Uniformity measurements of large-area indium gallium arsenide and germanium photodetectors

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Uniformity measurements of large-area indium gallium arsenide and germanium photodetectors

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Abstract.
The properties of six large area semiconductor photodetectors were investigated in the near infrared wavelength range. For potential use as transfer standard detectors in absolute spectral responsivity calibrations, the spatial uniformity and spectral responsivity of four InGaAs and two Ge photodiodes were characterized. Spatial uniformity measurements carried out at 1000 nm, 1550 nm, and 1650 nm show that photodiode spatial non-uniformity changes with wavelength for both InGaAs and Ge detectors. The photodiode characterization apparatus, results, and analysis are presented.

1. Introduction
The dissemination of optical power and spectral responsivity scales at national metrology institutes relies on high-accuracy transfer standard photodetectors. Several types of transfer standard detectors, including semiconductors, thermopiles, and pyroelectrics, can be implemented for measurements in the UV, VIS, and NIR spectral ranges. Thermopiles and pyroelectric sensors are spectrally flat, but generally have poor noise characteristics. Although the spectral range of semiconductor photodiodes is limited by the material band gap, they typically have superior electrical characteristics and higher spectral responsivity. Silicon photodiodes are widely used in the 250 nm to 1100 nm range, while InGaAs and Ge photodiodes can be utilized from approximately 750 nm to 1800 nm [1, 2]. The characterization of extended InGaAs photodiodes, which can reach up to 2500 nm, is discussed elsewhere [3]. The calibration of large active area photodetectors is necessary in many applications such as in radiometric temperature measurements using filter radiometers [4] and for cameras used in astronomical measurements [5]. Additionally, photodiode spatial non-uniformity can increase the uncertainties in spectral responsivity measurements when the application geometry is different from the calibration geometry. In this work, the properties of large active area (5 mm diameter) InGaAs and Ge photodiodes were investigated for use as transfer standard detectors in the NIR. Four InGaAs photodiodes were selected based on the size of the active area and product availability, where diodes 1 and 2 are from one manufacturer and diodes 2 and 3 are from a second manufacturer. The Ge photodiodes are from the same manufacturer, where diode 5 was purchased within the last year and diode 6 has been in use at NRC since 2000. Spatial uniformity measurements of other large area Ge and InGaAs photodiodes can be found in Refs [6–10].
2. Experimental Apparatus

The spatial uniformity of six photodiodes was measured at three different wavelengths using a monochromator based apparatus. Each diode was mounted in an NRC designed anodized aluminum housing. Diode 6 had a temperature controlled housing that was kept at 23.0 °C. All other housings were at ambient temperature (≈ 24 °C) throughout the measurements. The photodetector signal was measured using an NRC designed transimpedance amplifier (gain \(10^6\)) and a digital voltmeter. A 0.5 m Czerny-Turner monochromator with a 600 groove/mm diffraction grating blazed at 1250 nm was used to measured the uniformity if each diode at 1000 nm, 1550 nm, and 1650 nm. A 150 W tungsten light source illuminated the 2 mm monochromator entrance slit and a 100 µm pinhole as well as a motorized filter wheel equipped with order sorting filters were placed at the exit slit of the monochromator. Two lenses (focal lengths 100 mm and 50 mm) were then used to collimate and focus the light down to a 0.22 mm spot. The diode housing was mounted on a motorized XY stage to raster the focus spot across the diode surface which was aligned perpendicular to the optical axis. The measurements were done in a 6.25 mm x 6.25 mm grid in 0.25 mm steps to capture the entire 5 mm diameter active area of the diode face. The same horizontal and vertical scan directions were used for each diode. The spectral responsivity of each photodetector was measured from 900 nm to 1800 nm using a double subtractive monochromator system, a 100 W tungsten light source, and an NRC InGaAs sphere transfer standard [10] as the reference detector. The entrance and exit slits of both monochromators were set to 1 mm resulting in a bandwidth of 4 mm, and two curved mirrors focused the monochromator output to a 1.5 mm spot.

3. Results

Figure 1a) shows a representative sample of the measured spectral responsivity curves from one photodiode from each manufacturer. Measurement wavelengths of 1000 nm, 1550 nm, and 1650 nm were selected in order to investigate the spatial uniformity before, at, and after the peak responsivity. Figure 1b) shows a sample plot of the uniformity of diode 1 at 1550 nm. The photodetector uniformities were calculated by finding the average of the signal collected inside the central region of the diode face, indicated by the white square in the figure, and subtracting that value from the signal at each point in the scan, giving a deviation from the average at each point. Figure 2 shows the uniformity of diodes 1 and 2 at the three measured wavelengths. The small signal deviation scale reveals irregularities across the active area of the photodiode.
Figure 2. Spatial uniformity of InGaAs diodes 1 and 2 measured at 1000 nm, 1550 nm, and 1650 nm.

Figure 3. Spatial uniformity of InGaAs diodes 3 and 4 measured at 1000 nm, 1550 nm, and 1650 nm.

1000 nm and 1550 nm, the diodes are fairly uniform with a faint cross pattern of higher than average signal. At 1650 nm, the diode area is less uniform and the cross pattern is very evident. This may be caused by the composition or growth of the InGaAs material. The uniformity of diodes 3 and 4 is shown in Figure 3. Unlike Figure 2, diodes 3 and 4 show no distinct pattern and have an asymmetric wavelength-dependent spatial uniformity. Figure 4 shows the uniformity of the two Ge diodes (diodes 5 and 6). Both diodes have a mottled uniformity at all three wavelengths. Due to the age difference of the semiconductor material, the uniformity variation
between the two Ge diodes is more pronounced than in Figures 2 and 3.

From the data shown in Figures 2, 3, and 4, we can consider two alignment configurations: one with a 2 mm spot at the center of the diode and the other with the spot offset by 0.5 mm. Analysis of the response of diode 5 in these two configurations yielded a change in integrated signal of approximately -0.5% at 1550 nm, and 1% at 1000 nm and 1650 nm. For the InGaAs diodes, this change in signal with detector alignment was approximately 0.4% and did not vary considerably with wavelength.

4. Conclusions
The spatial uniformity of six large-area InGaAs and Ge photodiodes was found to vary with wavelength, semiconductor type and manufacturer. Data analysis considering different alignment configurations showed that a uniform response over the photodiode active area assists in minimizing the uncertainties due to area of illumination. InGaAs diodes 1 and 2 have the most uniform response (averages of 0.07% and 0.14% respectively), which is a small fraction of the overall uncertainty associated with spectral responsivity measurements in the NIR region. The measurements presented here can be used to elucidate uncertainty components related to uniformity and alignment.

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