Suppression of low-frequency acoustic resonances in integrated optic lithium niobate modulators

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Abstract. The influence of low-frequency acoustic vibrations on optical signals in integrated optic lithium niobate modulators is considered. It is shown that low-frequency acoustic vibrations can significantly contribute to the modulator transfer function. Characteristics of the acoustic vibrations have been observed. It is shown that these vibrations correspond to excitation of standing Lamb waves. Methods for acoustic resonance suppression have been suggested and verified.

1. Introduction
Fiber optic sensors are widely used as sensitive elements of various measuring systems (fiber optic gyroscopes, current and voltage sensors, seismic streamers and many others) [1-8]. In the applications of lithium niobate modulators dealing with analog signals, especially for high-sensitivity fiber optic sensor signal demodulation and processing [9-11], surface and volume acoustic waves excited by electrical control signals below 1 GHz can result in significant noises and spurious signals. The effects (electro-optic, acusto-optic, piezoelectric, photoelastic, nonlinear optical) exhibited by lithium niobate [12] can lead to a complicated nonlinear interaction of optical signals and excited acoustic waves.

2. Experimental samples and measuring techniques
2.1. Integrated optical phase modulator chips
This paper present a thorough study of acoustic resonant vibrations excited in integrated electro-optic modulators on lithium niobate substrates. Their influence on modulator optical signals was also observed. The object of study was a chip of a phase modulator for a fiber optic gyroscope fabricated on an X-cut plate of single crystal congruent lithium niobate (see figure 1). Titanium in-diffused optical waveguides [13] were oriented along the Y axis. An AC voltage in the frequency range from 0 to 2 MHz was used in the investigations.
2.2. Electrodes impedance measurements

The dependence of absolute value of the electrodes impedance on frequency was measured. It was normalized to the absolute value of capacitive component of the electrode impedance.

2.3. Adaptive interferometry method

An adaptive interferometer based on the non-steady-state photo-EMF [14] was used for vibration measurements and acoustic resonance observation (see figure 2). The continuous laser (Nd:YAG, 532 nm, 200 mW) was used as a light source in the adaptive interferometer. The objective beam reflected from the surface of the modulator chip. The surface vibrations resulted in phase modulation of the objective beam, a movement of the interference pattern. It led to the emergence of the nonstationary photo-EMF on an adaptive photodetector, which was recorded by a selective nanovoltmeter. Calibration of the adaptive interferometer was used to calculate the surface vibration amplitude through the nonstationary photo-EMF signal amplitude.

2.4. Half-wave voltage measurements

Measuring the frequency dependencies of half-wave voltage was carried out to investigate the influence of acoustic vibrations on the optical signal. Conversion of the phase modulation into intensity modulation was performed by a fiber-optic interferometer.

3. Results and discussion

First of all, resonance frequencies of vibrations in the investigated frequency range were obtained by impedance measurements. Excitation of the lithium niobate plate acoustic vibrations resulted in significant change of the electrodes impedance due to inter-electrode gap change and lithium niobate piezoelectric properties. These frequencies were 546 kHz, 735 kHz, 960 kHz (see figure 3), 1349 kHz, 1456 kHz and 1744 kHz.
Figure 3. Frequency dependence of the electrodes impedance near resonance frequency 960 kHz.

Frequency dependence of the surface vibration amplitude near resonance frequency 960 kHz was obtained (see figure 4).

It was found out that the surface vibration amplitude also had a resonance peak. A pattern of the spatial distribution of the acoustic vibration amplitude in this peak was obtained by objective beam scanning along the perpendicular to the inter-electrode gap along the sample surface (see figure 5).

The resonance frequencies were related to standing waves in the lithium niobate plate and depended on its shape and electrode configuration. It was found out that phase velocity of these waves depended on frequency at low frequencies \( (h/\Lambda < 0.5) \) - thickness-to-wavelength ratio, where \( h = 1 \text{ mm} \) - thickness of the sample plate, \( \Lambda \) - wavelength of the acoustic wave). The phase velocity didn't depend on frequency at high frequencies \( (h/\Lambda > 0.5) \). For example, the phase velocities were 1296 m/s \( (h/\Lambda = 0.185) \), 2670 m/s \( (h/\Lambda = 0.35) \), 2737 m/s \( (h/\Lambda = 0.37) \), 2965 m/s \( (h/\Lambda = 0.455) \), 3240 m/s \( (h/\Lambda = 0.6) \) and 3290 m/s \( (h/\Lambda = 0.8) \). Such behavior corresponded to well-known Lamb waves [15,16].

The frequency dependence of the half-wave voltage \( V_{\pi} \) is shown on figure 6. It was similar to the frequency dependence of the electrode impedance.
Figure 6. The frequency dependence of the half-wave voltage near resonance frequency 960 kHz.

The electrode impedance and electrooptic response had similar resonance behaviors [17] because of mechanical deformations and the inter-electrode gap change. The influence of the acoustic vibrations on optical signals could be estimated from impedance measurements.

4. Conclusions
Analysis of the vibration amplitude spatial distributions obtained by adaptive interferometry (see figure 5) was used to elaborate methods for resonance suppression. For example, a change in the chip geometry demonstrated efficient resonances suppression in the range 0 – 3 MHz (see figure 7).

Figure 7. New configuration of the phase modulator chip and admittance measurements of resonant excitation of acoustic vibrations up to 3 MHz. The lines are results of numerical simulation (left axis), the points are experimental data (right axis). Standard chip with parallel lateral edges - dashed line and rhombuses, chip with inclined lateral edges – solid line and triangles.

It is shown that the resonant acoustic vibrations corresponded to excitation of standing Lamb waves. Lamb waves are bulk waves, thus, it is also possible to achieve suppression of vibrations excitation by rigidly fixing the chip to a material having high acoustic energy absorption properties and an acoustic impedance matching the acoustic impedance of the crystal.

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