NASA TECHNICAL MEMORANDUM

NASA TM X- 62,271

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PVF PYROELECTRIC RADIOMETER

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May 1973

SUMMARY

Polyvinylfluoride (PVF) plastic film has been found to be a good pyroelectric material. Radiometers using PVF have been developed that exhibit high sensitivity and frequency response. Normalized detectivities of greater than 10^8 cm $Hz^{1/2}$ W^{-1} and responsivities on the order of 10^5 V/W have been measured (500°C BB source, 0.1 Hz chopping frequency and 1 Hz bandwidth.)

Introduction

Polyvinylfluoride plastic film (e.g., DuPont "Tedlar") has pronounced pyroelectric characteristics. When charged at a high voltage and temperature, and then cooled while maintaining the charging field, it acquires a permanent polarization which is very sensitive to temperature. This pyroelectric characteristic of polyvinylfluoride (PVF) was observed and used as a radiometer subsequent to investigations into the persistent polarization characteristics of polymers for radiometers[1]. Other descriptions of PVF pyroelectric radiometers have been recently made by Phelan, Mahler and Cook[2], and Cohen, Edelman and Vezzetti[3]. Pyroelectric effects in a similar fluorocarbon film, polyvinylidene fluoride, have also been recently reported[4,5].

Description

Tedlar PVF is a highly crystalline and ordered plastic film. It is also quite polar for a plastic dielectric, having a dielectric constant of 9. The pyroelectric characteristic of PVF appears to be related primarily to volume polarization, involving orientation of crystallites of high dipole moment. When PVF is charged at a high voltage (400 Kv/cm) and elevated temperature (80-100°C) and then cooled while imposing the external electric field, a persistent polarization is created due primarily to dipole orientation. Space charge polarization due to injected charge and ionic impurities may also be involved, but its effects are apparently secondary to dipole orientation. For example, the author has found that charging by the methods of corona discharge or electron beam irradiation (which produce space charge in the polymer at room temperature) produced negligible pyroelectric effects.

The persistent dipole orientation polarization formed by the charging process described above is quite long-lived, as evidenced by the fact that the PVF radiometers described below have not decayed in sensitivity in nearly a year. This permanency further indicates the presence of a pyroelectric mechanism involving a temperature-sensitive, metastable polarization state as opposed to a temperature-sensitive, time-dependent depolarization effect such as the gradual decay of absorption current found in many dielectrics.

A pyroelectric radiometer is electrically a capacitor. When the PVF dielectric is charged so as to produce persistent polarization, it acquires the ferroelectric characteristic of a spontaneous or persistent polarization which changes with temperature. Under constant temperature conditions, the persistent polarization charge is not apparent because it is exactly compensated by induced charge on the electrodes. However, by removing one electrode, the persistent polarization can be measured.

The removed electrode is vibrated a short distance away and within the static electric field of the exposed surface charge of the persistent polarization. This induces an AC voltage which can be amplified and nulled out by applying an opposing DC voltage. The required DC bias is a measurement of the permanent effective surface charge of the dielectric[6]. For PVF charged at 400 Kv/cm at 100°C, the charge is typically 2×10^{-7} coul./cm^2. This level of permanent charge is relatively high, being comparable to that of other polymers used specially for their high electret charge[7].

A slight increase in temperature causes a reversible reduction of the persistent polarization which produces free charge on the electrodes. The amount of charge, Q, per area, A, produced per unit temperature change, T, is the pyroelectric coefficient,

$$S = Q/AT$$

For PVF, the coefficient is on the order of 2×10^{-8} coulomb/°C cm^2 as calculated from the radiometer response.

Response

The signal charge produced can be detected with either a voltage or current amplifier. In the voltage mode, a high input impedance amplifier is utilized to produce maximum sensitivity or responsivity, but it causes the responsivity to drop off with frequency. In the current mode a low input impedance amplifier is used. The current mode responsivity is lower in proportion to the lower input impedance, but it remains constant with frequency, and thus the current mode is more suitable for high frequency response applications. These signal characteristics can be described in terms of the detector's equivalent circuit.

The equivalent circuit (Fig. 1) of the PVF pyroelectric radiometer can be considered to be a current source shunted by the detector resistance R_s and capacitance C_s and the amplifier input resistance R_a and capacitance C_a.

From the definition of the pyroelectric coefficient S the amplitude of the time varying component of current produced by incident radiation that is chopped sinusoidally at a circular frequency ω is

$$I_\omega = \omega S A T_\omega$$

The thermal equation of the detector is

$$P_\omega \sin\omega t = H \frac{dT}{dt} + GT$$

where P_ω is the amplitude of absorbed incident power, H is the detector element heat capacity and G is the thermal conductance away from the detector element. Solving this equation gives the amplitude of the time varying temperature rise of the detector,

$$T_\omega = (P_\omega/G)(1 + \omega^2/\omega_T{}^2)^{-1/2},$$

where $1/\omega_T = \tau_T = H/G$, the thermal time constant. For the PVF radiometer ω_T is on the order of 0.5 Hz.

The impedance amplitude of the equivalent circuit is

$$|Z| = R\,(1 + \frac{\omega^2}{\omega_E{}^2})^{-1/2}$$

where $1/\omega_E = \tau_E = RC$ is the electrical time constant ($R = R_sR_a/(R_s + R_a)$ and $C = C_s + C_a$).

The signal voltage amplitude is then

$$V_\omega = I_\omega|Z| = (\omega SARP_\omega/G)(1 + \omega^2/\omega_T{}^2)^{-1/2}(1 + \omega^2/\omega_E{}^2)^{-1/2}$$

and the responsivity is

$$R = V_\omega/P_\omega = (\omega SAR/G)(1 + \omega^2/\omega_T{}^2)^{-1/2}(1 + \omega^2/\omega_E{}^2)^{-1/2}.$$

In the voltage mode operation a high amplifier impedance of 10" Ω puts ω_E on the order of 0.5 Hz for a small PVF radiometer, and for chopping frequencies greater than 0.5 Hz the responsivity becomes proportional to $1/\omega$

$$R_V = \frac{SAR}{G\omega}.$$

In the current mode where the amplifier input resistance is much less than the film resistance, the voltage signal is effectively proportional to the current produced. Thus, for $R_a << R_s$, $\omega_E = \frac{1}{R_aC} >> \omega$ and $|Z| = R_a$. At frequencies above the thermal frequency $\omega_T \simeq .05$Hz, the responsivity becomes

$$R_I = \frac{SAR_a\ \omega_T}{G}$$

which is independent of frequency.

For the case of a pulse of radiation, the response can be described as the difference between two exponentials, one decaying with the thermal time constant τ_T, the other decaying with the electrical time constant

τ_E[8]. In the voltage mode pulses shorter than τ_E and τ_T are integrated.

Construction and Performance

The PVF radiometers were made by depositing thin (100nm) aluminum electrodes on both sides of 1.25μm DuPont "Tedlar" PVF film and blackening one electrode with either deposited gold-black (approximately 200nm thickness) or high absorptance paint (approximately 10μm thickness). A schematic diagram of the detector construction and high input impedance (10" Ω) source-follower FET preamplifier used for the voltage mode configuration is shown in Figure 2. The detector area ranged from 0.5 cm^2 for small detectors, conveniently constructed by mounting the film on the end of a BNC connector, to 5 cm^2 for large area detectors. Two such detectors are pictured in Figure 3.

The voltage mode responsivity of a PVF radiometer having a 1 cm^2 cross-sectional area and a FET source follower preamplifier was measured to be

$$R(500°K, 0.1 \text{ Hz}) = 10^5 \text{ V/W},$$

where the source was a 500°K blackbody chopped at 0.1 Hz.

Detector noise is due primarily to thermal fluctuations in the detector film, Johnson noise in the equivalent circuit resistance R, and amplifier noise. At 0.1 Hz, noise voltage of the above system was V_n = 100μV, giving a noise equivalent power of

$$NEP = V_n/R = 10^{-9} W,$$

and the detectivity normalized for amplifier bandwidth of f = 1 Hz was thus,

$$D^*(500°K, 0.1 \text{ Hz}, 1 \text{ Hz}) = \sqrt{\Delta f}/NEP = 3 \times 10^8 \text{ cm Hz}^{1/2} W^{-1}.$$

The responsivity is constant with radiant power so long as the detector is not thermally saturated.

Being a thermal detector, the PVF radiometer has a wide and flat spectral response limited only by the absorptivity of the blackening material used.

The effect of operating temperature is to increase the responsivity with increasing temperature up to the temperature at which the PVF film was initially charged, viz., 80-100°C. This temperature is analogous to the Curie temperature of crystalline pyroelectrics, above which the material loses its spontaneous polarization.

Application

The high detectivity of the PVF radiometer qualifies it as a sensitive infrared detector. It has the pyroelectric detector advantages of room temperature operation and wide, flat spectral response, and additionally, the PVF radiometer can easily be made with a large detector area. The sensitivity is comparable to existing TGS pyroelectric and thermistor bolometer detectors.

The small PVF radiometers have been used for wide spectral measurement of shock tube radiation. Spectral response from the IR to UV was obtained by using gold-blacked PVF films without any windows, and megahertz frequency response required for following the shock radiation waveforms was obtained by using the current mode configuration.

Large (5 cm^2) area PVF radiometers have been used to detect non-uniform beams from a CO_2 gas dynamic laser.

REFERENCES

1. Russell, L. and Beam, B.: "Thermodielectric Radiometer", J. Spacecraft and Rockets, 5, 1501 (1968); U.S. Patent #3,657,644.
2. Phelan, R.; Mahler, R. and Cook, A.: Applied Physics Letters, 19, 337 (1971).
3. Cohen, J.; Edelman, S. and Vezzetti, C.: Nature Physical Science, 233, 12 (1971).
4. Nakamura, K. and Wada, Y.: J. Polymer Science, A-2, 9, 161 (1971).
5. Bergman, J. Jr.; McFee, F. and Crane, G.: Applied Physics Letters, 18, 203 (1971).
6. Reedyk, C. and Perlman, M.: J. Electrochemical Society, 115, 49 (1968).
7. Sessler, G. and West, J.: J. Electrochemical Society, 115, 836 (1968).
8. Simhony, M. and Sanlov, A.: J. Applied Physics, 42, 3741 (1971).

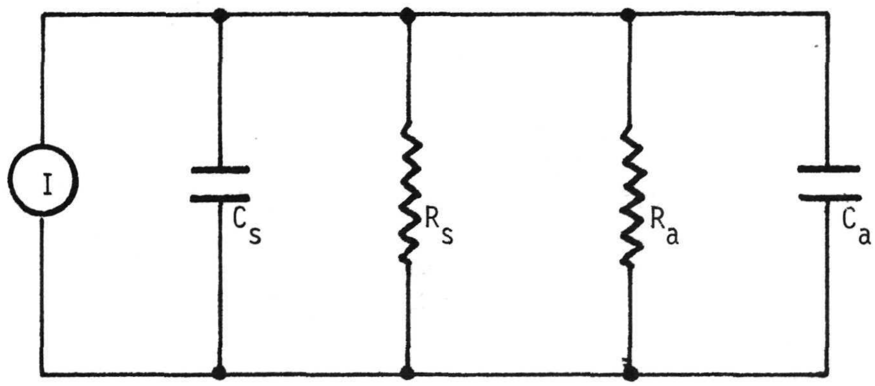

FIGURE 1 - Equivalent Circuit of the PVF Pyroelectric Radiometer

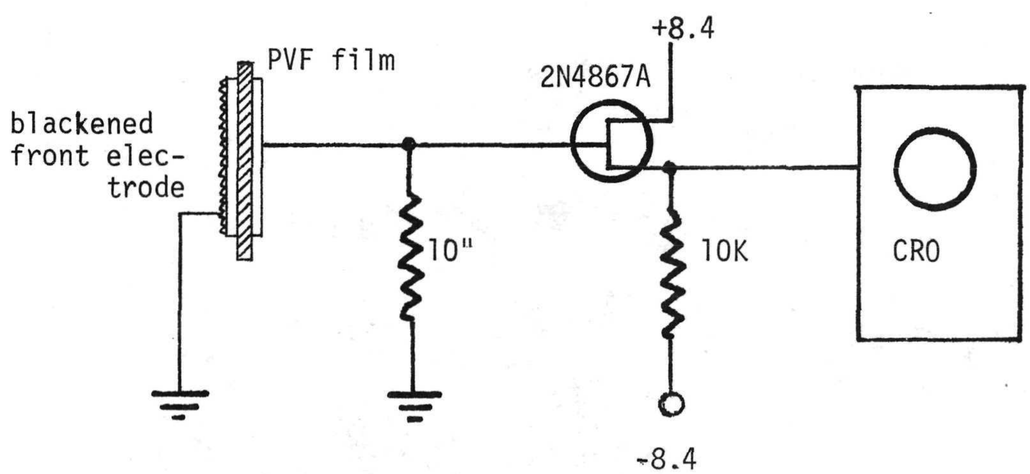

FIGURE 2 - PVF Radiometer Schematic

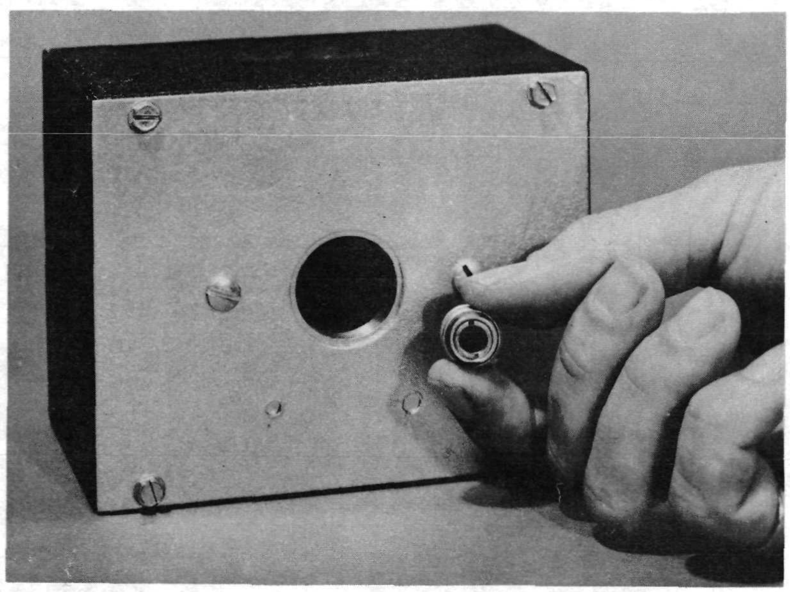

FIGURE 3 - PVF Radiometers