Voltage Response of Pyroelectric PVDF Detector to Pulse Source of Optical Radiation

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Abstract. *Voltage response of a designed and constructed pyroelectric PVDF detector to pulse radiation was experimentally investigated. The detector performance has been tested and its time parameters, response linearity as a function of energy and width of optical pulses, frequency response and temperature characteristics were determined.*

Keywords: pyroelectric detector, PVDF sensor, pyroelectric polymer

1. Introduction

Recent decades have witnessed considerable progress in the design, production and application of pyroelectric polymers [1,2]. Currently commercially available group of polymers includes polivinylidene fluoride (PVDF) and co-polymers of PVDF. Pyroelectric polymers have been applied in production of temperature monitors, fire alarms, intrusion detection systems. Literature reports attempts at the application of PVDF films for detection of laser radiation [3].
The paper reports some experimental results of investigation of voltage response of pyroelectric PVDF detector to short infrared optical signal. Infrared signal was much shorter than the electronic and thermal time constants of the sensor.

2. Subject and methods

Design and principle of work of the pyroelectric detector
Figure 1 presents a scheme of mechanical construction of the PVDF–based detector.
The sensing element is a piece of PVDF foil, cut into circle and metalized on both sides. The thickness of film is 25 μm and the active surface diameter is 13 mm. The detector's capacitance C_d is about 460 pF. A detailed description of the construction of the detector are given in [4].

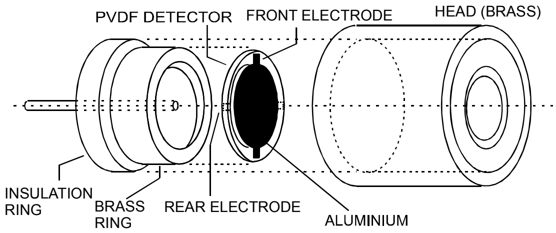

Fig. 1 Schematic outline of the detector construction

Absorption of a radiation pulse of energy E by the pyroelectric material changes its temperature and hence also the polarisation of the pyroelectric. The change in the pyroelectric polarisation changes the surface charge, producing a pyroelectric current $I_p(t)$. For analysis of the pyroelectric detector the equivalent scheme presented in Fig. 2 is assumed.

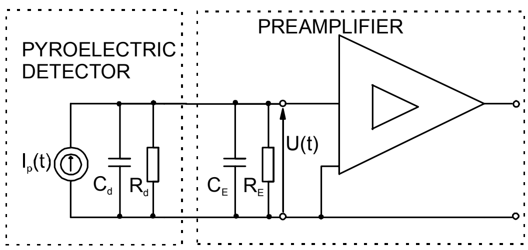

Fig. 2. Equivalent electric circuit of the pyroelectric detector where C_d is the detector capacitance, R_d is the detector resistance, C_E is the input capacitance of the amplifier, R_E is the amplifier input resistance, I_p is the induced pyroelectric current intensity.

In response to the radiation pulse excitation, a characteristic saw-tooth pulse is generated at the output of the detector. If the radiation pulse duration is negligibly small relative to the electric time constant given by $\tau_e = (C_d + C_E)[R_d R_A/(R_d + R_E)]$ and to the thermal constant τ_t, then the peak value U_{max} of the signal is proportional to the energy E of the radiation pulse:

$$U_{\max} = \frac{E}{C_d + C_E} \cdot R_i \qquad (1)$$

where: R_i –a coefficient dependent on the thermo-physical parameters of the pyroelectric material.

3. Results

Time parameters of the detector response

The time parameters of the detector response are important for estimation of the frequency band of the detector and limitations on the pulsewidth of optical radiation. The response of the PVDF detector constructed to a short pulse of infrared radiation of 20 µs duration recorded on a digital oscilloscope is shown in Figure 3.

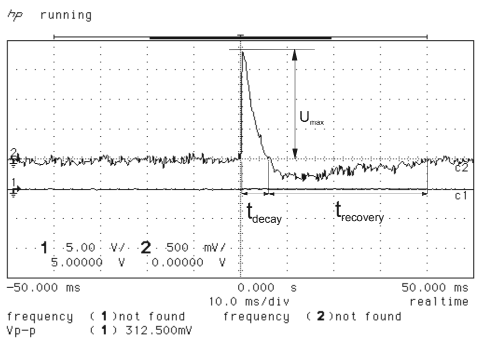

Fig. 3. The voltage response of the PVDF detector to the infrared radiation pulse of 20 µs duration.

The voltage response was studied using the input resistance of the preamplifier of R_E = 10 MΩ and the input capacity of C_E = 25 pF. Figure 3 shows that the decay time (t_{decay}) is about 6 ms and the recovery time ($t_{recovery}$) is about 34 ms. Figure 3 also shows that recovery time is needed for the detector to return to the initial state. These times are a function of electric time constant and thermal phenomena in detector.

A decrease in the input resistance R_E of the preamplifier causes a decrease in the sum of the decay time and recovery time. On the one hand, this decrease can bring an increase in the frequency limit of the detector, but on the other hand, it can bring a decrease in the detector's sensitivity and a risk of appearance of a nonlinear detector's response as a function of the input signal.

Linearity of the detector's response

The energy of the pulse radiation signal can be changed either by changing the power at the optical pulse duration or by changing the pulse duration at the same power.

Exemplary results in the form of plots of the PVDF detector response signal on the power and duration of the radiation pulse are shown in Figures 4 and 5.

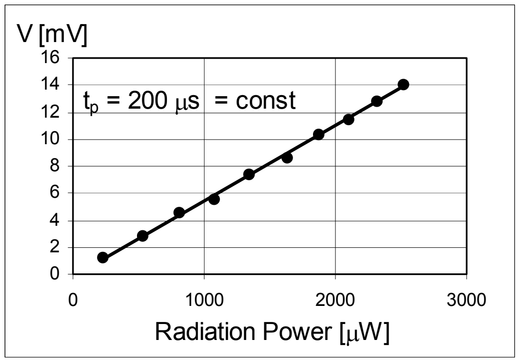

Fig. 4 The voltage response of the PVDF detector as a function of the radiation pulse power for the pulse duration of t_p =100 µs

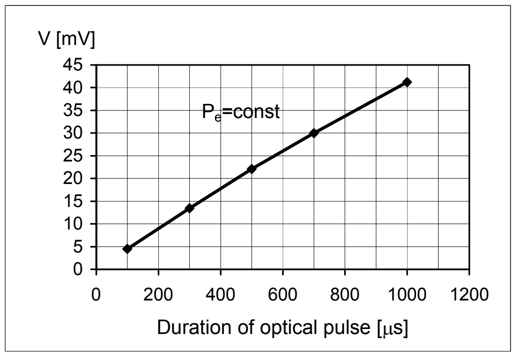

Fig. 5 The voltage response of the PVDF detector as a function of the pulse duration t_p for a constant pulse power of P_e = const.

It has been shown that the deviation from linearity does not exceed 4%. Thus, it can be assumed that the values are satisfactory. Important advantage is also possibility of measuring pulses of relatively long duration – even up 1 ms.

Frequency characteristics

Fig. 6 presents the dependence of the voltage response of the PVDF detector on the frequency of radiation pulses of duration of 100 μs. As follows from these results, for the preamplifier applied of the input resistance of 5 MΩ the frequency band is relatively broad, practically up to about 300 Hz the amplitude of the response signal is constant.

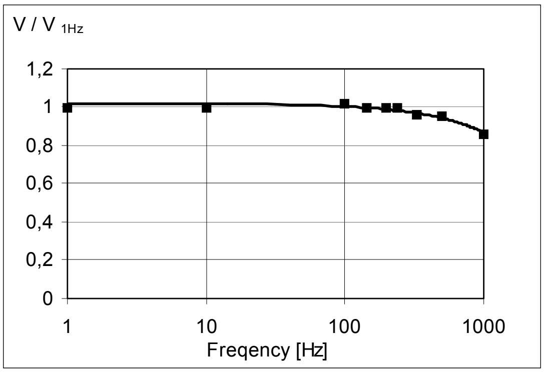

Fig. 6. Frequency characteristics of the PVDF detector.

Intuition prompts that the measurement of the radiation energy will be accurate only when the minimum time interval *T* between subsequent radiation pulses is equal or greater than the sum of the times t_{decay} and $t_{recovery}$, needed for the detector to return to full electric and thermodynamic equilibrium. However, the measurements performed have shown that the minimum time interval between the subsequent radiation pulses for which the energy measurement gives a correct result is *T*=3.3ms, so much smaller than the sum of the times of decay and recovery being close to 40 ms. Thus, the hypothesis based on intuitive knowledge is not valid. Detailed analysis of this problem is - to the best of our knowledge- not available in literature, however, this effect is probably well known to the constructors of devices for measurements of radiation energy. This effect is well illustrated in Fig. 7, showing the recorded of the detector response to a series of radiation pulses of the same energy whose period *T* is much smaller than the sum of the decay and recovery times. As the charge of the detector cannot be dissipated, subsequent voltage pulses start from different levels of the voltage pedestal. However, as can be seen, this effect does not influence the magnitude of the amplitudes of particular voltage pulses.

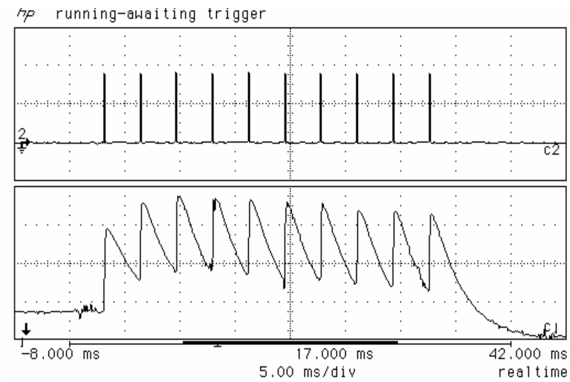

Fig. 7. The PVDF detector response to a series of 10 pulses.

Temperature characteristics

Figure 8 presents the temperature characteristic of the PVDF detector constructed. It shows that with increasing temperature the detector's sensitivity decreases.

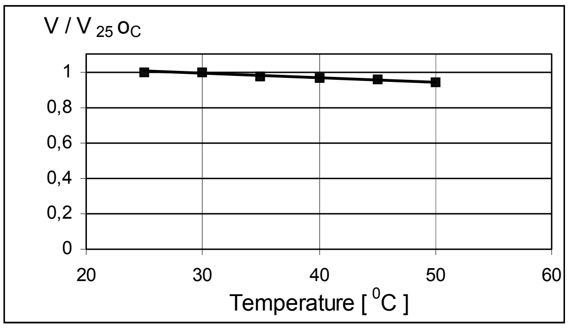

Fig. 8 Temperature dependence of the voltage response of the PVDF detector.

On the basis of the results obtained the temperature coefficient of sensitivity of the detector constructed can be estimated as α_S close to $0.002/^0C$.

The effect of input resistance on the detector response signal

As follows from (1) the peak value of the voltage response of the detector does not depend on the input resistance of the amplifier, assuming that the radiation pulse duration is negligibly small relative to the electric time constant τ_e and thermal time constant τ_t of the equivalent scheme of the detector and the amplifier. If the input resistance is relatively small, a too low value of the electric time constant of discharge will decrease the system's sensitivity and will open a possibility of the appearance of nonlinearity of the detector conversion.

Fig. 9 presents an exemplary dependence of the voltage response of the PVDF detector on the input resistance of the amplifier, to the radiation pulses of duration of 100 μs.

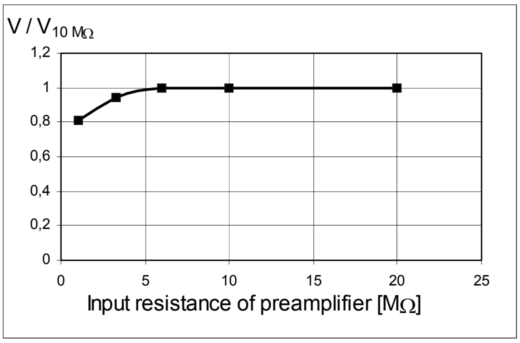

Fig. 9. The voltage response of the PVDF detector on the input resistance of the preamplifier to radiation pulses of 100 μs duration.

The measurements performed for the radiation pulse duration of 100 μs, have proved that for the input resistance greater than 5MΩ the system's sensitivity does not depend on the input resistance.

4. Conclusions

The voltage response of the designed and constructed pyroelectric PVDF detector to pulse radiation signal has been experimentally tested. As shown by the test results the detector is characterised by the following desired properties: relatively broad frequency band, good linearity, possibility of measuring pulses of relatively long duration and good thermal parameters. Taking into regard also the other commonly known advantages of pyroelectric polymers (resistance to moisture and chemical agents, possibility of large active area, very low cost), it is reasonable to expect that in many applications the use of a detector based on PVDF pyroelectric is the best choice.

References

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