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Temperature Dependence of the Responsivity of Indium-Doped Silicon Infrared Detectors

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Center for Electronics and Electrical Engineering
National Bureau of Standards
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Temperature Dependence of the Responsivity of Indium-Doped Silicon Infrared Detectors

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Abstract

Measurements were made to determine the degradation of responsivity of indium-doped extrinsic infrared detectors at temperatures above their normal operating range. The responsivity was found to fall off very rapidly with temperature above the optimum, and if operation at liquid nitrogen temperature is desired, one must accept a degradation in responsivity of an order of magnitude or more.

Key Words: Indium-doped silicon; infrared detectors; responsivity.

I. INTRODUCTION

An infrared laser-scan technique for measuring the uniformity of photoresponse over the surface of a wafer is being explored to determine its suitability for screening out starting wafers of indium-doped silicon which, if processed, would yield unacceptable detector arrays. Since measurement time and cost are important considerations, the technique is being studied at liquid nitrogen temperature instead of the lower operating temperature of indium-doped silicon infrared imaging arrays. The main drawbacks of operation at higher temperatures are: 1) decreased signal-to-noise ratio and 2) large dependence of the photoconductivity on temperature. The present study was undertaken to examine the temperature dependence of the photoconductivity in state-of-the-art indium-doped silicon detectors in order to better appreciate the nature and magnitude of the effects of higher than normal array operating temperature.

II. MEASUREMENT TECHNIQUES

A schematic illustration of the test detectors which were fabricated from wafers of indium-doped silicon for the present measurement are shown in figure 1. The evaporated aluminum contacts were alloyed at 650°C for 5 min, but otherwise the silicon was not subjected to high temperatures during the detector fabrication. A schematic diagram of the apparatus used in making the responsivity measurements is shown in figure 2. Photons from a 500-K blackbody radiation source pass through a mechanical chopper and through a germanium-sapphire filter and then are incident on the test detector which is located on the cold finger of a mechanical refrigerator. A conventional measurement of the responsivity at the wavelength of peak response requires that the relative spectral response be measured in addition to the blackbody responsivity at each temperature of

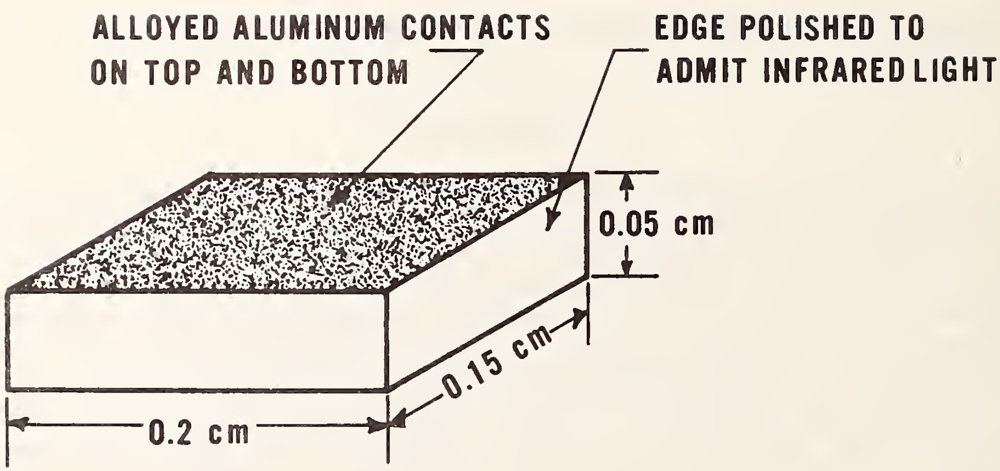

Figure 1. Schematic illustration of the test detectors.

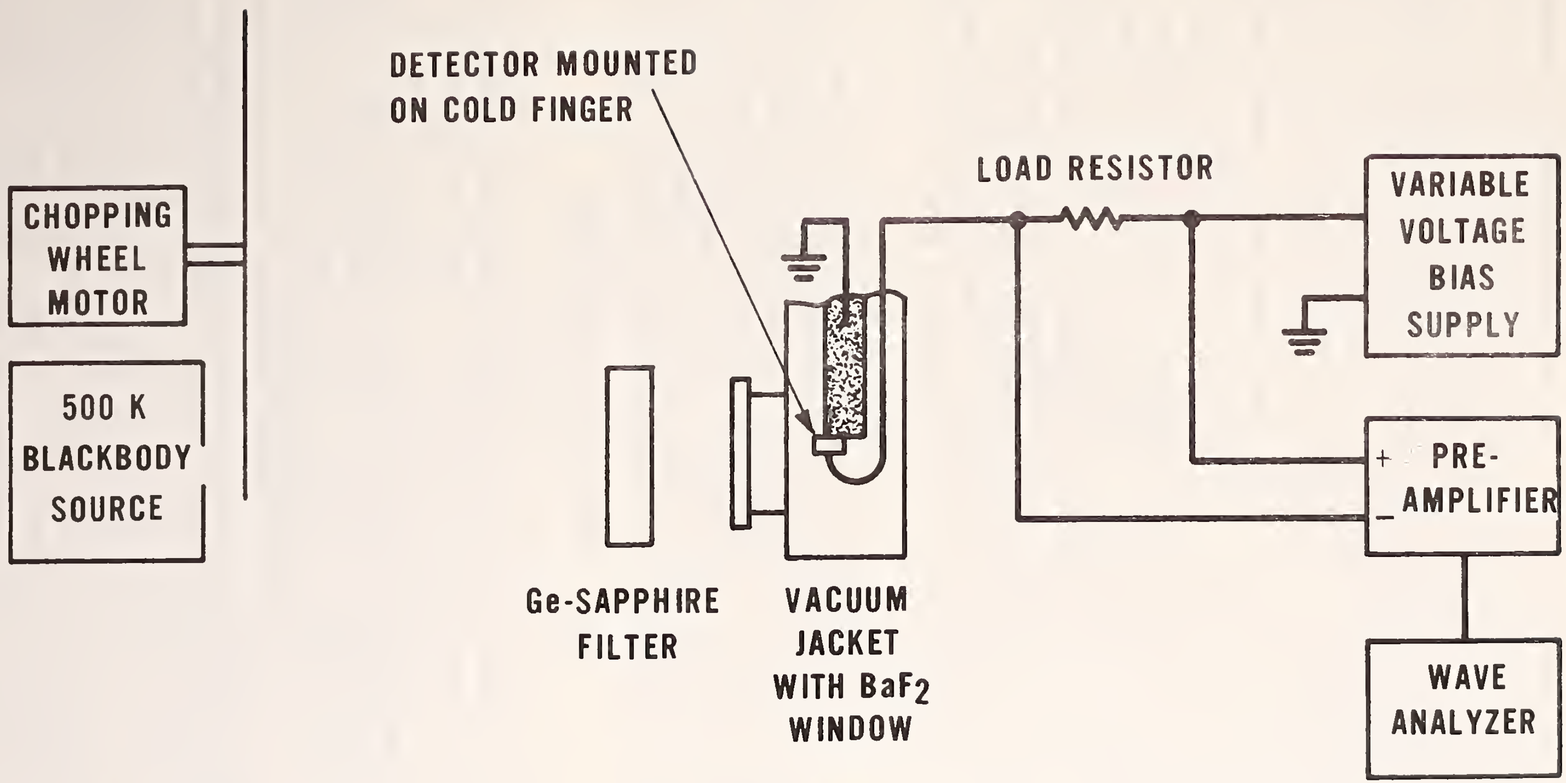

Figure 2. Schematic diagram of the apparatus used to measure the responsivity of the test detectors as a function of bias and operating temperature.

interest. A conversion factor is then computed from the relative spectral response and used to convert the measured blackbody responsivity to a peak wavelength responsivity. In the present measurement, the sapphire component of the germanium-sapphire filter is used to determine the long wavelength response characteristic of the system instead of relying on the cut-off characteristic of the indium-doped silicon test detectors to perform this function. Therefore, it was not necessary to measure the relative spectral response characteristic of each test detector at each temperature. The ratio of peak responsivity to filtered 500-K blackbody responsivity was computed using the measured spectral transmission characteristic of the room temperature germanium-sapphire filter and found to be 10.64. Responsivity measurements were made both with and without this filter, and it was found that the values obtained without the filter (using a nominal peak-to-blackbody response ratio of 2.32) averaged about 12 percent higher than the values obtained with the filter. All of the responsivity data reported below were measured with this filter in place. The germanium component of the germanium-sapphire filter was included to absorb any short wavelength radiation from the blackbody source (and ambient room light) that could otherwise excite electron-hole pairs across the bandgap of the silicon test detectors and possibly perturb the dynamics of the extrinsic photoconductivity mechanism.

The test detectors were biased with a constant voltage source through a small load resistor (i.e., a resistor with a resistance that is small compared to the test detector resistance at all temperatures of interest). The change in current due to chopping the incident radiation from the blackbody source was measured as the change in voltage across the load resistor and converted to a value of responsivity in amperes per watt of incident radiation at an assumed peak wavelength of 6.4 μm.

III. RESULTS OF MEASUREMENTS

The results of responsivity measurements for test detectors fabricated from three wafers cut from a single float-zoned crystal of indium-doped silicon are summarized in figure 3. Wafers B8 and B6 were subjected to nuclear transmutation doping [1] (NTD) techniques to precisely compensate the background shallow acceptor impurities while wafer B3 was not given this treatment. These data were observed at 20-V bias with a variety of load resistors, each selected to have a small resistance compared to the test detector resistance as the temperature varied over the range indicated in figure 3. The NTD treatment has produced about an order of magnitude improvement in the responsivity at the optimum temperature, but this responsivity falls off very rapidly at temperatures above this optimum.

The results of responsivity measurements for test detectors fabricated from two wafers cut from a single crystal of Czochralski (CZ) indium-doped silicon are summarized in figure 4. These data were also observed with 20-V bias and a variety of load resistors. The responsivity of the test detector from wafer A5 was comparable to that measured

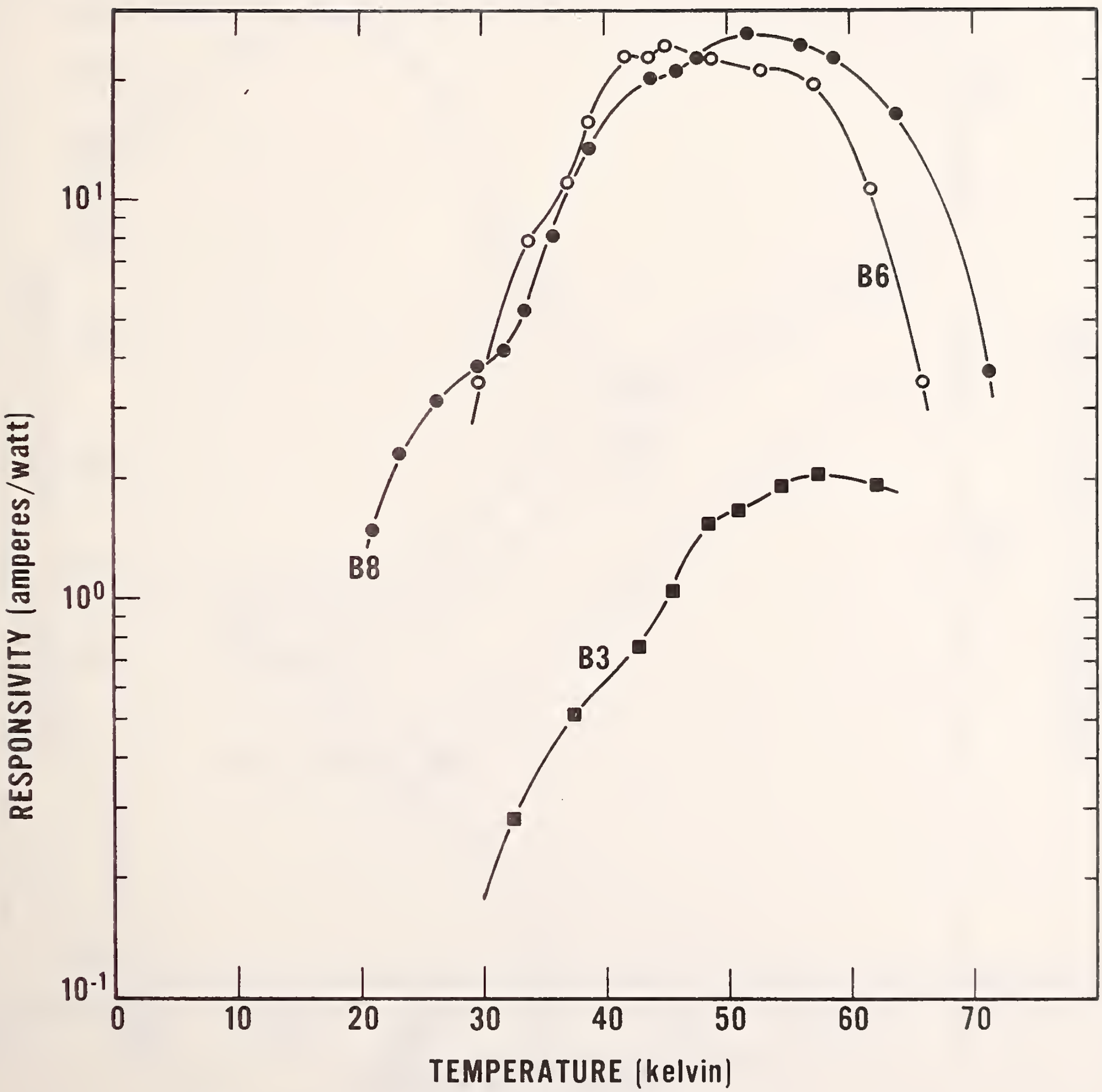

Figure 3. Peak responsivity *vs*. temperature for 20-V bias (400 V/cm) for three test detectors from a single float-zoned crystal of indium-doped silicon. Wafers B8 and B6 were compensated by NTD techniques, while wafer B3 was not given this treatment.

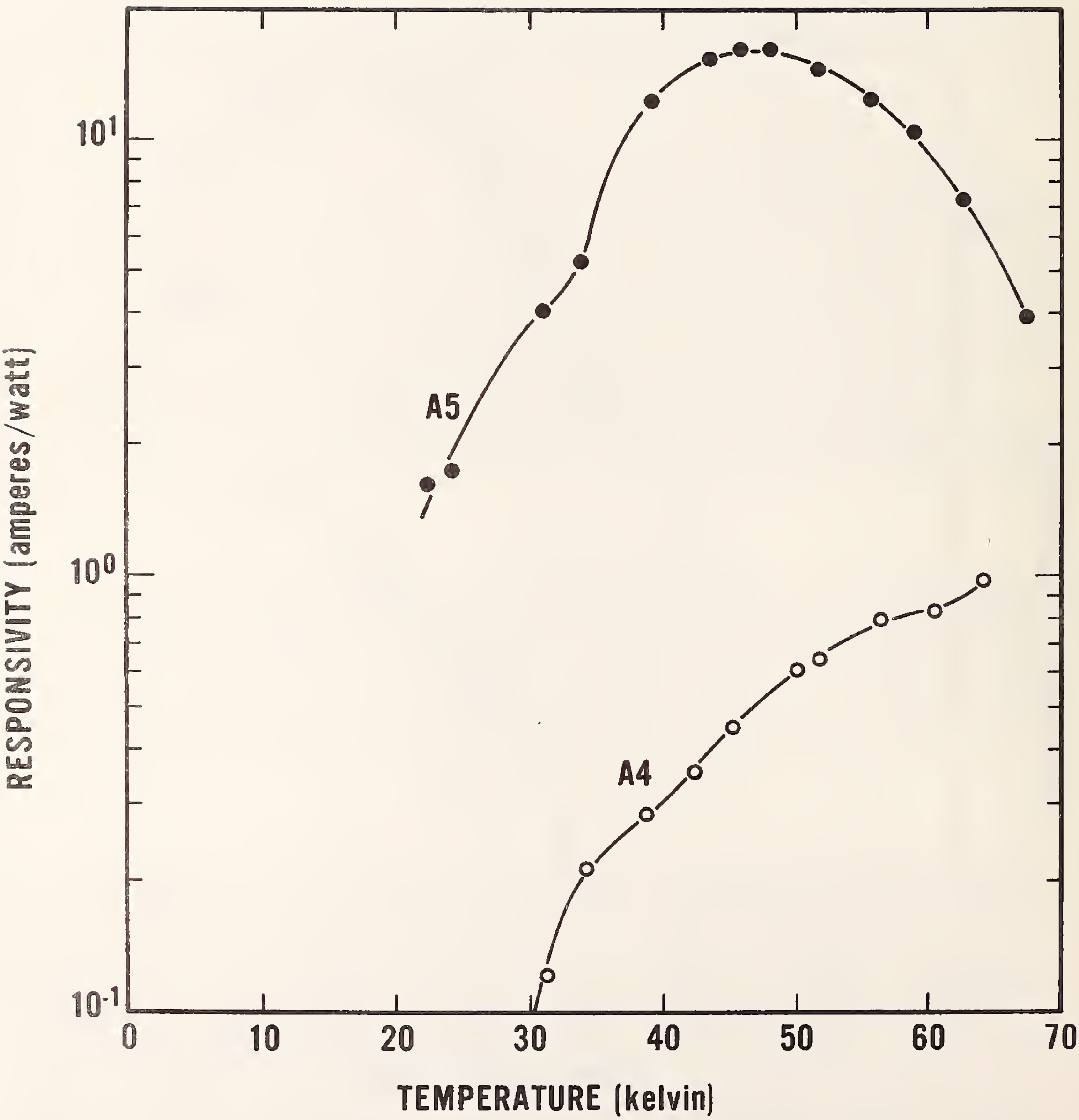

Figure 4. Peak responsivity *vs*. temperature for 20-V bias (400 V/cm) for two test detectors from a single CZ crystal of indium-doped silicon.

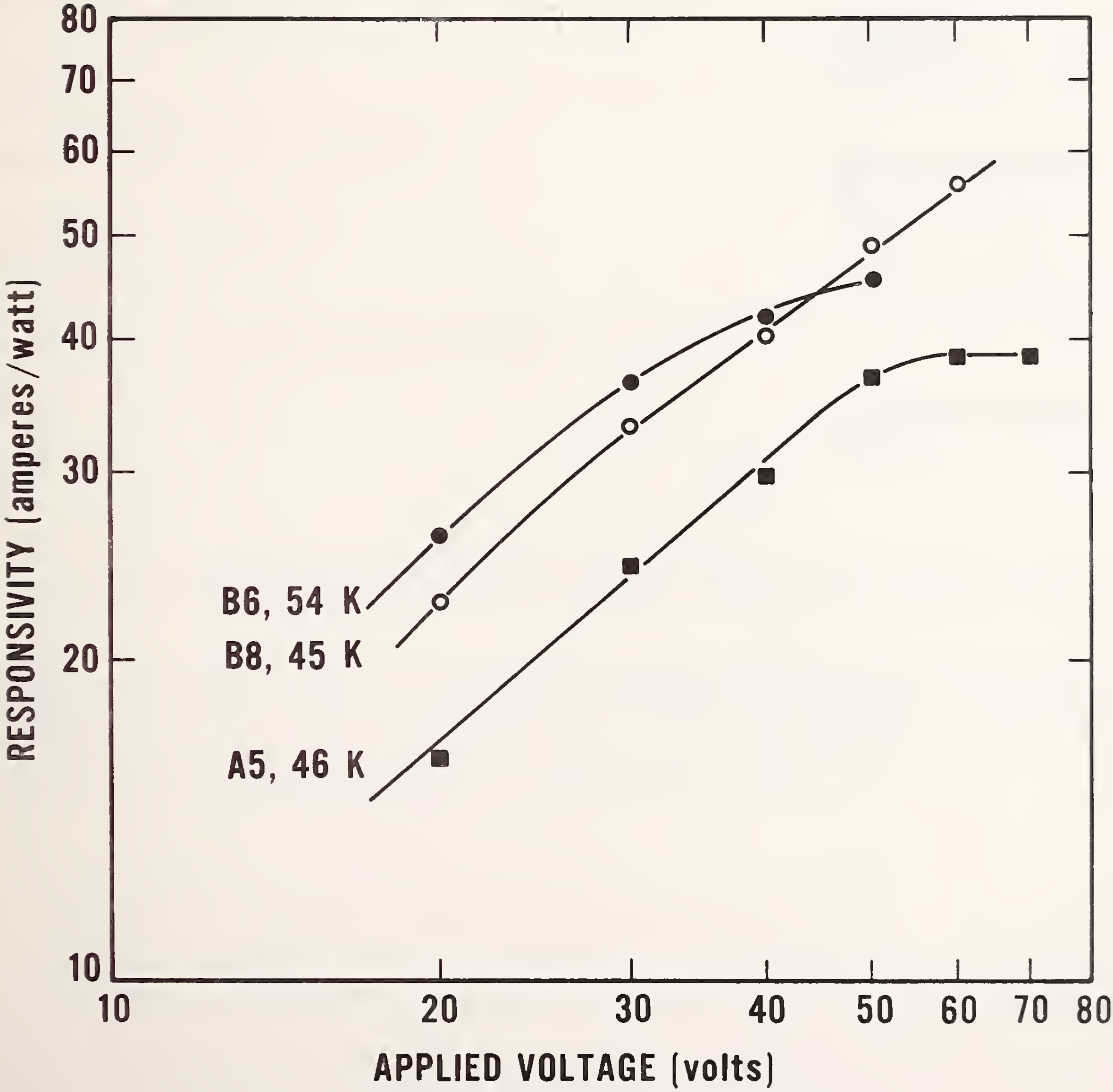

Figure 5. Peak responsivity *vs.* bias voltage for the best two float-zoned and best CZ test detectors at the temperature of maximum response with 20-V bias. The test detector designation and temperature of measurement are indicated for each curve.

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15. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Measurements were made to determine the degradation of responsivity of indium-doped extrinsic infrared detectors at temperatures above their normal operating range. The responsivity was found to fall off very rapidly with temperature above the optimum, and if operation at liquid nitrogen temperature is desired, one must accept a degradation in responsivity of an order of magnitude or more.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Indium-doped silicon; infrared detectors; responsivity.

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