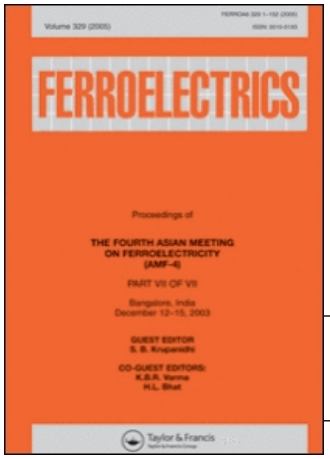

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Pyroelectric response to near infrared radiation of a ferroelectric liquid crystal

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PYROELECTRIC RESPONSE TO NEAR INFRARED RADIATION OF A FERROELECTRIC LIQUID CRYSTAL

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Abstract We have explored the potential of ferroelectric liquid crystals (FLCs) for applications in the area of the pyroelectric infrared detection. In the homogeneous geometry, the pyroelectric response of an electroclinic mixture, 854E, was measured by using a near infrared light-emitting diode with the maximum intensity of 20 mW at the wavelength of 0.95 μm. In the range of the modulation frequency between 8 and 400 Hz, the pyroelectric characteristics of 854E in the current mode were determined in terms of the duration of the irradiation and the associated thermal relaxation of the detector. It is indicated that FLCs are emerged as a new class of promising candidates for pyroelectric applications.

INTRODUCTION

Since the pyroelectric (PE) effect as the potential use for the infrared radiation detection has been put forward by Ta,[1] numerous ferroelectric solids have been used for detecting the thermal signals. Although such materials having larger PE coefficients ($p = dP_s/dT$) have attracted great interest for practical applications, the figure of merit of actual devices remains to be improved because of a rapid increase in the dielectric loss on approaching the critical point T_c of the ferroelectric phase transition. Therefore, the development of a new material, exhibiting rather weaker weaker divergence of the dielectric constant near T_c, is continued for device applications. In search of potential candidates, FLCs have been recently studied so as to evaluate their PE properties.[2,3]

In FLCs, the dipolar coupling between molecules is relatively small compared to conventional ferroelectric solids since the spontaneous polarization mainly arises from the ordering of chiral molecules in the smectic layers, and thus no strong

correlations exist in the direction of the layer normal. Consequently, in contrast to ferroelectric solids, there is no catastrophic divergence of the dielectric properties at the ferroelectric smectic C* (Sm C*) to the paraelectric smectic A* (Sm A*) phase transition.

In this paper, we report on the PE response of a FLC, one of the electroclinic mixtures, measured using a light-emitting diode (LED) as the source of infrared radiation. A commercially available FLC, 854E (T_c = 42° C), was used for this study. Its PE response was found to follow a few hundreds Hz of the modulation frequency.

EXPERIMENTAL

The liquid crystal cell studied was made of patterned indium-tin-oxide glass substrates (5mm×5mm). The cell thickness was maintained by glass spacers of 5 μm. Two inner sides of the glass substrates were coated with poly(1,4-butylene terephthalate), followed by the rubbing process,[4] so that the homogeneous alignment of LC was promoted. The Sm A-Sm C* transition for 854E occurs at 41.5° C.

The PE response of 854E was measured using the dynamic Chynoweth technique.[5] The sample cell and the LED (λ = 0.95 μm and I_{max} = 20 mW) were placed in a shielding case, made up of Al, so as to prevent from any electrical noise. The LED generates a square wave of infrared radiation in the frequency range of 8 Hz to 400 Hz.

The schematic diagram of the experimental set-up is shown in Fig. 1. The ac PE current, produced in the FLC layer in response to the heating by the infrared radiation, was measured with a digitizing oscilloscope in conjunction with the current amplifier.

RESULTS AND DISCUSSION

Suppose that an amplitude-modulated irradiance is absorbed by an illumi-

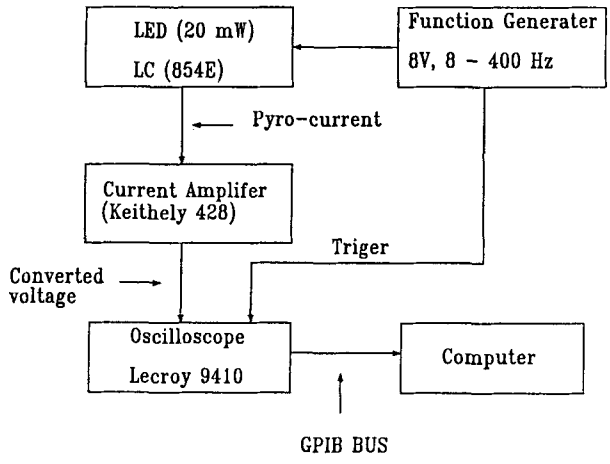

FIGURE 1: The schematic diagram of the experimental setup.

nated area A with the absorption efficiency η less than 1. This will cause the rise in temperature $\theta(t)$ as a function of time t in the sample according to the following equation for thermal flow,[6,7]

$$\frac{d\theta(t)}{dt} + \frac{\theta(t)}{\tau_T} = \frac{A}{C_T}\eta F(t). \tag{1}$$

Here τ_T and C_T denote the thermal relaxation time and the heat capacity of the sample, respectively. Eq. (1) is valid only for a uniform temperature throughout the sample. For the case of a weak temperature gradient, i. e., for the finite thermal diffusion, as a first approximation,[8] one can use the temperature averaged over the thickness of the sample for $\theta(t)$, defined in Eq. (1) The input irradiance $F(t)$ is applied for the period of $0 < t < \tau/2$, where τ is the modulating period. The measured current i is then simply $i = pAd\theta/dt$, where p and $d\theta/dt$ represent the PE coefficient and the rate of heating of the sample.

If $\tau_T \ll \tau/2$, the first term in Eq. (1) is negligible since the irradiation sequence is long compared to thermal inertia of the sample. Thus, under this condition, only the second term contributes to the PE current. meaning that for the rectangular pulse input, i follows simply the spike-like form. On the other hand,

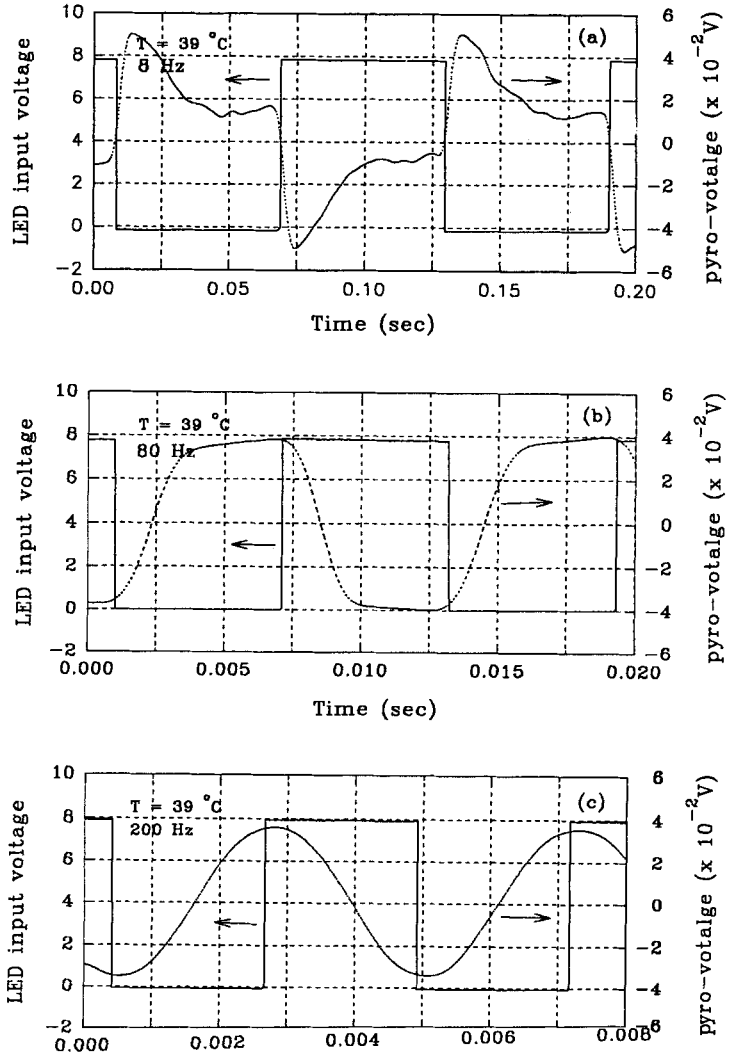

FIGURE 2: The pyroelectric response of 854E at various frequencies at 39° C; (a) 8Hz, (b) 80Hz, and (c) 200Hz.

if $\tau_T \gg \tau/2$, the second term in Eq. (1) can be ignored. Then, one should replace $dF(t)/dt$ by its average value over $\tau/2$, i. e., $(d/dt)\int_0^{\tau/2} dt' F(t')$. The current i is then given by

$$i = \frac{pA^2\eta\tau_T}{C_T}\frac{dF(t)}{dt}, \tag{2}$$

In this case, the PE current i of the sample resembles the form of irradiation, and i becomes constant.

Fig. 2 shows the characteristic curves for the PE response of 854E at various frequencies, which are consistent with the arguments discussed above. Beyond the frequency of 200 Hz, the PE response belongs to another regime which distinguishes between the collective reorientation of molecules and smectic layers in the presence of the infrared radiation. A full response of the layer reorientation usually takes longer time than that of the molecular rotations.

In the current mode, the PE signal depends on both the thermal relaxation time τ_T and the period of irradiation τ. As already indicated in Eq. (2), the thermal behavior of the PE signal originates primarily from the PE coefficient. Fig. 3 shows the frequency dependence of the PE response of 854E at different temperatures. The PE response becomes smaller with increasing the frequency, and an abrupt change was observed on further increasing the frequency.

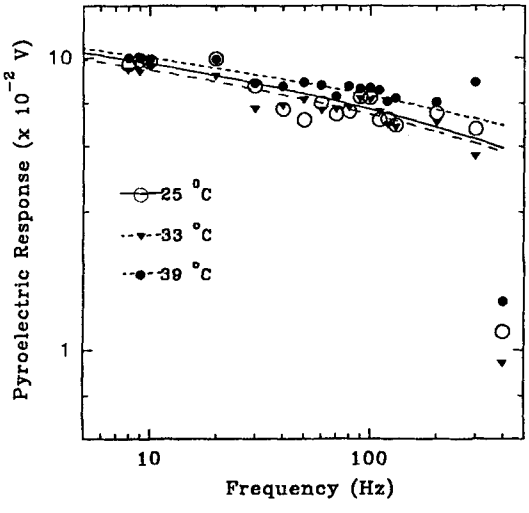

FIGURE 3: The frequency dependence of the peak to peak pyroelectric current at several different temperatures. The open circles, filled triangles, filled circles represent 25° C, 33° C, and 39° C, respectively.

The PE response becomes more profound at temperatures closer to the

Sm A-Sm C* transition. The decrease in the PE signal with increasing the frequency f is probably associated with $1/f$ response of the system. The cutoff frequency is about 400 Hz, at around which the molecules will not generate the full PE current in the presence of the heating. Even below this cutoff, the exact frequency dependence remains to be explored.

CONCLUSION

The use of FLCs for PE applications is of significant benefit compared to that of conventional ferroelectric solids. Particularly, as a PE detector, FLCs have several advantages over other materials, such as non-catastrophic divergence of the dielectric and PE coefficient near the phase transition. Although the operating frequency is one of the limitations, FLCs seem one of promising candidates as the use for practical applications.

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