OPTICAL ELECTRIC FIELD MEASUREMENTS BASED ON NON-LINEAR PHENOMENA IN A_2MX_4 CRYSTALS

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Summary

Investigations into the non-linear phenomena in A_2MX_4 (where: A – organic cation or ion of alkaline metal, M – metal, X – halogen) crystals with incommensurate phases are very interesting both from scientific and practical point of view. The thermal hysteresis of birefringence and absorption coefficient, piezooptic, thermooptic and electrooptic effect are observed in selected A_2MX_4crystals. That suggests the possibility of applying these materials to the measurements of electric field intensity by optical methods.

Keywords: optoelectronics, A_2MX_4 type crystals, incommensurate phases, non-linear phenomena, electric field sensors

Pomiary optyczne pola elektrycznego oparte na zjawiskach nieliniowych w kryształach typu A_2MX_4

Streszczenie

Zjawiska nieliniowe w kryształach typu A_2MX_4 (gdzie: A - kation organiczny lub jon metalu alkalicznego, M - metal, X - chlorowiec) z fazami niewspółmiernymi znajdują zastosowanie w pomiarach w praktyce różnych wielkości fizycznych. Najczęściej są to: cieplna histereza dwójłomności, absorpcja piezo-, cieplno- i elektrooptyczna. W pracy podjęto próbę zastosowania kryształów A_2MX_4 w pomiarach natężenia pola elektrycznego metodami optycznymi.

Słowa kluczowe: optoelektronika, kryształy typu A_2MX_4, fazy niewspółmierne, zjawiska nieliniowe, czujniki pola elektrycznego.

Introduction

A quick development of information processing by optical methods as well as measurement methods has been observed over the last few years. It is therefore important to look for new materials that possess useful optical properties. Contactless optical methods of electric field measurement make use of semiconductors and optically transparent dielectrics. The latter are represented by ferroelectric crystals with incommensurate phases of A_2MX_4 type [1-4], where A is an ion of alkaline metal or organic cation, M - metal (e.g. Zn,

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Cu, Co, Mn, Fe, Cd, Be), X – halogen (Cl, Br, F, J). Those crystals are grown from water solutions [1]. It is quite easy to obtain samples of the following dimensions: 1.0 cm x 1.0 cm x 0.5 cm. Depending on the metal ion, the crystals differ in hue: e.g. crystals with zinc are colourless, those with copper are green. Manganese gives them light pink colour, whereas iron makes them resemble amber in colour. Structure modulations, including incommensurate ones, are observed in those crystals [1, 3]. Hygroscopicity is the main disadvantage they have.

Possible applications of A_2MX_4 crystals optical properties

Below, a proposal for the electric field sensor is presented. It makes use of non-linear optical phenomena characteristic of A_2MX_4 crystals with incommensurate phases.

Measurement methods

The basic methods involved in investigations into A_2MX_4 crystals are optical measurement methods of absorption coefficient, absorption spectra and birefringence as the temperature function [1]. The measurement of absorption spectra with spectrophotometric method is taken with the measurement set which consists of the light source (helium or xenon lamp and the like), the optical spectrometer with spectrum recording system and the cryostat which ensures the sample will have appropriate temperature. Birefringence measurement by Senarmont method makes use of the change in light polarisation at birefringence medium. The measurement apparatus includes the light source and detector, polarizer and analyser and a sample located in the optical cryostat. Those methods provide a basis for investigations into electrooptic effect.

Electrooptic effect

Electrooptic effect consists in changes in optical parameters (values of refractive index) of a material upon the impact of the external electric field [5-9]. The general description is much simpler if the electric field is applied along one of crystallographic axes (co-ordinate axis for optic indicatrix description).

Two types of electrooptic effect are differentiated, depending on the direction along which the electrostatic field is applied:

a) longitudinal effect – the direction of the vector of the electric field follows to the light propagation direction;

b) transverse effect – the direction of the vector of the electric field is perpendicular to the light propagation direction.

The values of electrooptic coefficients for selected dielectrics are given in the literature [7]. The linear electrooptic effect comes useful in optoelectronics, while constructing amplitude and phase light modulators and also for light switches [5]. In those applications, the electrooptic effect for quick alternate fields is of particular importance. For the majority of cases, the values of electrooptic coefficients for high frequencies are clearly lower [7]. As regards crystals of A_2MX_4 type, the electrooptic effect has been investigated in many crystals, for instance, K_2Se0_4, $(NH_4)_2BeF_4$, Rb_2ZnCl_4, K_2ZnCl_4, Rb_2ZnBr_4, $[N(CH_3)_4]_2ZnCl_4$ [1, 9].

In the present paper, we present a concept of electric field meter, which relies on the optic phenomena that are observed in A_2MX_4 type crystals (Fig. 1).

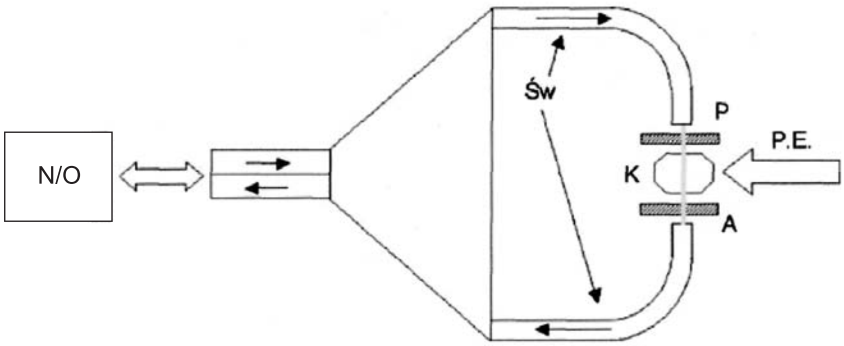

Fig. 1. Concept of the optical system for electric field intensity measurements: N/0 – sending-receiving system, Św – optic fibres, P – polarizer, A – analyser, K – A_2MX_4 crystal, P.E. – electric field

The measurement of the electric field intensity makes use of the changes in the intensity of a light beam passing through a crystal located at the measurement point. As the crystal does not change the absorption coefficient but it does change the birefringence value, a polariser and analyser should be used, placed on both crystal sides. A pair of optic fibres guides the laser light to and from the crystal. The polarizer shows the light from the laser at the angle 45° to the transverse crystallographic axis. In a birefringent sensor crystal, two rays: an ordinary ray and an extraordinary one of approximately the same amplitudes propagate at different velocities. The difference of optical paths is described by the dependence (1), in which *An* is the crystal birefringence when the electric field is lacking.

$$\Delta\gamma = \frac{2\pi}{\lambda}\Delta nd \qquad (1)$$

where: λ – wavelength, Δn – crystal birefringence at room temperature, d – sample thickness

A change in the electric field intensity is accompanied by the value Δn increase by $\delta\,(\Delta n)$, which affects the change in the optical paths difference by $\delta\,(\Delta\gamma)$, which in turn has an effect on the polarisation of the output beam. The light beam having passed through the crystal gets to the analyser, where it is partially attenuated at a degree dependent on the polarisation plane rotation. A photodetector converts the beam into an electric signal. The output power of the light beam can be expressed by the formula (2):

$$I_{wy} = I_{we}\cos^2\left(\frac{\delta(\Delta\gamma)}{2}\right) \qquad (2)$$

if the angle between the polarizer and the analyser equals $\Delta\gamma/2$ and when Fresnel reflection is disregarded [5].

From expressions describing the electrooptic effect, it can be concluded that the power of the output beam received by the detector depends on changes in birefringence caused by electric field. For example, the value of the effective electrooptic coefficient for the crystal K2ZnCU is approx. 9 10^{-8} cm/kV (it was measured for λ – 632 nm). When the sample thickness is approx. 0.8 cm, we obtain $\delta\,(\Delta\gamma) \sim 0.41°$. Therefore, it can be deduced that the power changes by 0.1% per each kV/cm, at the assumption that the difference in optical paths under initial conditions amounts to 90°. Recording such small changes in power is possible when we use 12-bit analogue-to-digital transducer. The sensor can work as a detector of strong electric field at the sites that are not easily accessible. There is little likelihood that it will be applied to high accuracy measurements or when the fields are weak. The sensor has a number of advantages as it is relatively cheap to manufacture due to the low cost of the crystals that are used, moreover it is resistant to the action of strong fields and also that electrooptic coefficient is weakly dependent on temperature.

At the current stage of work, it is not possible to present practical measurements that could be applicable to mechanical engineering. Crystal laboratory investigations (i.e. stating the crystals processing characteristics) [1] indicate how it could be used for the construction of field measurement converter. The method of optical measurement of electric field, presented in the paper, is applied to the prototype construction of the position converter used in robotics and production automation.

The principle of magnetic reading is based on the use of hard magnetic metal covered with permanent magnetisation (Fig. 2). It is composed of alternately arranged positive and negative poles.

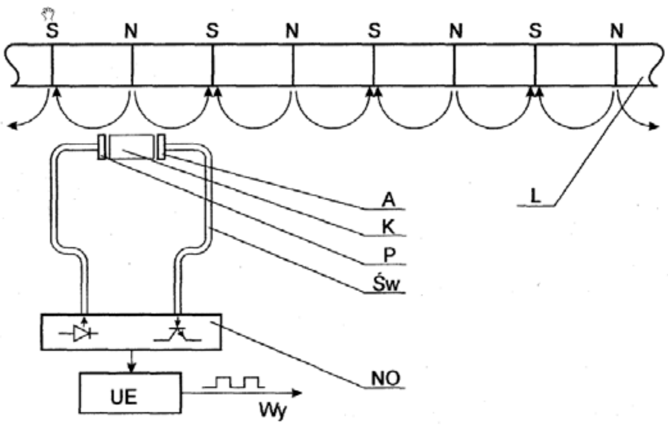

Fig. 2. Magneto-optic position converter, T – measurement gauge period, L – gauge, Św – optical fibre, A – analyser, K – crystal, P – polarizer, NO – sending-receiving system, UE – processing system of light intensity signal

The pitch is read by an optical sensor (A_2MX_4 type crystal), in which the light beam is changed in the magnetic field. The electrooptic phenomena is modulated in accordance with alternate magnetic field in the course of the measurement gauge shift. At the electronic system output, one receives a rectangular signal whose period is equal to the magnetic gauge period.

Systems that process signals from position converter are presented in literature [10-12]. Due to magnetic reading sensitivity to differences in the reading space, small quantization periods are very difficult to obtain. HEIDENHAIN magneto-resistance converters using magnetic reading have got quantization periods of the order of 400 μm.

That is why in rotation-impulse converts, depending on the pitch circumference, magnetic converts have got 2600 signal periods per rotation at the most.

Conclusions

The paper shows the possibility of the application of new optically active A_2MX_4 type crystals with incommensurate phases to the measurements of the electric field. The concept of sensors developed by the authors shows it is necessary to conduct further investigations into other crystals of A_2MX_4 type. Special attention should be paid to the temperature impact on very small changes in birefringence. It is a very important issue for the temperature measurement accuracy and for thermal compensation while measuring the electric field. In this paper, we present the prototype of the position converter, which is constructed.

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