THERMOCHROME DISPLAYS BASED ON METAL – SEMICONDUCTOR PHASE TRANSITION IN VANADIUM OXIDES

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Operating principles of thermochrome displays of a new type are examined. Underlying these displays is the phenomenon of a metal–semiconductor phase transition observed in vanadium oxides.

An enlarged search for new methods and principles to produce displays to exhibit literal, digital, and other information has recently been conducted. In addition to the so-called active displays (incandescent bulbs, cathode-luminescent and gas-discharge instruments), passive displays which change color or transparency in the visible spectrum range under different external effects are attracting special attention. An example of this kind of display which is already operating successfully in many instruments is the liquid-crystal display.

Despite the number of evident advantages, liquid-crystal displays have substantial disadvantages, such as the tendency to an irreversible color change with time and the difficulties in producing large dimension items.

The properties of a thermochrome film material, which are based on the phase-transition phenomenon occurring in some vanadium oxides [3], have been described in a number of recent papers [1, 2]. The phase transition is characterized by the fact that at a definite temperature the electronic properties of the vanadium oxide layer and, particularly, its optical characteristics, the index of refraction and light absorption in the visible-wavelength band, change abruptly and reversibly. The temperature of the vanadium oxide layer transition can be given in the 40-70°C band depending on the technology of layer fabrication. In order to magnify the effect related to the change in optical properties which occurs during the phase transition, the phenomenon of light interference is used in the material produced, where the oxide layer is superposed on a metal mirror sputtered on a dielectric substrate, for instance, mica, quartz, etc. The thickness of the oxide layer fluctuates within 500-2500 Å limits. As a result of the interference of the light reflected from the oxide–air and oxide–metal mirror interfaces, part of the waves from the visible spectrum is extinguished and does not reach the eye of the observer. We hence observe a material colored light-blue, blue, green and other colors. The film color is interferential in nature and depends on the optical path length of waves of the visible band in the oxide film. The optical pathlength is determined by the initial thickness of the vanadium oxide film, as well as by its refractive and absorptive indices. All these parameters are varied in a controlled manner during manufacture, which explains the extensive set of colors obtained. A change in the optical constants, and therefore, in the optical path length of the light occurs during heating of the film above the phase-transition temperature because of rearrangement of the electron configuration of the oxide. Consequently, the interference conditions change and the other wavelengths are already subtracted from the spectrum of wavelengths reflected from the material and incident on the eye of the observer, as compared with the initial state. Hence, the color of the material changes sharply during a phase transition.

The spectrum behavior of the light reflection coefficient before and after the phase transition, as well as the construction of the light reflector, are shown in Fig. 1. It is clear that such a light reflector possesses reversibility because of the reversibility of the phase transition in the oxide layer. The thermochrome material produced has been designated FTIROS for phase-transformation, interference, and reversing light reflector.

Structurally, the reflector is executed so that the heat to the thermochrome layer comes from the plane thin-film resistance electrical heater through the dielectric layer. Hence, in thermal respects we deal with the problem of heating an unbounded plate [4].

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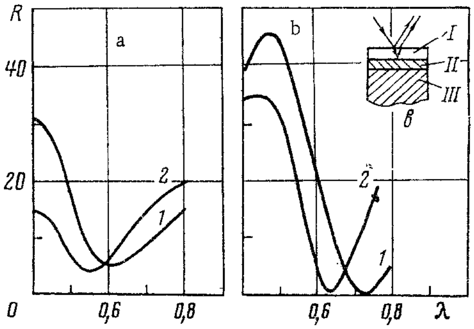

Fig. 1. Spectrum behavior of the light-reflection coefficient before (1) and after (2) the phase transition; R is the coefficient of reflection, %, and λ, the wavelength of light, μ. a) A layer with 0.25 color contrast; b) a layer with 0.55 color contrast; c) light-reflector construction; I) thermochrome vanadium oxide layer; II) reflecting mirror; III) substrate.

TABLE 1. Comparative Display Characteristics

Display	Shape	Specific power consumption (minimal), mW/cm²	Minimum actuation time, msec	Color	Longevity, h	Utilization temperature range, °C
Liquid crystal	Planar	10^{-3}	10—200	White, black	15000	10—70
Incandescent	Cylindrical	110—165	200	Arbitrary with color-filter use	10000	—50—125
Thermochrome	Planar	5—10	200	Arbitrary	Not below 10000	—60—60

In practice it is required to estimate the "switch-on" and "switch-off" time for the display, as well as the power needed to communicate the phase-transition temperature to the thermochrome layer. Since the thickness h of the dielectric is small, usually $\leq 10^{-3}$ m, the Biot criterion for such a problem is $\mathrm{Bi} = \alpha h/\lambda < 0.1$. The coefficient of heat conduction for such dielectrics as mica, glass, fused quartz was taken for this estimate, while the heat-elimination coefficient α in air was considered equal to 10 W/m · deg. As is known [4], the surface temperature in this case is close to the temperature of the center of the plate; there is practically no temperature drop between the surface and the middle of the plate. We deal here with heating according to the Newton law, the so-called external problem.

The solution of the Newton equation for the heating ($T_0 > T_i$) or cooling ($T_0 < T_i$) cases will have the form

$$\frac{T - T_0}{T_i - T_0} = \exp(-\mathrm{BiFo}). \tag{1}$$

Estimates by means of the formula show that the "switch-on" and "switch-off" times of a thermochrome layer deposited on one side of a 10^{-4}-mm-thick mica plate heated by a nichrome electrical heater on one side of the plate is 2 sec. This agrees well with the experimental results obtained.

It is also easy to show that the heat flux S needed to heat the layer to the phase-transition temperature is

$$S = \alpha(T - T_i) \tag{2}$$

and has the value ~50 mW/cm², which also agrees satisfactorily with experimental results. Higher values of the thermal fluxes ~100-150 mW/cm² obtained in experiment are explained by heat flowing away on the current-delivering contacts and also by the fact that a power ~10 mW/cm² leaves the surface of the heated layer because of radiation.

One of the most important display parameters is the color contrast. Different methods of determining the color used in colorimetry [5] can be used and then the concept of color contrast can be a combination of them. However, the most rigorous method of estimating the color contrast is apparently the method for which the colors are determined by using measurements of the spectrum behavior of the reflections from the colored surface [6]. Color contrast is hence determined by analogy with brightness contrast for black-and-white objects [7].

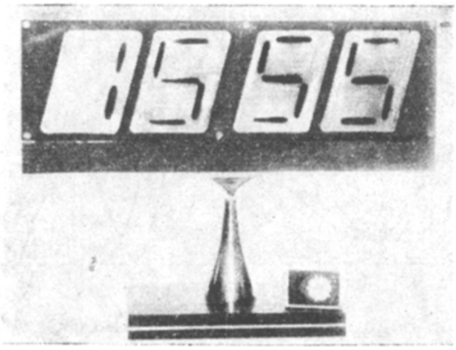

Fig. 2. Display face of operating electronic clocks with displays from the material FTIROS.

The contrasts calculated in this manner lie within the limits 0.25-0.6 for different color transitions in the FTIROS films. These numbers are close to the corresponding contrasts realizable in many industrial thermal dyes of single utilization [8]. Because the thermochrome layer is deposited on a large surface, we have the opportunity to produce large size displays of the large-screen type for collective and group utilization. The large angle of view of the thermochrome display also contributes to this.

The use of such displays is also possible in other units with digital readout. Thermodisplays of the reversible thermocolor type for different kinds of visual temperature control are of interest.

Different displays of similar purpose are compared in Table 1.

It is therefore seen that the thermodisplays developed on the basis of the phase transition in vanadium oxides are prospective for utilization in display engineering.

A photograph of the display face of a clock executed from the thermochrome material FTIROS is presented in Fig. 2.

NOTATION

T, body temperature; T_0, ambient temperature; T_i, initial temperature; Fo, Fourier criterion.

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