

Absolute linearity measurements on a PbS detector in the infrared

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Abstract. The non-linearity characteristics of a commercially available thin-film photoconductive PbS detector were experimentally investigated in the infrared using the NPL detector linearity characterization facility. The deviation from linearity of this detector was shown to be significant even for relatively low values of radiant power incident on the active area of the detector. For example, the linearity factor was approximately 0.8 when 0.6 μW of radiant power at a wavelength of 2.2 μm was illuminating a spot of 1 mm in diameter on the active area of the PbS detector. These figures demonstrate the very poor linearity characteristics of this detector and provide a warning to other users of PbS detection systems. The deviation from linearity was shown to be a function of the size of the spot being illuminated on the detector active area, as well as the wavelength of the incident radiation. The plot of the linearity factor as a function of irradiance was shown to be independent of the wavelength of radiation illuminating the detector as well as the area of the spot being illuminated, thus confirming that the non-linearity is a function of the incident spectral irradiance.

Introduction

PbS detectors are widely used in radiometry for the detection of infrared radiation in the 1 μm to 3.2 μm wavelength region as well as in instruments such as gas analysers. This is because PbS detectors offer relatively high D^* values in this wavelength region at relatively high operating temperatures, which can be attained by thermoelectric coolers [1, 2]. Photoconductive (PC) PbS detectors are operated with a constant DC bias current to sense the photo-generated change in the detector electrical conductance, which should be proportional to the radiant power incident on the detector. While the change in the conductance at low incident radiant power levels is expected to be proportional to the change of the incident radiant power, at higher radiant power levels the dependence is expected to be non-linear.

The purpose of this paper is to report the results of an experimental investigation carried out at NPL into the characterization of the linearity of a commercially available thin-film PC PbS detector. Special care was paid to the identification of the true dependence of the deviation from linearity of this detector on parameters such as the area of the detector being illuminated by the incident radiation as well as the wavelength of the incident radiation.

The PbS detector whose linearity characteristics are reported in this paper was manufactured by Hamamatsu [2], Model No. P2682-01. The detector had a 4mmx5mm active area and was mounted in a hermetically sealed TO-8

package so it could be cooled using a two-stage thermoelectric cooler. A Hamamatsu C1103-series temperature controller was used to maintain the PbS detector at $-20\text{ }^\circ\text{C}$ throughout the work described in this paper. The detector was biased with a 10 V bias voltage and had a 560 k Ω load resistor, as recommended by the detector manufacturer [2]. A modulation frequency of 70 Hz was used throughout the characterisation of this detector.

Results

The NPL detector linearity measurement facility was used to evaluate the linearity characteristics of the PbS detector. A full description of this facility, which is based on the double-aperture linearity measurement method, can be found elsewhere [3]. The linearity of the PbS detection system was investigated at 1.3 μm and 2.2 μm in order to identify the dependence of the non-linearity on the wavelength of the incident radiation. A tungsten strip lamp with a 2 mm wide element and a silica window was used as a source for all measurements performed. The double-aperture linearity characterization method was adopted for these measurements because it is an absolute linearity measurement method. The adoption of a relative linearity measurement method would have required the availability of an infrared detection system whose linearity characteristics are known. Field stops of diameters 1.8 mm, 1.0 mm and 0.76 mm were used in order to identify the dependence of the linearity factor on irradiance. The magnification of the optics used to image the field stop on the active area of the PbS detector was unity (two identical off-axis parabolic mirrors were used) so the diameter of the spot formed on the active area of the test detector was equal to the diameter of the field stop. Knowledge of the diameter of the illuminated patch allowed the irradiance (radiant areance) to be calculated.

The absolute spectral responsivity of the PbS detector was measured on the NPL infrared responsivity measurement facility [4] so the output voltage could be converted to radiant power incident on the detector.

Figure 1 shows the linearity factor of the PbS detector as a function of radiant power incident on the detector when the radiant power is imaged into spots of 0.76 mm, 1 mm and 1.8 mm diameter, for radiation of wavelength 1.3 μm and 2.2 μm . Figure 1 confirms that the linearity factor is strongly dependent on spot diameter. Data in Figure 1 are plotted on a linear scale to demonstrate that for low incident radiant powers the linearity factor decreases linearly with increasing radiant power.

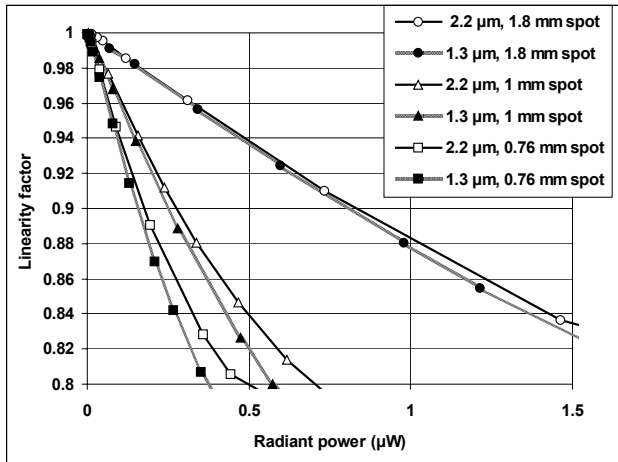


Figure 1. Linearity factor of the PbS detector as a function of incident radiant power at 1.3 μm and 2.2 μm for 0.76 mm, 1 mm and 1.8 mm diameter spots illuminating the active area of the detector.

Figure 2 shows the linearity factor of the PbS detector as a function of irradiance (radiant areance) incident on the detector when the radiant power is imaged into spots of 0.76 mm, 1 mm and 1.8 mm diameter, for radiation of wavelength peaking at 1.3 μm and 2.2 μm . Figure 2 shows that the linearity factor plotted as a function of irradiance is largely independent on the diameter of the illuminating spot and the wavelength of the incident radiation. It is therefore safe to conclude that the plot of the linearity factor as a function of irradiance is independent of the illumination conditions and the wavelength of incident radiation. It is therefore this parameter which should be used in correcting for the non-linear behaviour of PbS detectors [5]. This is only valid for irradiance values below $1 \mu\text{W mm}^{-2}$, whereas for higher irradiance values at the 2.2 μm wavelength, the dependence of the linearity factor on irradiance ceases to be linear and “oscillations” are observed on the linearity factor versus irradiance plots (see Figure 2).

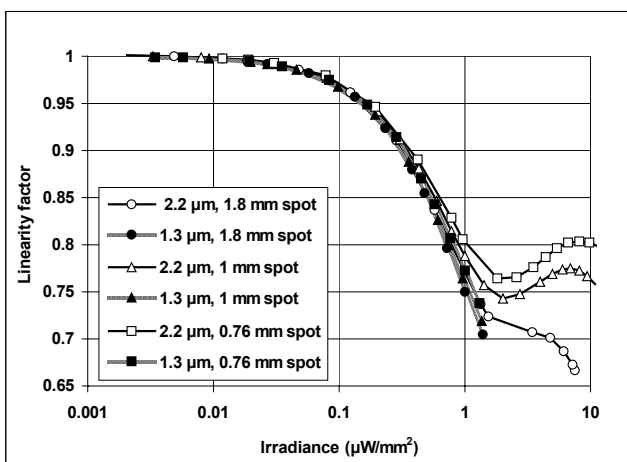


Figure 2: Linearity factor of the PbS detector as a function of incident irradiance at 1.3 μm and 2.2 μm for 0.76 mm, 1 mm and 1.8 mm diameter spots illuminating the active area of the detector.

The dependence of the linearity factor on irradiance suggests that the heating effect due to the incident radiation and the subsequent rise in the local temperature of the detector could be the source of the non-linearity. The temperature coefficient of response of the PbS detector was investigated and was shown to be independent of the bias voltage in the 5 V to 10 V bias voltage range. The values of the temperature coefficient of response of the PbS detector were measured to be $-3.44 \text{ \% } ^\circ\text{C}^{-1}$ and $-3.08 \text{ \% } ^\circ\text{C}^{-1}$ at 2.2 μm and 1.6 μm respectively for a detector temperature of $-10 \text{ }^\circ\text{C}$. The corresponding values of the temperature coefficient of response of the PbS detector were $-3.10 \text{ \% } ^\circ\text{C}^{-1}$ and $-2.77 \text{ \% } ^\circ\text{C}^{-1}$ at 2.2 μm and 1.6 μm respectively for a detector temperature of $-16 \text{ }^\circ\text{C}$. The corresponding values increase to $-4.04 \text{ \% } ^\circ\text{C}^{-1}$ and $-3.86 \text{ \% } ^\circ\text{C}^{-1}$ at 2.2 μm and 1.6 μm respectively for a detector temperature of $0 \text{ }^\circ\text{C}$. The negative sign indicates that the response of the detector decreases as the temperature increases. These figures indicate that it is unlikely that the observed non-linearity is due to the local increase in the detector temperature, as this would require local temperature increases above $10 \text{ }^\circ\text{C}$.

Reference

1. <http://www.calsensors.com>
2. http://usa.hamamatsu.com/assets/applications/ssd/ch_arcateristics_and_use_of_infrared_detectors.pdf
3. E. Theocharous, J. Ishii and N. P. Fox, “Absolute linearity measurements on HgCdTe detectors in the infrared”, *Applied Optics*, **43**, 4182-4188, 2004.
4. E. Theocharous, F. J. J. Clarke, L. J. Rogers, N. P. Fox, "Latest measurement techniques at NPL for the characterization of infrared detectors and materials", *Proc. of SPIE* Vol. **5209**, 228-239, 2003.
5. C. L. Sanders, "Accurate Measurements of and Corrections for Nonlinearities in Radiometers", *J. Res. Nat. Bur. Stand.*, **76A**, 437-453, 1972.