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# PLZT ceramic optoelectronic analog, logic and switch devices

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The new concept of light modulation transmitted through a 9/65/35 PLZT ceramic plate at room temperature has been described. The four-electrode PLZT ceramic light modulators have been used to construct analog, logic and switch devices.

## 1. Introduction

In the previous paper [1] the technology of PLZT ceramic material production has been described*. The electric, piezoelectric and electrooptic properties and the structure of such a material has been also presented. The PLZT 9/67/33 material was used to construct white and Ne-He laser light modulator. The static and dynamic properties of a simple light modulator have been investigated.

The subject of the paper is a new concept of light modulation by using PLZT 9/65/35 ceramic material. PLZT 9/65/35 ceramic material was made in the same way as PLZT 9/67/33 ceramics. In this case better properties, in particular a better transparency, have been obtained. It was possible due to the elaboration of optimal technological parameters.

The table contains some characteristic parameters of the improved PLZT ceramic material.

Table

| Tan of loss angle $\tan\delta$ | Relative dielectric constant $E_{33}^{T}/E_0$ | Differential resistance $\Omega$ | Poisson coefficient $\sigma$ | Electromechanical coupling coefficient $k_p$ | Maximal residual polarization $Ps_{\max}$ C/m² | Diameter $d = 18$ mm<br>Thickness $g = 0.94$ mm<br>Resistance $R = 10^{11}\,\Omega$ |
|---|---|---|---|---|---|---|
| 0.0260–0.0347 | 4561–4914 | 94.6–141.5 | 0.291–0.304 | 0.088–0.212 | $28 \cdot 10^{-2}$ | |

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* In the paper [1] an obvious mistake has been made. The ceramic PLZT samples were made not by using pressing sintering techniques but by traditional technique. The samples were perched in the lab-oven at atmospheric pressure.

## 2. Some electric and piezoelectric properties of investigated PLZT ceramics

All dielectric and piezoelectric measurements were made by the resonance method, according to the IRE Standard, using two-terminal-pair $\pi$ type systems. Measurement of histeresis loop made by the Sowyer-Tower method was performed at room temperature and at the frequency of 0.1 Hz. All the measurements refer to polarized samples, $E = 2000$ kV/m.

PLZT 9/65/35 ceramic material shows electrooptic Kerr-effect [2]. The samples 200 $\mu$m thick are characterized by transparency of about 52°/₀, mass density 7,740-7,788 kg/cm$^3$, porosity of about 1°/₀, the size of crystallites being 2–10 $\mu$m (Figs. 1 and 2). In the structure there appears a crystalic solid which crystalizes in a regular crystall lattice with a lattice coefficient $a = 0.408$ $\mu$m.

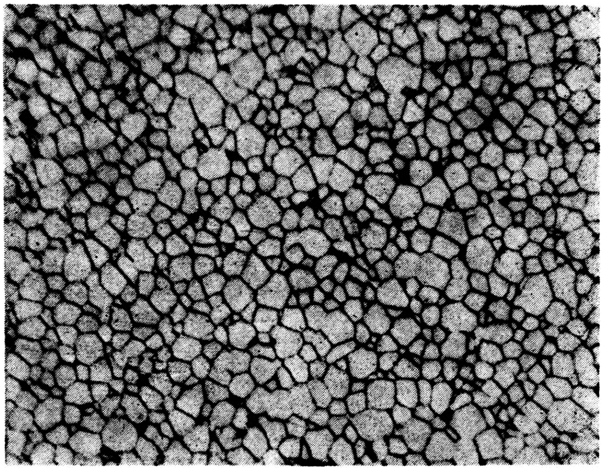


Fig. 1. The grain structure photomicrography of ceramic PLZT 9/65/35 sample (1 cm–2 $\mu$m)

The new electrooptical ceramic material was used to construct special light modulator. The light modulators were investigated in optoelectronic analog, logic and switch devices.

## 3. Optoelectronic analog devices

Optoelectronic PLZT ceramic modulator can be used for construction of optoelectronic analog devices. The simplest application of such modulator is a voltage transformer. In order to investigate its metrological properties a measuring system has been constructed which is schematically shown in Fig. 3. It consists of glow (redheat) light source (electric bulb) *B* in which the electric current of glow fiber may be controlled. Mat plate *MP* makes the output signal value independent of the state of electric bulb filters. Lens $S_1$ concentrates the scattered light beam which next passes through the red filter *RF*. Polarizer *P* polarizes nearly monochromatic light beam, which further on passes through a four-electrode PLZT modulator.

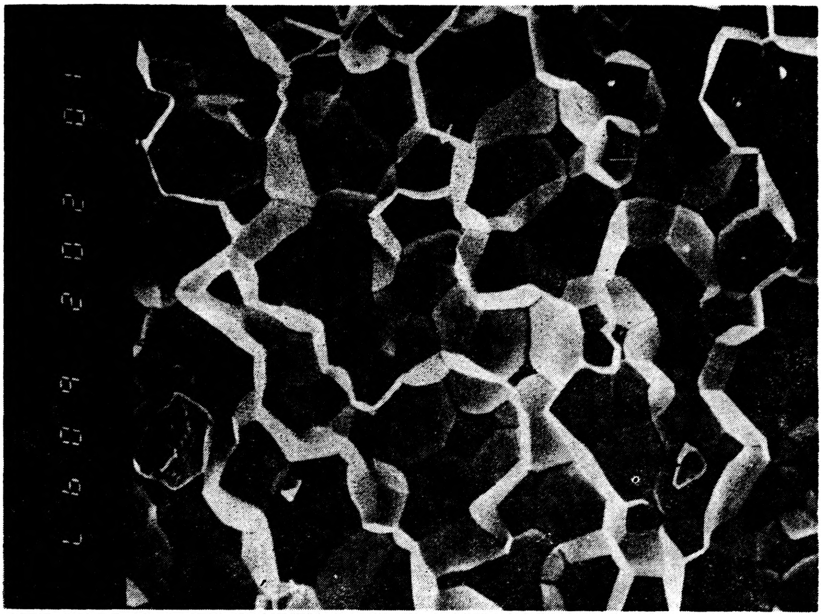


Fig. 2. Turning-point of scanning photomicrography of ceramic PLZT 9/65/35 sample (1 cm–0.5 $\mu$m

The way in which modulator electrodes are connected with the source of the voltage being measured guarantees that electrooptic Kerr-effect is utilized in all inter-electrode working space of the plate. Due to such a construction of PLZT modulator greater amount of the incident light may be utilized. Behind the analyzer *A* and lens *S*2 there is situated a photodetector *Phot.* Polarization plane of the analyzer is perpendicular to the polarization plane of the polarizer. Phototransistor connected in temperature-compensated bridge-system was used as the photodetector. In the bridge-system the compensation of the initial photodetector current was forseen. Modulator and optical system have the volume equal to $4 \cdot 10^{-6}$ m$^3$ the volume of the whole transformer being equal to $15 \cdot 10^{-6}$ m$^3$.

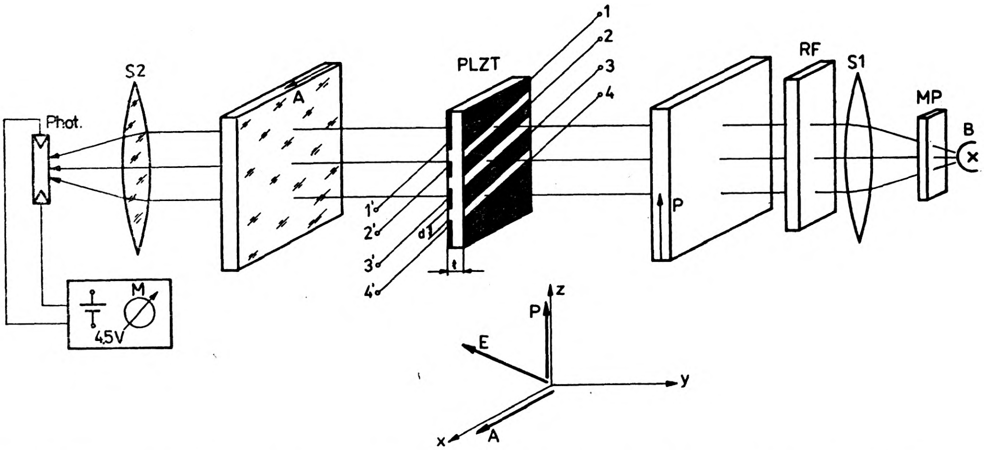


Fig. 3. The scheme of construction of PLZT ceramic voltage transformer, shown schematically

The optical transfer function of the device is a nonlinear function (see Fig. 8 – curve 1) which is not a shortcoming provided that the transformer is used to measurements of approximately constant value, for example the voltage in electric power line. The advantage of the said modulator is that it can work at constant and alternating voltages.

In the case of alternating voltage the mean value of this voltage is measured. By simple changes of the simplifier gain in photodetector circuit an analog meter can be obtained, its indications being proportional to the rms (efficacy) value of alternating voltage. For alternating voltage the transformer works properly within acoustic frequency range. In other frequency ranges the device was not tested. The measured voltage range of the described transformer was equal to 1000 V. The shortcoming of electrooptic voltage transformer is its temperature error reaching $5^0/_0$ in the 283–303 K temperature range. Another shortcoming was noted also, i.e. the evaporation of metal electrodes from ceramic surfaces occurring after a longer work-time.

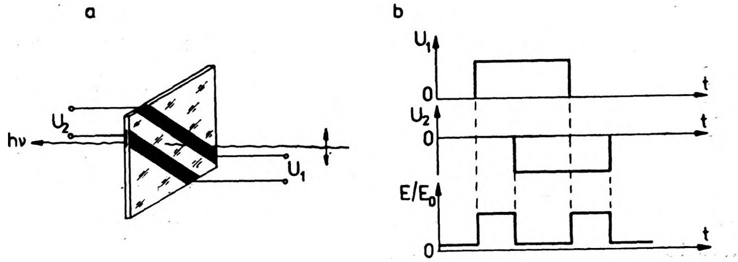
## 4. Optoelectronic switch and logic devices

Further progress of electronics depends on the development of technology assuring a high operation velocity of electronic elements and possibility of their miniaturization. New possibilities in this respect are offered by optoelectronics and, particularly, by integrated optoelectronics. An achievement of the integrated optoelectronics is the construction of a modulus containing a controlled source of light, modulating element, waveguides, and photodetector. At present, the optoelectronic systems use an outside light source, most frequently in form of lasers. Laser gives the possibility of producing interference patterns. The integrated optoelectronic moduli containing an interferometer are described in the work [3]. Due to the possibility of changing the interference patterns, the systems described do not require the application of polarizers. Optical triode, [3] as well as other optical switch and logic devices [4, 5] are also built in.

All these devices are characterized by a high operation rate and high resistance to disturbances.

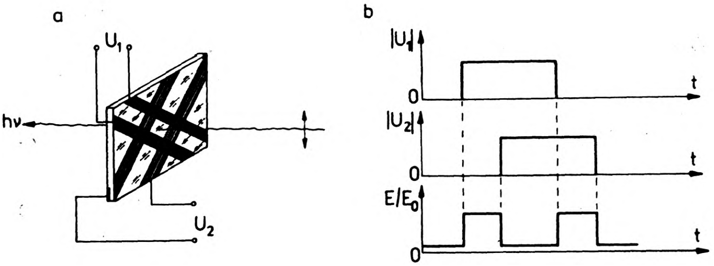
The PLZT ceramic elements can be also succesfully used in construction of optoelectronic logic systems. These systems contain: light source, polarizer, modulating element, analyzer and photodetector. In the investigated switch systems Ne-He laser was used as a light source, while a thin plate of PLZT ceramics with metallic electrodes located on its surfaces worked as the modulating element. Electric voltage applied to the electrodes generates an electric field in the plate. The direction of electric field makes the angle 45° with respect to the laser beam polarization plane. Electrooptic Kerr-effect observed in the PLZT ceramic material is responsible for the amplitude light modulation. The depth of light modulation is transformed into the electric current in the photodetector circuit. All the investigated optoelectronic switch and logic devices are schematically presented in Figs. 4–7.

All the devices have a common feature – they include light modulator which is equipped with four electrodes. The four-electrode modulators are particularly useful for construction of optoelectronic switch and logic devices.



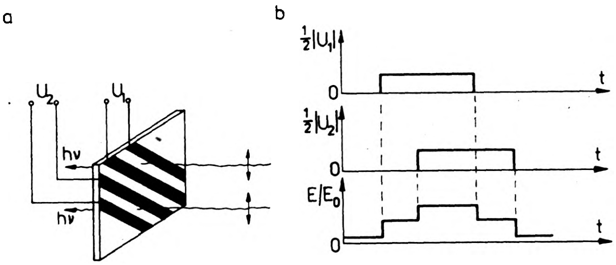
| Logic States | | |
|---|---|---|
| $U_1$ | $U_2$ | $E/E_0$ |
| 0 | 0 | 0 |
| 0 | -1 | 1 |
| 1 | 0 | 1 |
| 1 | -1 | 0 |

Fig. 4. Four-electrode PLZT ceramic switch light modulator: a. two pairs of electrodes are placed parallelly on both sides of PLZT plate, b. timing of modulating voltage, c. table of logic states



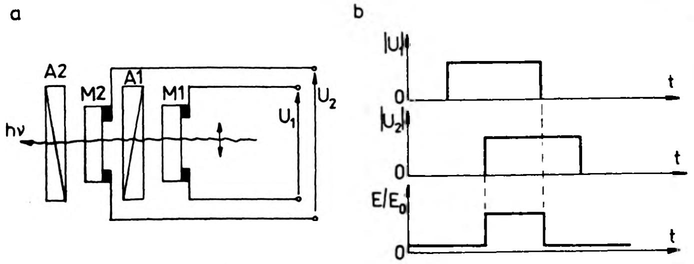
| Logic States | | |
|---|---|---|
| $\|U_1\|$ | $\|U_2\|$ | $E/E_0$ |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |
| 0 | 0 | 0 |

Fig. 5. Four-electrode PLZT ceramic switch light modulator: a. two pairs of electrodes are placed perpendicularly on both sides of PLZT plate, b. timing of modulating voltage, c. table of logic states



| Logic States | | |
|---|---|---|
| $\|U_1\|$ | $\|U_2\|$ | $E/E_0$ |
| 0 | 0 | 0 |
| 0 | 0.5 | 0.5 |
| 0.5 | 0 | 0.5 |
| 0.5 | 0.5 | 1 |

Fig. 6. Four-electrode PLZT ceramic switch light modulator: a. two pairs of electrodes are placed parallelly on one side of PLZT plate, b. timing of modulating voltage, c. table of logic states



| Logic States | | |
|---|---|---|
| $\|U_1\|$ | $\|U_2\|$ | $E/E$ |
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

Fig. 7. Double PLZT ceramic light modulator: a. schematic construction of double modulator, b. timing of modulating voltage, c. table of logic states

Switch system shown in Fig. 4 contains two pairs of parallel electrodes situated on either sides of ceramic plate. The pair of electrodes situated on one side of plate are supplied with electric voltage. If the direction of the polarizer polarization plane is perpendicular to the direction of the laser beam polarization plane and $U_1 = 0$, $U_2 = 0$ – the light modulation is not observed. If the voltage is applied to one pair of electrodes, the system operates as a common ceramic light modulator. If, however, $U_1 = -U_2$, the output signal is also equal to zero, since the resultant intensity of electric field in the working space of modulator decreases to the minimum (Fig. 4b). Logical states (levels) of these devices are shown in the table (Fig. 4c).

The switch light modulator shown in Fig. 5 includes also two pairs of electrodes. In this case the electrodes situated on both the sides of ceramic plate are in mutually crossed position. Such a modulator operates as common light modulator if $U_1 \neq 0$ and $U_2 = 0$, as well as if $U_1 = 0$, $U_2 = 0$, If, however, $U_1 = U_2$, the output signal decreases to the minimum, since the resultant electric field in the working space of plate is directed parallelly or perpendicularly to the direction of the incident light beam polarization plane, and in such a case the light modulation is not possible (Fig. 5b). Logical states of the described devices are shown in the table (Fig. 5c).

An example of a multilevel optoelectronic switch device is shown in Fig. 6. The device contains two pairs of electrodes situated on one side of a ceramic plate. The device can distinguish three logic levels (Fig. 6b):

1. $U_1 \neq 0$, $U_2 = 0$ or $U_1 \neq 0$, $U_1 = 0$,
2. $U_1 \neq 0$, $U_2 \neq 0$,
3. $U_1 = 0$, $U_2 = 0$.

The logical states of such devices are shown in table (Fig. 6c). The extinction ratio was as high as 10.

Other interesting results can be obtained with a four-electrode modulator which is shown in Fig. 7. It is a coupler switch modulator complex of two single modulators *M*1 and *M*2. These modulators are separated by an analyzer. The polarization plane of the latter is crossed with respect to the polarization plane of the incident light beam. The polarization plane of the external analyzer *A*2 is perpendicular to the polarization plane of polarizer *A*1 and parallel to the laser beam polarization plane. Such system operates when the voltages $U_1$ and $U_2$ are applied simultaneously to the modulator electrodes. When only a single voltage, i.e. either $U_1 \neq 0$, $U_2 = 0$ or $U_1 = 0$, $U_2 \neq 0$ is applied, the output signal is contained in 3–7⁰/₀ range of its maximum level in the whole voltage range (Fig. 8) A simultaneous work of both the voltages $U_1$ and $U_2$ causes electrooptic transfer function of the modulator to be of switch type (curve 2). In the same figure electrooptic transfer function of single modulator is shown, for comparative reasons.

The said modulator can be used in multiplication of two voltage signals, however, within very limited voltage range. Moreover, in order to multiply voltage signals $U_1$ and $U_2$ the initial voltage polarization of PLZT ceramic sample by direct voltage is required. In the system investigated the polarization voltage was 750 V and multiplication range for direct voltages was equal to only 100 V. The output light intensity was measured by the voltages $U_1 = U_2 = 750$ V with respect to the level of output light intensity.

The system operates properly as an analog/switch modulator as well. Table of logic states of such devices is shown in Fig. 7c.

In the case when the sinusoidal alternating voltages $U_1$ and $U_2$ are applied the output signal contains, in general, dc and ac components. In other switch/amplitude modulators the d.c. signal components are the functions of $U_1U_2\cos\varphi$ or $U_1U_2\sin\varphi$, while for the established amplitudes of voltages, $U_{1m}$, $U_{2m}$, they are the functions of the angle $\varphi$. The angle $\varphi$ is a phase shift between the signals $u_1$ and $u_2$: $u_1 = U_{1m}\sin\omega t$; $u_2 = U_{2n}\sin(\omega t+\varphi)$.

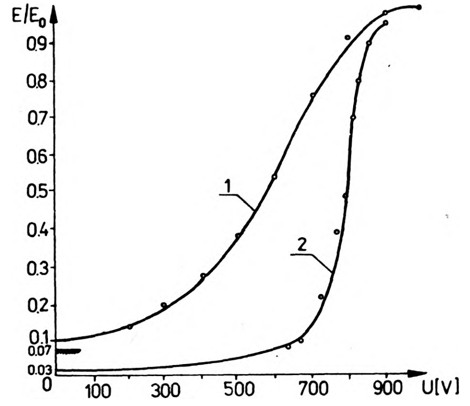


Fig. 8. Static electrooptic characteristics of PLZT modulator at room temperature: 1 — single modulator, 2 — double modulator, $E/E_0$ — light intensity ratio

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## Керамические оптоэлектронные аналоговые, логические и переключательные приборы PLZT

В работе описана новая концепция модулирования светового потока, проходящего через керамическую пластинку 9/65/35 при комнатной температуре. Четырёхэлектродный керамический модулятор PLZT использован для построения аналоговых, логических и переключательных приборов.