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Response of edge- and face-electroded pyroelectric detectors to infrared laser signals

M. Simhony,* A. Shaulov, and S. Lavi
The Racah Institute of Physics, The Hebrew University, Jerusalem, Israel
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Expressions are given for the peak voltage responses to infrared laser signals in pyroelectric detectors with edge electrodes (EE) and face electrodes (FE). When the response is independent of the capacitance C_s of the samples, the FE detector has a much higher responsivity. When the response depends on C_s and the capacitance C_i of the preamplifier input is negligible for both samples, the EE design can give only a slightly higher response (the high gain expected in the literature comes from considering the EE sample as a parallel-plate condenser). However, when $C_{sEE} \ll C_i \ll C_{sFE}$, the EE detector response is higher by a factor of $\epsilon l/C_i$, where ϵ is the permittivity and l is the length of the edge electrodes.

Pyroelectric (PE) detectors with face electrodes [FE, see Fig. 1(a)] and edge electrodes [EE, see Fig. 1(b)] were first described by Cooper.[1] Considering the samples as parallel-plate capacitors (PPC) and assuming that the capacitance C_i of the preamplifier input can be disregarded, Cooper found that the responsivity of an EE detector is as many times higher than that of the FE detector as the radiation-receiving area A (equal in both samples) is larger than the electrode area A_e. This conclusion was adopted in later works[2-4]; however, it contains an intrinsic contradiction, because PPC conditions cannot be simultaneously satisfied by EE and FE samples of the same dimensions. For an EE sample $A/A_e = w/d$, but the PPC formula can be applied only if $w < d$, i.e., when the gain is reversed! However, then the PPC formula cannot be applied to the FE sample, the condition for it being $w > d$. In addition, the reported comparisons are for signal durations (or modulation periods) $\mathcal{J}$ much shorter than the electronic time constant τ_e of the samples. Meanwhile, we have shown[5] that the opposite case of $\tau_e \ll \mathcal{J}$ is very important in the detection of single ir laser pulses because this is when the PE response exactly depicts the signal. In the present letter we thus compare the PE responses in EE and FE samples for both τ_e cases, avoiding unlawful use of the PPC formula, and also take some account of C_i.

We consider signals much shorter than the thermal time constant τ_T of the samples (usually 10 msec $< \tau_T <$ 10 sec). Also, because the resistance of the samples is always much smaller than the resistance R_L of the parallel load, we have $\tau_e \equiv RC = R_L(C_s + C_i)$, where C_s is the capacitance of the sample. Temperature T is considered far from the Curie point, and its rise during the signal is considered small and spatially uniform so that τ_e and τ_T remain constant.

For $\tau_e \ll \mathcal{J}$ we have shown[5] that the response exactly follows the signal, i.e., has identical rise time, fall time, and duration (see Fig. 2), and at the time when the absorbed signal flux reaches its peak value F_p ($F_p \equiv W_p/A$, W_p being the absorbed peak power) the response has the peak value V_p,

$$V_p = (\lambda A_e/cd)F_p R_L . \tag{1}$$

Here λ is the PE coefficient of the material, $\lambda \equiv dP_s/dT$, where P_s is the spontaneous polarization, and c is the volume specific heat. V_p does not at all depend on C and is given by

$$V_{pEE} = (\lambda/c)lF_p R_L = (\lambda/cw)W_p R_L , \quad \text{for EE} \tag{2a}$$

$$V_{pFE} = (\lambda A/cd)F_p R_L = (\lambda/cd)W_p R_L , \quad \text{for FE} \tag{2b}$$

so that

$$V_{pEE}/V_{pFE} = d/w. \tag{2c}$$

(l is the length of the sample, or length of EE.)

Condition $\tau_e \ll \mathcal{J}$ can be achieved in EE detectors with larger R_L (because their C_s is smaller) so that, according to Eqs. (2a) and (2b), they may have higher responsivity. However, if this condition is reached in both samples with the same R_L, then the EE detector yields a peak response as many times lower as the thickness of the detectors is smaller than their width. To increase V_p, when the radiation flux has a cross section larger than A, in an EE detector one has to increase the length l (d and w unimportant), while in a FE sample the area has to be increased and/or the thickness reduced. If all the signal power is focused on the sample, to increase V_p in an EE detector one has to reduce its width (d and l unimportant), while in a FE detector the thickness has to be reduced (A unimportant). Clearly, Eqs. (2a)–(2c) apply as long as condition $\tau_e \ll \mathcal{J}$ remains unaffected, without the need to reduce R_L.

We have shown[5] that for $\tau_e \gg \mathcal{J}$ the response rises as long as the signal persists, reaching at the end of the signal the peak value

$$V_p = (\lambda A_e/cdAC)E_a, \tag{3}$$

where $E_a \equiv A\int_0^{\mathcal{J}} F(t)\,dt$ is the absorbed signal energy. After the end of the signal the response decays exponentially to zero with fall time τ_e. Thus the duration of the

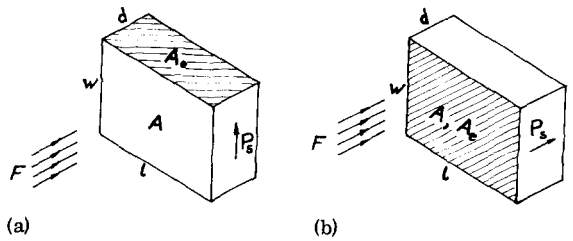

FIG. 1. Geometry of (a) edge- and (b) face-electroded pyroelectric samples. F is the radiation flux and P_s is the spontaneous polarization vector.

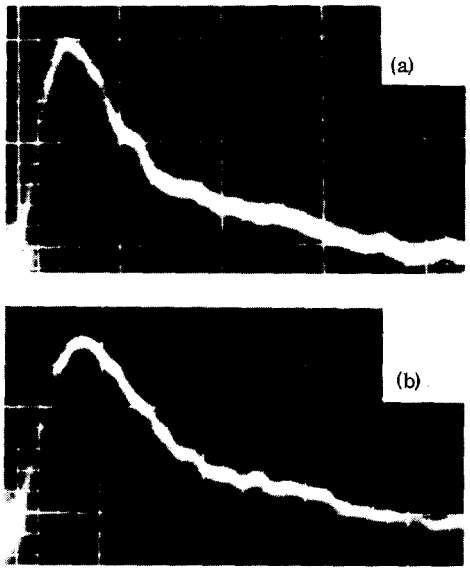

FIG. 2. (a) ir laser signal (as detected by a photon drag detector EL-OP Type 5413), and (b) the PE response in a SBN sample P-3 in case $\tau_e \ll \mathcal{F}$. Large division is 200 nsec horizontally and 1 mV vertically. Peak incident power on sample is 0.6 W.

response is determined by τ_e ($\mathcal{F}$ unimportant). V_p is independent of R_L, but it does depend on C.

Let us first consider $C_s \ll C_i$, so that $C = C_i$ and Eq. (3) yields

$$V_{pEE} = \lambda E_a / cwC_i, \quad V_{pFE} = \lambda E_a / cdC_i, \quad V_{pEE}/V_{pFE} = d/w. \tag{4}$$

Obviously, the EE design is again disadvantageous, and to increase V_p one should use a FE sample, as thin as possible; for $C_s \ll C_i$ to hold, one may reduce the area if this does not affect E_a.

When $C_s \gg C_i$ so that $C = C_s$, Eq. (3) yields, for FE samples,

$$V_{pFE} = (\lambda / c\epsilon_0\epsilon) E_a A^{-1}, \tag{5}$$

where $\epsilon_0 = 8.85 \times 10^{-12}$ F/m and ϵ is the dielectric constant along the PE axis. Thus, to increase V_p one should use materials with larger $\lambda/c\epsilon$, e.g., triglycine sulphate (TGS) rather than strontium-barium niobate (SBN), and reduce A without affecting E_a (d unimportant). For EE samples the capacitance cannot be expressed analytically.[6] In addition, the EE configuration is an open system whose capacitance is highly influenced by the adjacent wiring, mounting, and encapsulation. To get an idea only, one can use the approximation of two parallel wires in a medium of permittivity ϵ. When the distance w between their axes is much larger than their diameter d, this yields[6] $C/l = \pi\epsilon_0\epsilon / \ln(2w/d)$. (The PPC formula would give $\epsilon_0\epsilon d/w$.) Accordingly, the capacitance of the conducting wires is much less affected by reducing distance and width and is therefore much higher than it follows from the PPC formula; in vacuum, e.g., for $w/d = 10$, 50, and 200 it is, respectively, 10, 34, and 100 times higher. If ϵ is small, so that one can still disregard the fact that the volume of the sample is limited, rather than filling (*isotropically*!) the whole space around, this approximation yields $V_{pEE} = (\lambda / \pi c \epsilon_0 \epsilon) \times \ln(2w/d) E_a A^{-1}$ and $V_{pEE}/V_{pFE} \approx 0.3 \ln(2w/d)$. Thus, e.g., when $w/d = 200$, the responsivity of an EE detector will be higher by only a factor of 2. However, in high-ϵ materials this factor is larger.

Let us now assume that C_i is between the capacitances of the EE and FE samples, or $C_{sEE} \ll C_i \ll C_{sFE}$. Then, for $\tau_e \gg \mathcal{F}$, one has [Eq. (4)] $V_{pEE} = \lambda E_a / cwC_i$ and [Eq. (5)] $V_{pFE} = (\lambda / c\epsilon_0\epsilon) E_a / A$, so that $V_{pEE}/V_{pFE} = \epsilon_0 \epsilon l / C_i$. Here the EE detector is very advantageous, especially if a high-ϵ material is used, the sample is long, and C_i is small. For example, if $\epsilon = 10^4$, $l = 1$ cm, and $C_i = 1$ pF, $V_{pEE}/V_{pFE} \approx 10^3$. Such might have been the case of the high responsivity gain of 500, observed by Glass[2] in EE samples of SBN. Detailed results of our measurements will be reported elsewhere.[7]

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*At present on sabbatical leave at the University of Wisconsin—Milwaukee, Department of Electrical Engineering, Milwaukee, Wis. 53201.

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