2900-129-R

Memorandum of Project MICHIGAN

ULTIMATE SENSITIVITY AND PRACTICAL PERFORMANCE OF THE TELLURIUM PHOTOCONDUCTIVE DETECTOR

DAVID F. EDWARDS

December 1959

SOLID-STATE PHYSICS LABORATORY

Willow Run Laboratories

THE UNIVERSITY OF MICHIGAN

Ann Arbor, Michigan

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PREFACE

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Robert L. Hess
Technical Director
Project MICHIGAN

ABSTRACT

Calculations of the ultimate sensitivity and measurements of the practical performance have been made for the tellurium photoconductive detector. For the condition that detector sensitivity is limited by fluctuations of background radiation, the theoretical NEP (noise equivalent power) at the peak of spectral sensitivity (λ = 3.4 μ) was calculated to be 5.1×10^{-13} watt. For the "best" tellurium detector the measured value of NEP was 3.1×10^{-13} watt at the same wavelength and at the optimum chopping frequency. These values indicate that the tellurium photoconductive detector is background limited and thus is an ideal detector.

INTRODUCTION

The purpose of this memorandum is to report the results of calculations of the ultimate sensitivity of the tellurium detector and of measurements of sensitivity for a select few of these detectors as prepared by Suits, et al. The results indicate that the tellurium detector is an ideal detector. The fact that only one of six detectors measured approached the ultimate sensitivity indicates the need for continued development. Of the other five, two detectors had an NEP (noise equivalent power) (3.4 μ) within a factor of about 10 of the ideal. For the ideal detector, i.e., one that is background-radiation limited, the addition of a cooled radiation shield to match the aperture of the detector to that of the optics should increase the detector sensitivity by as much as a factor of 10.

The use of tellurium as a photoconductor was first investigated in 1949 by Moss (References 1 and 2), who used evaporated thin films. The most sensitive cell that he reported, when cooled to liquid-nitrogen temperature, had a signal equal to the rms (root-mean-square) noise in 1-cps bandwidth for incident radiation of 1.2×10^{-10} watt of monochromatic radiation at 1 μ. This quantity is called the NEP and is defined as the incident radiation necessary to produce a signal equal to the rms noise. This same tellurium film was only moderately sensitive (NEP = 10^{-6} to 10^{-7} watt, at 1 μ and 1-cps bandwidth) at room temperature. Loferski (Reference 3) in 1954 made photoconductivity measurements on single crystals of tellurium with about the same results as those obtained for evaporated films. Loferski's data were extrapolated and the NEP was found to be about 10^{-8} to 10^{-9} watt for the most sensitive photoconductor when cooled to liquid-oxygen temperature. The single crystals used by Loferski were cut or cleaved from large tellurium crystals, ground, polished, and sometimes etched to the desired dimensions.

Suits (Reference 4) in 1957 found that thin hexagonal single-crystal prisms of tellurium when cooled to liquid-nitrogen temperature had sensitivities and response times comparable to those of the lead-salt detectors. These thin single-crystal prisms were grown from the vapor phase in a low-pressure hydrogen atmosphere, starting with 99.999+% pure material.[1] The electrical contacts were made by welding a hot wire, in most cases platium, to the tellurium. The crystals were then mounted in a more or less standard glass dewar with a sapphire window.

2
ULTIMATE SENSITIVITY

The ultimate sensitivity was calculated for the tellurium detector for the condition that fluctuation in background radiation is the fundamental limitation of detector sensitivity. Recently, several articles have been published (References 5-8) that describe methods for calculating the ultimate sensitivity of a photoconductor for the background-limited condition. The calculations reported in the present paper follow closely those of Moss (Reference 6).

The background radiation is taken as a 300°K blackbody with the spectral distribution given in Figure 1, curve (a). Only that radiation that lies within the sensitive spectral region of the detector will affect the ultimate sensitivity. The relative spectral response of the tellurium detector at 77°K is given in Figure 1, curve (b). The product of these two curves is the spectral distribution of the effective radiation incident on the detector (Figure 2). It is seen that the effective wavelengths are limited to a narrow band centered at 3.7 μ. For purposes of calculation it is assumed to a good degree of approximation that the effective radiation is monochromatic with the wavelength of the peak, 3.7 μ. The area under this curve is the equivalent energy falling on the detector and equals 82.2 microwatts/cm^2. This corresponds to $N_o = 1.5 \times 10^{15}$ quanta/cm^2/sec at 3.7 μ. The number of absorbed quanta producing a detector signal, N_s, will depend on the absorption properties of the material, the quantum efficiency, and the diffusion length of free carriers. The relation between N_s and N_o has been given by Moss (Reference 6) as

[1] American Smelting and Refining Co., South Plainfield, New Jersey.

$$N_s^2 = 2AN_o \Delta f/(1 - r - t),$$

where A is the sensitive area of the detector, Δf the bandwidth of the measuring equipment, and r and t are the reflection and transmission coefficients. For a detector with $A = 0.0025\ cm^2$ and $\Delta f = 5$ cps, $N_s = 9.55 \times 10^6$ quanta/sec at 3.7 μ. The reflection coefficient r (= 0.48) was calculated from the weighted average for the index of refraction (Reference 9) $\bar{n} = 5.5$. The transmission coefficient t (= 0.10) was calculated from the absorption coefficient value of Loferski (Reference 3) and the sample thickness. This calculated value of N_s corresponds to a theoretical NEP (3.4 μ) = 5.1×10^{-13} watt at the peak of the spectral response ($\lambda = 3.4\ \mu$) and represents the ultimate sensitivity of the tellurium detector for the background-radiation limited condition.

3
PRACTICAL PERFORMANCE

The absolute spectral sensitivity of the "best" tellurium photoconductor measured is shown in Figure 3. The measured NEP at 3.4 μ is $(3.1 \pm 0.8) \times 10^{-13}$ watt. This was measured for radiation chopped at 5000 cps and 5 cps bandwidth. The assumptions used in the calculation of the ultimate sensitivity result in the value of the ideal NEP being larger than the measured value. A more refined calculation does not seem warranted at this time. The monochromatic radiation calibration was made with a Reeder[2] thermocouple that had been calibrated with a 500°K standard blackbody[3] and checked with a National Bureau of Standards calibrated lamp. The rms values of noise and signal voltages were calibrated with a Weston a-c thermocouple.

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[2]Chas. M. Reeder Co., Detroit 3, Michigan.
[3]Model RS-1A Blackbody, Barnes Engineering Co., Stamford, Connecticut.

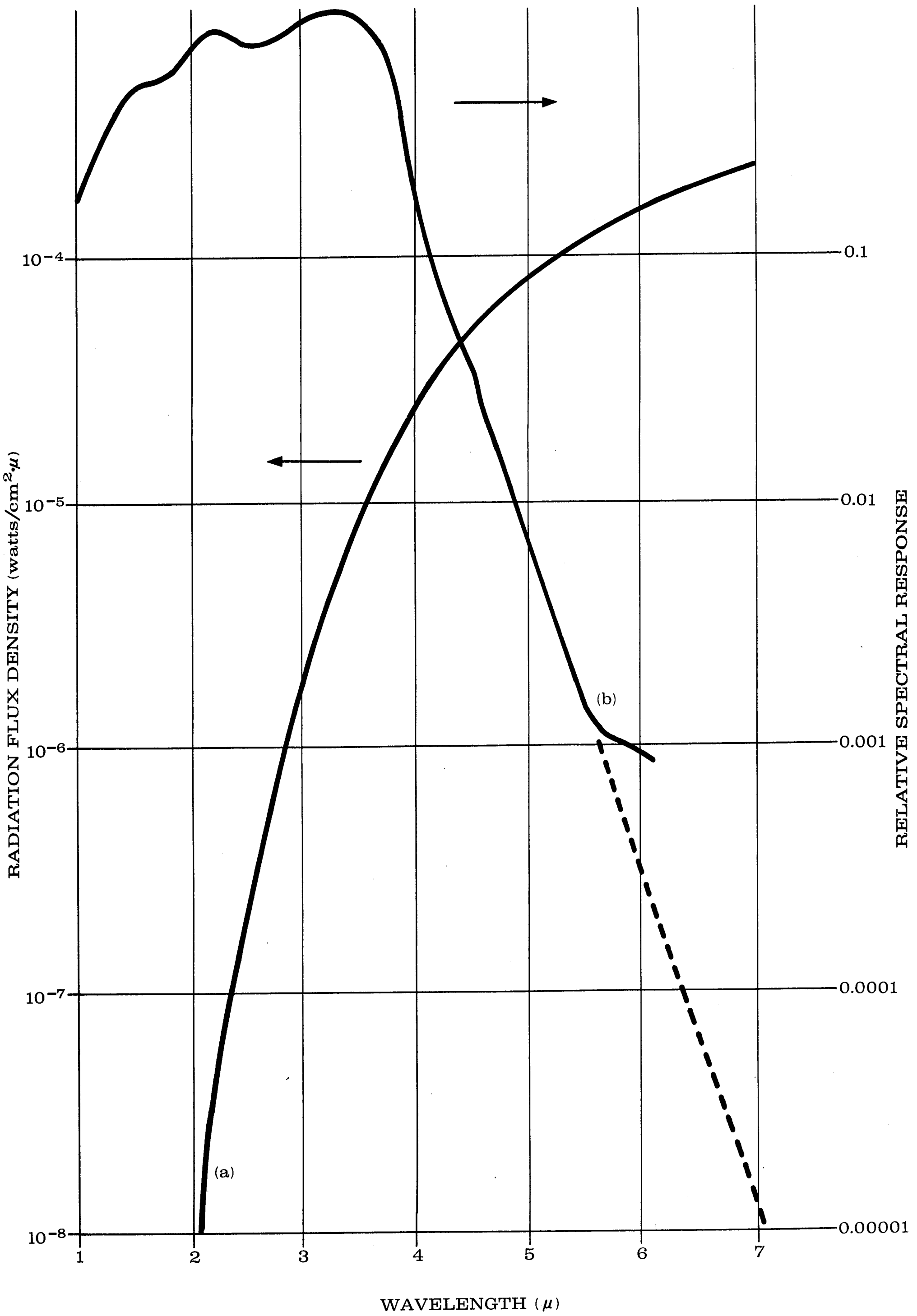

FIG. 1. (a) Spectral distribution for a 300° K blackbody. (b) Relative spectral response of the tellurium detector at 77° K.

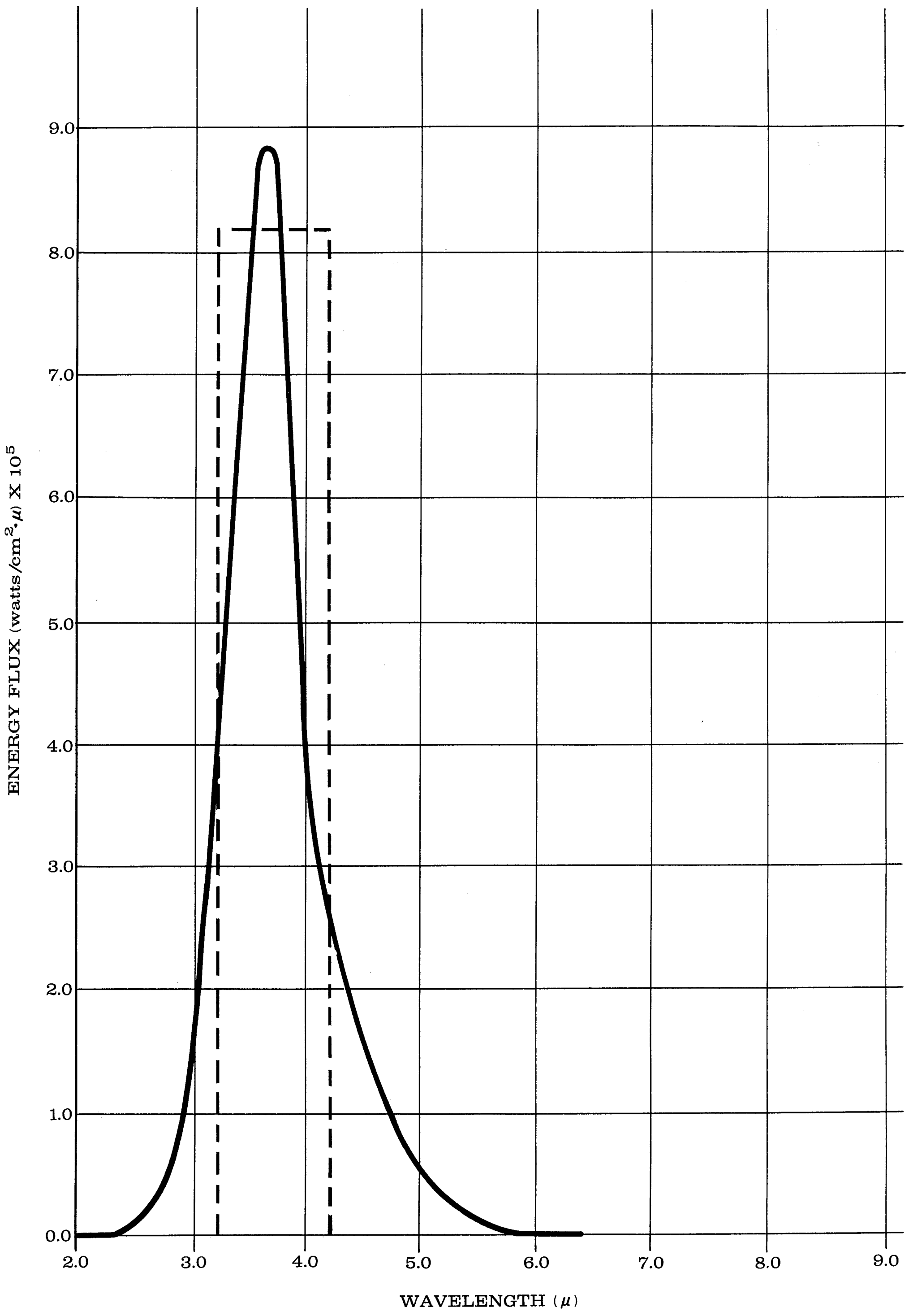

FIG. 2. SPECTRAL DISTRIBUTION OF EFFECTIVE RADIATION INCIDENT ON DETECTOR

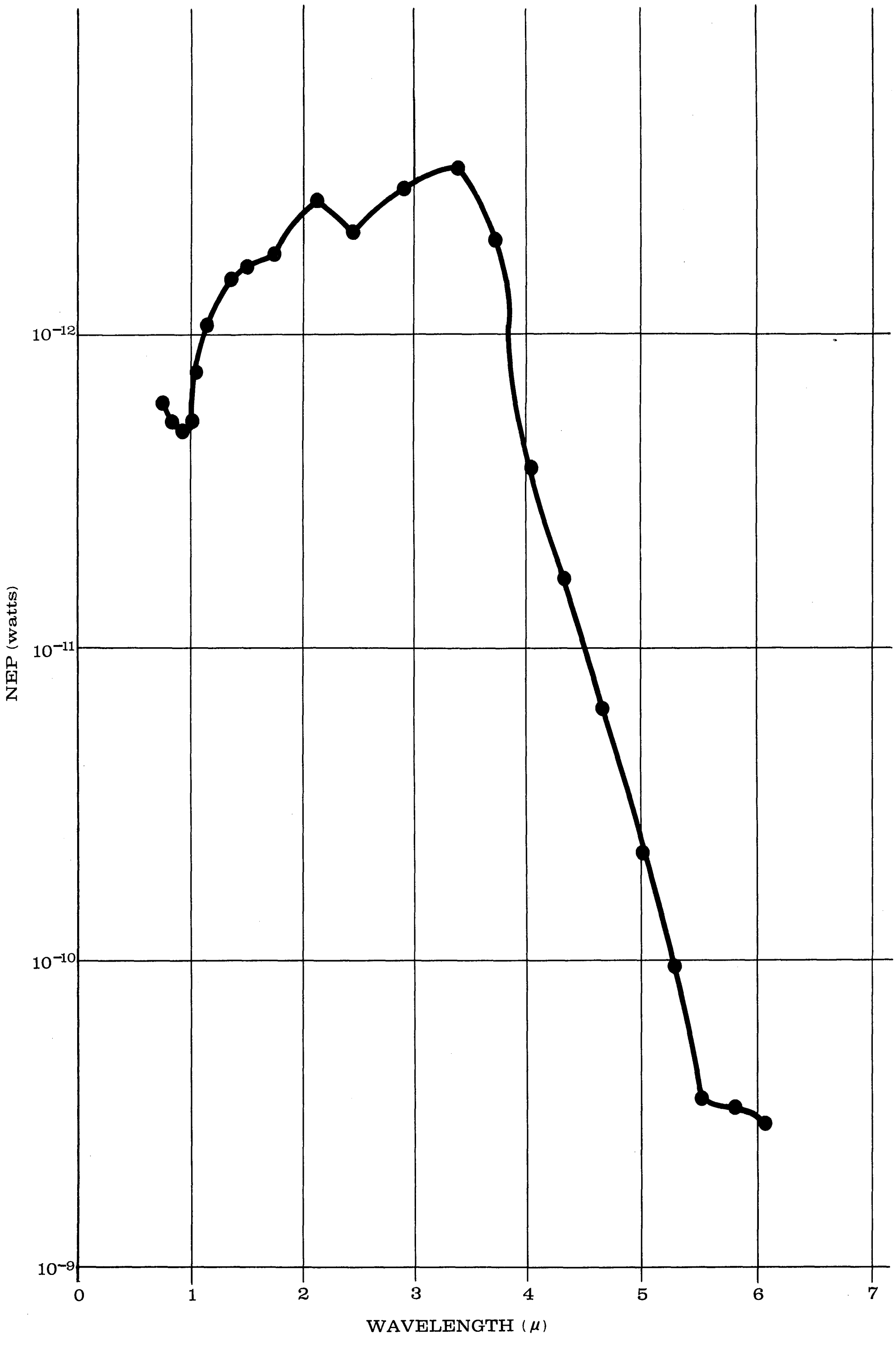

FIG. 3. ABSOLUTE SPECTRAL SENSITIVITY OF THE TELLURIUM DETECTOR. At 77° K with a chopping frequency of 5000 cps and a 5-cps bandwidth.

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Dec 59. 7 p. incl. illus., 9 refs.
(Memo no. 2900-129-R)
(Contract DA-36-039 SC-78801) Unclassified memorandum

Calculations of the ultimate sensitivity and measurement of the practical performance have been made for the tellurium photoconductive detector. For the condition that detector sensitivity is limited by fluctuations of background radiation, the theoretical NEP (noise equivalent power) at the peak of spectral sensitivity ($\lambda = 3.4\ \mu$) was calculated to be 5.1×10^{-13} watt. For the "best" tellurium detector the measured value of NEP was 3.1×10^{-13} watt at the same wavelength and at the optimum chopping frequency. These values indicate that the tellurium photoconductive detector is a background-limited detector and thus is an ideal detector.

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IV. Contract DA-36-039 SC-78801

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Detector
Background radiation
Spectral sensitivity
Noise equivalent power

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