# $Bi_{12}TiO_{20}$ – Based Fiber-Optical Voltage Sensor

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## 1. INTRODUCTION

There is a greate interest for fiber optical sensor of voltage and electric field in industries at present. These sensors doesn't contains any conductive elements and, as result, doesn't introduce any pertubation in the measuring electric field and very safely. The first works in this field was made quite a long time ago[1-4]. Meanwhile, there are two obstacles for using these sensors in the industries.

Firstly, a sensitivity of the sensors, which have been developed before, are low. The typical sensitivity of the voltage sensors with longitudinal modulation are between 0.039% per 1V RMS[2] and 0.051% per 1V RMS[1].

Secondly, it is unsatisfactory temperature stability of the an entire sensor. Usually, attention has been payed to temperature stability of a crystal parameters[1,2]. Meanwhile, there are additional sources of temperature drift of sensitivity inside the sensor, such as a quarter wave plate. This birefringent element has a temperature sensitivity.

We are proposed the new configuration of a fiber optic voltage sensor, based on the $Bi_{12}TiO_{20}$ crystal. Instead of quarter wave plate we have used the glass back-reflecting prism as a phase-retarding element. By use of this prism, the good temperature stability and excellent sensitivity have been demonstrated.

## 2. BASIC PRINCIPLE OF THE SENSOR

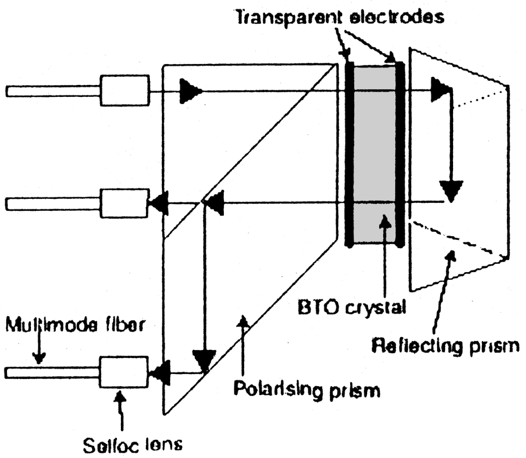


Fig.1. Electric field sensor

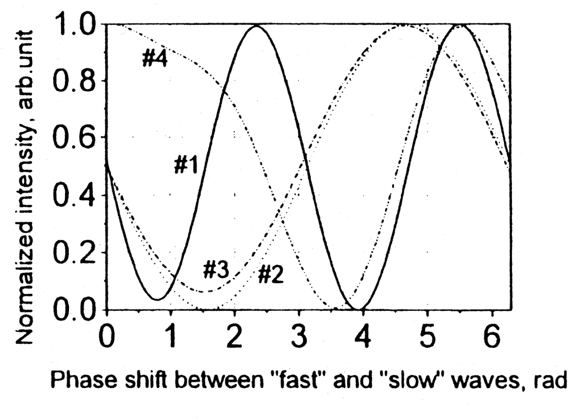


Fig.2.

The optical schemeof the sensor is shown on the Fig.1.

The light from the 850nm-LED is launched into the sensor, using a multimode fiber (300/320μm) and selfoc lens. The light beam goes through the glass polarizing prism and the BTO crystal. The crystal had a parallelepiped shape (5*5*2mm). The sides of a parallelepiped was coincides with the directions of the 001, 010 and 100 axes.

There were transparent electrodes on the surfaces of the crystal. The measuring voltage was supplyed to the transparent electrodes. Further, beam has returned back to the crystal after two reflection from both cathetuses of the prism. The vertical axes of reflecting prism and polarizing prism was misaligned at $45°\pm\vartheta$ angle. The angle $\vartheta$ it is the angle of rotation azimuth of linear polarization due to crystal's intrinsic optical activity. Sign «+» or «-» changes accordingly modification of the crystal (left or right side rotating). Thereby, the beam, which pass through the crystal twice, came back to the polarizing prism. Now, the polarizing prism it is an analyzer. The analyzer has converted the polarisation modulation to modulation of intensity. Both intensity-modulated beams was launched into the fibers, using by selfocs (Fig.1).

The reflecting prism in this case accomplishes two functions. On one hand, it is the beam reflecting devices. Actually, the phase retardance between «fast» and «slow» waves after double passing through the crystal will be doubled. It means, the sensitivity of the sensor will be doubled too. On the other hand, using this

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prism, there is a π/2-phase shift between «fast» and «slow» waves in the crystal. It is necessary for condition of the best sensitivity[5] of the sensor.

Using Jones matrix formalism, the amplitude transfer function of the sensor (Fig.1) can be determined as

$$I=|P^* R(-45°)^*C_{ref} R(45°)^*R(-45°-\vartheta)^*PHASE^* R(45°+\vartheta)^{**}R(-45°)^*C_{dir}^* R(45°)^*E|^2 \quad (4)$$

,where E – the Jones vector of light, which passed through the input polarizing prism; R(.....) – the rotation matrix; $C_{dir}$ – the Jones matrix of the BTO crystal for light, which propagated directly; PHASE – the Jones matrix of back reflecting prism; $C_{ref}$ – the Jones matrix of the BTO crystal for back reflected light; P – the Jones matrix of the analyzer.

Using equation (4) it is possible to compare the sensitivity of the present sensor with the sensitivities of the sensors, which was described before[1,2,4]. We used two-pass sensor in contradistinction from[1-4] when usually authors has used only one pass through the crystal. The dependence of transfer function of the two-pass sensor versus phase shift between "fast" and "slow" waves in the BTO crystal is shows at Fig.2 (curve#1). The curve#2 (Fig.2.) presents the transfer function of the single-pass BTO sensor. The first minimum was achived by the curve #1 when the phase difference between "fast" and "slow" waves is equal by 0.817 radians; while the curve #2 was achived the first minimum when phase difference equal 1.571 radians. It means, the sensitivity of the two-pass sensor approximately in two times more, than the sensitivity of the single-pass sensor.

It is very interesting to compare the sensitivity of different types of crystals as a sensitive medium of the voltage sensor. For instance, the authors[1,2] used the $Bi_{12}SiO_{20}$ as a sensitive crystal. The BSO crystal has a high value of electro-optical constant **r41** and this crystal is well available. The feature of the BSO – it is a high intrinsic optical activity (11.5°/mm). The BTO crystal has a same value of electro-optical constant **r41** , but just a less value of optical activity (1.5°/mm). Usually, the thickness of the crystals was 2mm. There are the transfer functions of BSO-based single-pass (curve #3) and double-pass (curve #4) sensors at the Fig.2. The thickness of the crystal was 2mm. As follows from the callculations, the presence of the optical activity is rather slight influence for the sensitivity of the single-pass sensor (Fig.2, #2 and #3) and extraordinary decrease the sensitivity of double-pass sensor (Fig.2, #1 and #4). It is possible to draw conclusion about desireability of using the crystals with small optical activity (like $Bi_{12}TiO_{20}$ or $Bi_4Ge_3O_{12}$) in the double-pass sensor.

## 3. EXPERIMENT

We have studed the amplitude and temperature dependences of the sensor in the experiment. The amplitude dependence has a good linearity up to 600 V RMS (400Hz). The sensitivity of the sensor (modulation depth) was 0.145% per 1 V RMS. The depth of light modulation due to amplitude 220 V RMS was approximately 32%. The minimum detecting voltage (SNR=3dB, frequency band 1.5-25000Hz) was 0.35V RMS.

We have investigated the temperature stability of the sensor. The phase and counter-phase outputs channels of the sensor was subtract by electronic processing unit for purposes of enhance signal-to-noise ratio and temperature stability. The temperature dependence of the BTO sensor sensitivity was better than ±1.5% in the temperature range from -20°C to +60°C.

## 4. CONCLUSIONS

We have succeeded in developing of new type of the fiber-optic electric voltage or field sensor based on the BTO crystal. The sensor has a excellent sensitivity (0.145% per 1 V RMS) and good temperature stability, within ± 1.5% from -20°C to +60°C.

There is a possibility that this sensor can be use for measurements high voltage impulse phenomena with high accuracy.

## 5. REFERENCES

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