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VISUALIZATION OF RADIATION IN THE MILLIMETER AND SUBMILLIMETER RANGE BY MEANS OF LIQUID CRYSTALS

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A waveguide variant of a liquid-crystal indicator, for the millimeter and submillimeter range, is considered. Its design, principle of operation, and basic parameters are described. Pictures of the heat field, recorded by the indicator, are presented, with variation of the wavelength of the radiation. Within the operating temperature range, it is determined how the wavelength selectively reflected by the liquid crystal structure, under illumination with white light, depends on the value of the absorbed power.

A characteristic property of cholesteric liquid crystals is the selective reflection of visible light by the layered structure of the material in a certain temperature interval ΔT; this makes possible their application for visualization of electromagnetic radiation[1,2]. When a liquid crystal is illuminated with white light, there is observed in the reflected beams a colored picture, whose tint is determined by the spectral content of the reflected light. Upon change of the specimen temperature, the wavelength of the reflected light changes within the visible range from the red to the violet. The size of the interval ΔT depends on the chemical composition and structure of the liquid-crystal material; it varies over a wide range and may amount to a few degrees or to tens of degrees. Because of this, liquid crystals can be used for visualization both of large and of small levels of electromagnetic radiation.

The principle of the research and the design of liquid-crystal indicators (LCI) have been quite fully described in a number of papers devoted to visualization of the infrared and centimeter range[3,4]. An LCI for indicating the radiation of a submillimeter laser has been described[5]. The greatest difficulty arises in application of liquid crystals to the study of the distribution of the intensity of high-frequency power in waveguide transmission lines in the millimeter and submillimeter range; this is chiefly due to the extremely small dimensions of the waveguide circuits. The periodicals contain practically no data on the waveguide variants of such liquid-crystal indicators.

We have developed an experimental model of a waveguide LCI in the millimeter and submillimeter range, for study of the distribution of absorbed power in a film bolometer, and have determined its basic parameters. The scheme of the indicator is shown in Fig. 1. On a lavsan ($CC_{10}H_8O_4$) base of thickness 30 microns, possessing sufficient simplicity, rigidity, and thermal and chemical stability, is deposited a dark background of finely divided carbon black. The dark background of black color serves to increase the contrast of the colored image. A uniformly thick layer of liquid-crystal material, consisting of a mixture of 40% cholesteryl nonanoate and 60% cholesteryl oleate, transforms the heat image of the received signal to a visible one. The thickness of the liquid-crystal layer is 15 to 20 microns; the operating temperature interval is ΔT = 4.5°C (from 32 to 36.5°C). On the liquid crystal is fastened a thin lavsan film of thickness 10 microns, to protect the system from external influences. For absorption of the radiation being investigated, there was vacuum-deposited on to the reverse side of the base a thin metallic film of nichrome, with surface resistivity $R_\square$ = 90 ohms per square.

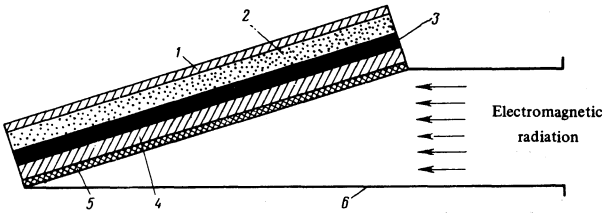

FIG. 1. Scheme of the liquid-crystal indicator: 1, protective covering; 2, liquid crystal; 3, dark background; 4, base; 5, absorbing layer; 6, waveguide section.

The system described overlaps the whole cross section of the waveguide, 1.8×3.6 mm^2, at a small angle to its axis, and insures good absorption of the types of wave whose polarization vector lies in a plane normal to the plane of the film. The heat energy liberated in the absorbing layer on conversion of the electromagnetic radiation is transmitted to the liquid-crystal layer. The latter becomes heated and, on illumination with white light, reproduces a colored image corresponding to the distribution of temperature in the absorbing layer under the influence of the incoming signal. The operation of the indicator was calibrated on the basis of its change of color when a constant current was passed through the metallic absorbing layer. The experiment was conducted at wavelengths 5.6, 4.6, 3.8, 2.2, 1.9, 1.7, and 0.34 mm. Visual observation and photography were carried out in the direction perpendicular to the plane of the LCI. For illumination with white light, two powerful photoflood-lamps were used.

Figure 2 shows black-and-white photographs, obtained with color negatives, illustrating the distribution of heat energy over the area of the indicator as the

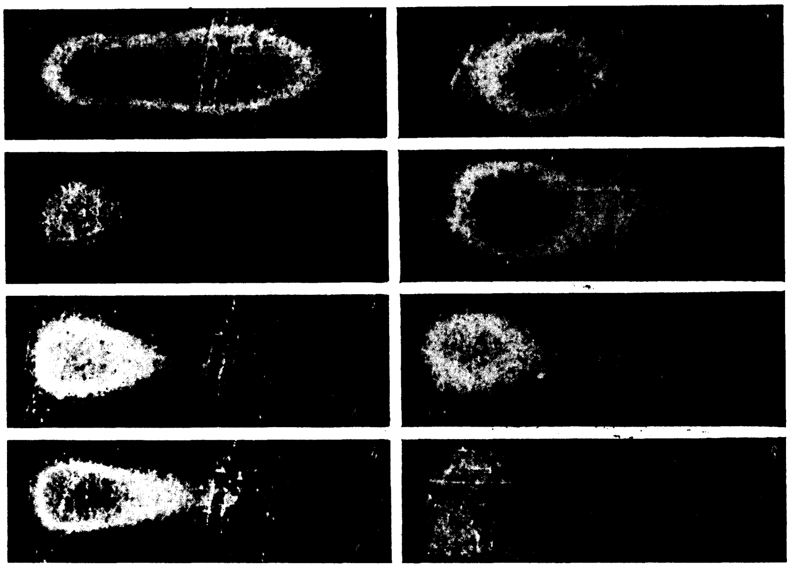

FIG. 2. Pictures of the heat field observed on the indicator: 1, at constant current; 2, at wavelength (in mm) 5.6; 3, 4.6; 4, 3.8; 5, 2.2; 6, 1.9; 7, 1.7; 8, 0.34.

wavelength of the radiation is changed. The incident field for each wavelength was polarized in the plane parallel to the narrow wall of the waveguide. The pictures of the heat distribution are observed on the black background of the backing. The dark regions correspond to the maximum level of liberated heat energy and have a blue-violet color. The light regions are characteristic of a drop of temperature and are successively colored green and red.

As is seen from Fig. 2, in work on the fundamental H_{10} mode, heating of the film occurs only on a small section toward the incident radiation. This is explained by the large transformation of the H_{10} wave to waves of higher types, for which the conditions for optimal absorption are not fulfilled. With increase of frequency, obviously, there is an increase in the part of the energy of the incident field that is transformed to energy of magnetic types, and this causes a spreading of the heat contour over a larger part of the surface. In the submillimeter range, an almost uniform temperature profile is observed along the film; that is, in this case the absorber behaves as a good quasioptic device. The power level of the radiation was kept the same in all cases.

In the course of the experiment, we found the dependence of the wavelength of the light reflected by the liquid-crystal structure, that is the color of the indicator, on the value of the absorbed power ΔP (mW) = $P - P_0$, where P_0 is the minimum power level of the incoming signal, corresponding to the initial value of the temperature in the interval ΔT (Fig. 3), With the aid of Fig. 3 one can estimate the relative distribution of the intensity of the electromagnetic radiation over the cross section of the waveguide, in power units, with allowance for the thermal boundary conditions.

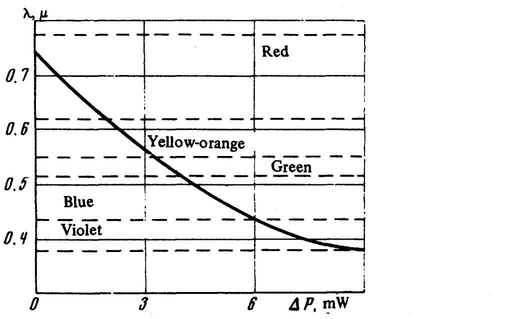

FIG. 3. Dependence of the wavelength selectively reflected by the liquid-crystal structure, under illumination by white light, on the value of the absorbed power.

Within the limits of the operating temperature interval, the liquid-crystal indicator showed good efficiency, with the following values of the basic parameters: sensitivity $\sim 10^{-3}$ W, time constant ~0.1 sec, resolving power ~2 to 3 lines per mm.

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