about 3.0μm and 0.8μm, respectively. Finally, 1.7μm-thick Al asymmetric coplanar electrodes were formed on the waveguide by thermal vapor deposition and standard photolithography techniques, after sputtering of a 0.1μm-thick SiO_2 buffer layer. The length of the electrode on the waveguide was 20.5mm. The width of the hot electrode was 15μm and the spacing of the hot and the ground electrodes was 30μm, where the intrinsic impedance was calculated as 50Ω.

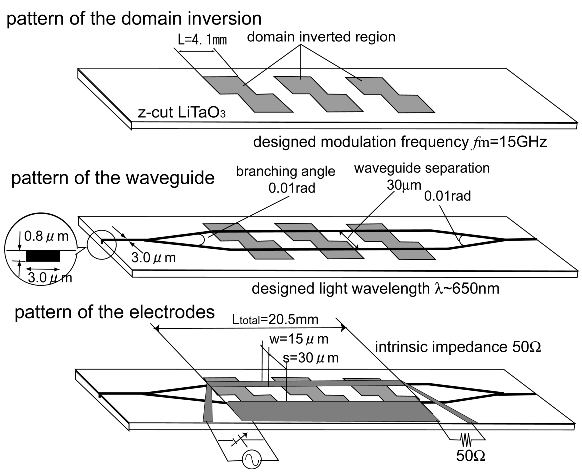

Fig. 3. The designed SSB modulator/OFS and its fabrication sequence.

4. Experiments

The performances of the fabricated devices were measured by a scanning Fabry-Perot interferometer. Figure 4 shows the result obtained for a microwave frequency of 14GHz, a microwave power of 200mW, and an applied DC bias voltage of +10V. In Fig.4, the lower side-band spectrum was almost suppressed and the upper side-band spectrum was observed clearly. The measured conversion efficiency from the carrier to the upper side-band spectrum was about -3dB, which was in good agreement with the calculated one for the modulation power of 200mW. The ratio of the upper side-band spectrum to the lower one was changed by adjusting the DC bias voltage.

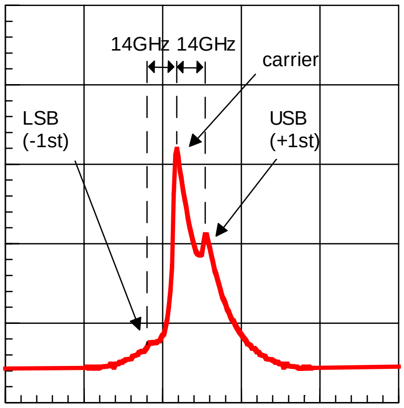

Fig. 4. Observed spectrum of the modulated light.

5. Conclusion

We confirmed successfully the basic operation of the proposed SSB modulator/OFS near the designed frequency. We are now trying to make the further measurements of the fabricated device. Utilizing non-periodic domain-inversion schemes and adjusting each length of inverted and non-inverted regions, it is also possible to enlarge the operation bandwidth and to tune the frequency responses. The details will be presented at the conference.

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