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On the Fabrication and Characteristics of Bismuth-Antimony Thermopile Detectors

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Abstract

Fabrication of thin-film bismuth-antimony thermopile detectors are described and their characteristics as radiation detectors are examined in some detail.

I. Introduction

Several workers(1)(2)(3) have described on the fabrication techniques and thermoelectric properties of thin-film thermocouples. With the development of laser research, various thermocouple detectors have been made as a means to measure absolute power of laser beam,(4) and recently such thermocouples are fabricated that can respond up to 10^{-7} sec.(5)

The electrical and thermoelectric properties of thermocouples are found to depend not only on the film thickness but also on the base properties and vacuum conditions during evaporation of materials. Moreover, in order to increase the fraction of the incident radiation which is absorbed by the thermocouple, it is necessary to coat the hot junction with highly absorbent layer, and its character complicates the performance of the detector.

In view of the above situations, we have constructed thin-film bismuth-antimony thermopiles evaporated on a thin cleaved mica plate, and examined in some detail their characteristics as radiation detectors. Although other metals, semiconductors and alloys are usable, bismuth and antimony have beee chosen for the following reasons:

(1) ease of evaporation by resistive heating in a vacuum system,
(2) good adherence to mica substrate,
(3) suitably good "factor of merit", (Actually "factor of merit" M' defined by

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Horning[6] is found to become 16.8×10^{-3} in our bismuth-antimony combination.) and

(4) use of metals rather than alloys eliminates the possibility of fractionation during evaporation.

II. Experimental Procedure

Manufacture of the experimental thermopile detector needs three main procedures; evaporating the thermoelectric materials, blackening the heat absorbing region (terget) and housing the thermopile element.

Thermopiles are fabricated through the evaporation of bismuth and antimony from tungsten boat on to a cleaved thin mica plate by resistive heating. All the evaporation processes are carried out in a vacuum system maintained at 10^{-5} mmHg. As shown in Fig. 1, eight thermocouples are connected in series to increase equilibrium (d.c.) sensitivity. To get thermoelectromotive force, silver leading-wires are connected to the terminals of the thermopile with silver paint. Silver paint ensures not only electrical conduction but also mechanical strength.

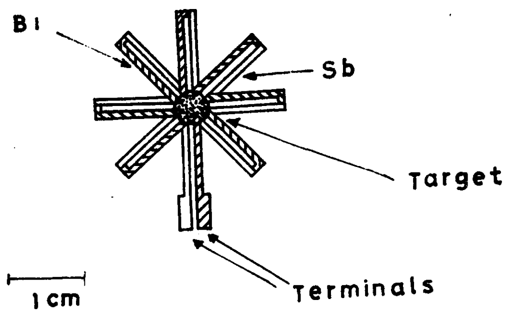

Fig. 1. Construction Diagram of Thermopile Element.

Blackening of the hot junction region is made by spraying black-flat paint. This paint, owing to the acrylic resin included, is electrically highly resistive so that no insulation is needed between blackened layer and junctions. (In the usual thermocouple detector, radiation absorbing layer is conductive and insulation should be inserted between hot junction and layer.)[7]

Then the thermopile element is fixed on bakelite plate, housed in an aluminium box with a hole through which light beam can be irradiated on the blackened region of the detector. The main construction of the detector system is represented in Fig. 2.

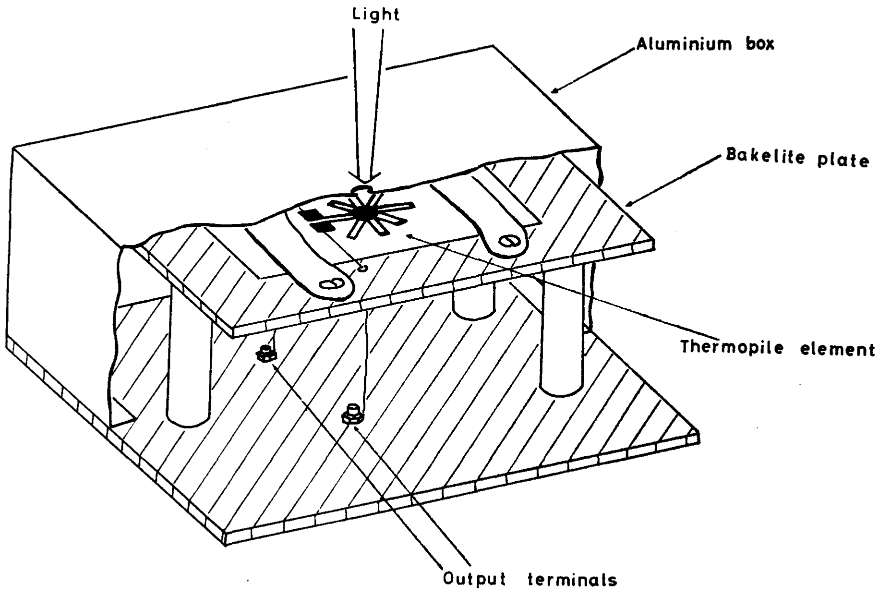

Fig. 2. Schematic Representation of Thermopile Detector.

III. Results and Discussions

a) Basic Characteristics

Table 1 shows the typical results of film thickness, resistance and thermoelectric power of the constructed detectors. Film thickness is measured by interference microscope using green light of Hg lamp and resistance, by bridge. Thermoelectric power is calculated, based on the measurement of radiation energy from tungsten lamp of known brightness-temperature.

Table 1. Basic Characteristics of Thermopile Detectors.

Sample Number	Film Thickness (Å)		Total Resistance (kΩ)	Thermoelectric Power (μV/mW)
	Bi	Sb		
# 112	1060	1380	7.83	90
# 105	3890	4650	1.39	80
# 109	11850	7650	1.51	120
# 111	26500	17400	0.56	140

It is confirmed that in the visible wavelength region, between 400 and 700 mμ, the blackened part of the detector absorbs approximately 95% of incident radiation. Resistance of the films is about four to seven times as high as that of the bulk materials. Thermoelectric power increases with increasing film thickness, similarly to the results obtained by Koike *et al.*[8] on bismuth-silver and antimony-silver thermocouples.

b) *Sensitivity*

The increase in sensitivity is observed when the fabricated detector is operated in vacuum. In Fig. 3, experimental results are obtained for #109 thermopile detector fixed in a glass bell jar, which can be evacuated through diffusion pump. He-Ne gas laser light of 6328 Å is irradiated on to the target of the detector from the outside of the bell jar.

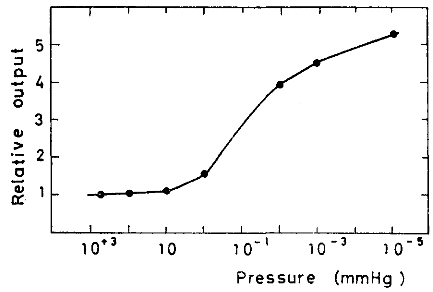

Fig. 3. Thermoelectromotive Force of #109 Detector as a Function of Pressure.

As is seen in Fig. 3. experimental curve shows rapid increase at about 10^{-1}mmHg and the sensitivity at about 10^{-5}mmHg becomes approximately five times as large as that at atmospheric pressure. As Lion pointed out,[9] this increase in sensitivity is considered to be due to the decrease of heat-escape from the detector to the surroundings, as evacuation proceeds.

c) *Response Time*

Response curves of #109 detector to the sudden application of the radiation are shown, at typical three different conditions. in Fig. 4. Radiation is applied by means of a shutter which is inserted and removed abruptly across the light path of d.c. He-Ne gas laser of 6328 Å. The observed rise-response of relative output E in Fig. 4 may be approximated by the empirical equations such as

$$E=0.97-[0.43 \exp(-t/2.5)+0.55 \exp(-t/26)] \qquad (1)$$

at atmospheric pressure

$$E=3.9-[2.6 \exp(-t/2.7)+1.3 \exp(-t/16)] \qquad (2)$$

at approximately 10^{-2} mmHg

and

$$E=4.8-4.8 \exp(-t/7.7) \qquad (3)$$

at approximately 10^{-5} mmHg

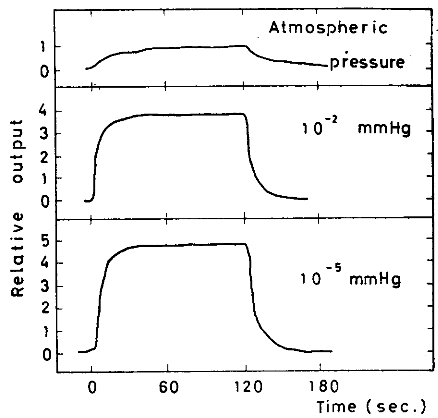

Fig. 4. Time Response of Thermoelectromotive Force at Atmospheric Pressure, about 10^{-2}mmHg and about 10^{-5} mmHg.

respectively, which are obtained by fitting the above equations to the observed curves. In the above equations, t denotes time in seconds. It should be remarked that in our other samples, rise-response be expressed by similar equations which involve two exponential terms such as Eq. (1) and (2).

From the response-time results mentioned above, it seems probable that E will be generally represented in the form

$$E=E_0-[A\exp(-t/\tau_1)+B\exp(-t/\tau_2)] \tag{4}$$

where E_0 shows the ultimate value of E (t tends to infinity), A and B numerical constants, and τ_1 and τ_2 proper relaxation times. Furthermore, both τ_1 and τ_2, together with E_0, A and B, will be supposed to vary with pressure which suggest that in the higher vacuum region two relaxation times coincide, whereas in the lower vacuum region two relaxation times remain at different values.

A detailed explanation of the above empirical formula will need further study concerning heat-transfer mechanism between blackened region, bismuth-antimony thin-film elements, mica substrate and surroundings.

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