Characterization of germanium photodiodes and trap detector

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Abstract. We have developed and characterized new detectors based on germanium (Ge) photodiodes. Our results for the spatial uniformities show improvements as compared with earlier studies. The spectral reflectances of a Ge photodiode and trap detector are studied, and the trap reflectance is found to be less than 10^{-4} in the near infrared wavelength region.

Introduction

The use of Ge photodiodes in the trap configuration [1, 2] has been reported earlier by Stock *et al.* in 2003 [3]. Also the spatial uniformities of Ge photodiodes have been reported in various publications, and they have been found to be a significant source of uncertainty at the level of ~1 % [4, 5].

On the contrary to the large area InGaAs photodiodes, Ge photodiodes with 10-mm diameter are available at moderate prices. The biggest drawback of the Ge photodiodes is low shunt resistance and in turn significant dark current. However, filter radiometers made of Ge photodiodes and the trap detector are suitable in applications, such as spectral irradiance measurements, due to the good spatial uniformity and low reflectance.

In order to extend the Finnish national scale of spectral irradiance [6] to the near infrared wavelength region, we have developed new detectors based on Ge photodiodes, which have sufficient responsivity between 900 and 1650 nm. In this work, we discuss the characterization of Ge photodiodes and a trap detector, consisting of three Ge photodiodes. Characterized quantities are spectral responsivity and spectral reflectance. The effects of spatial uniformity, temperature, polarization and low shunt resistance on the responsivity measurements are also studied. Finally, we analyze the anti-reflection (AR) coating of the photodiodes based on the spectral reflectance measurements at oblique angles of incidence.

Characterization of germanium detectors

The spectral responsivity measurements were carried out by using the monochromator-based spectrophotometer built at TKK [7]. All the studied photodiodes were manufactured by Judson Technologies LLC and their model number is J16-P1-R10M-SC. These photodiodes are large area diodes with circular active area of 10-mm and were ordered without any protecting windows.

The spectral responsivity results for a Ge photodiode and the Ge trap detector are illustrated in Fig. 1. In the responsivity measurements the spectral bandwidth was set to 2.9 nm. The spectral temperature coefficient of the Ge detectors was also studied and found to vary from -0.003/°C to 0.007/°C between the wavelength range of 850 nm and 1650 nm. The shape of the spectral temperature coefficient is comparable to earlier studies [3]. The temperature of the detectors was monitored during the responsivity measurements.

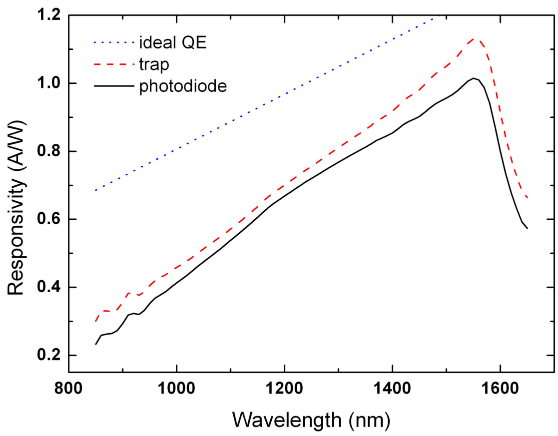

Figure 1. Spectral responsivity of the Ge photodiode and the Ge trap detector at 22.4 °C.

Spatial uniformity

The spatial uniformity was measured at 900 nm, 1308 nm, and 1550 nm wavelengths with three different laser sources. The measurement setup features a cube beam splitter to divide the beam to the monitor detector and the Ge detector under study. The results for a single photodiode at 1308 nm and 1550 nm are presented in Fig. 2. In these measurements the beam diameter was 1 mm and the step size was 0.5 mm.

With 3-mm beam diameter used at the circular central region of 5-mm, the spatial nonuniformity of all four Ge photodiodes is within 0.1 % at 1308 nm and 1550 nm wavelengths. At 900 nm, the spatial nonuniformity varies from 0.22 % to 0.55 % among the four studied diodes.

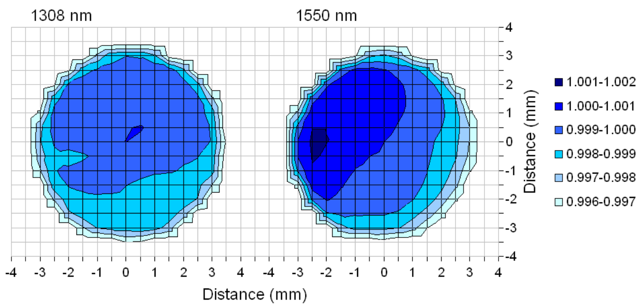

Figure 2. Spatial uniformity of a Ge photodiode at 1308 nm and 1550 nm. Legend lists relative differences compared to the center value of the photodiode.

In the trap configuration the light illuminates a larger area on the first two photodiodes, because they are at 45 degrees angle with respect to the incident light. As the spatial uniformity of a single diode is worse closer to edges and single photodiodes have reasonably low reflectances, the Ge trap detector does not improve the spatial uniformity.

Spectral reflectance

The reflectance measurements were performed for the photodiodes using the absolute gonioreflectometer programmed for specular reflectance measurements [8]. Comparison measurements were done with three different lasers at 1308 nm, 1523 nm, and between 1480 nm and 1600 nm. The results for a Ge photodiode are shown in Fig. 3.

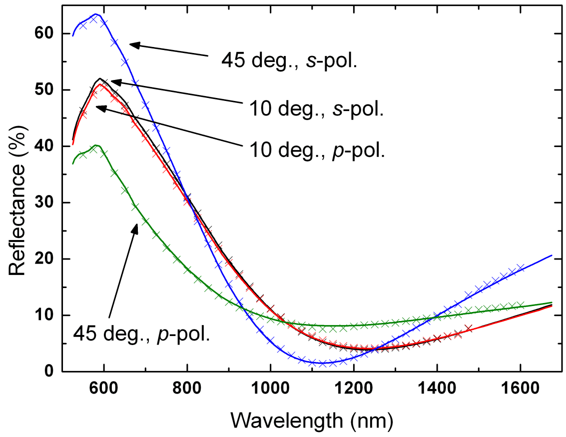

Figure 3. Spectral reflectance of the photodiode measured at 10 and 45 degrees with both *s*- and *p*-polarizations.

The reflectance of the Ge trap was calculated based on the reflectance measurements of the individual Ge photodiodes. This is needed, as the components of the filter radiometers are characterized separately. The result was verified with a laser measurement at 1523 nm. The spectral reflectance of the Ge trap is plotted in Figure 4.

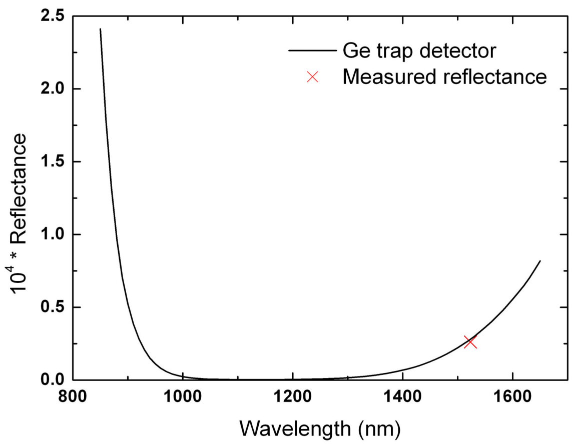

Figure 4. Calculated spectral reflectance of the Ge trap detector verified with a laser measurement at 1523 nm.

All the Ge diodes have AR coating, which explains the shape of the spectral reflectance. In the analysis of AR coating, we combine the spectral reflectance measurements at oblique angles of incidence with a mathematical model that considers a thin homogeneous layer of a dielectric material deposited on a macroscopically thick plane-parallel substrate [9]. For the substrate characteristics, we used tabulated values for bare Ge [10].

The analysis revealed that the thickness of AR coatings of the four Ge photodiodes varies between 175 nm and 182 nm. As the refractive index is found to be at the level of ~1.7, the optical thickness of the antireflection coating is approximately 300 nm, which makes it optimized for the wavelength region around 1200 nm. The analysis did not reveal any reasonable absorption in the AR coating.

Effects of shunt resistance on responsivity

When the gain setting of a current-to-voltage converter (CVC) is adjusted, the input impedance of the device can change. Therefore, reasonably low shunt resistances of the Ge photodiodes (~5 kΩ) and trap detector (~1.7 kΩ) need to be taken into account. Otherwise, a significant ratio of the photocurrent can leak through the shunt resistance instead of CVC. If the input impedance of the CVC increases from 1 Ω to 100 Ω, this can affect the apparent responsivity level of the Ge photodiodes or the trap detector by ~2 % or ~6 %, respectively. To overcome this, the detectors should be calibrated for the different gain settings or the shunt and input impedances should be measured.

Conclusions

The large area Ge photodiodes provide a cost-effective alternative for the InGaAs photodiodes of similar sizes. When the Ge detectors are used for high accuracy measurements, their shunt resistances, dark currents and temperature sensitivities need to be taken into account. The Ge photodiodes have nowadays good spatial uniformities, and the Ge trap detector offers a good alternative for the applications, where we want to avoid harmful interreflections. These properties make Ge detectors well suitable for e.g. the applications of spectral irradiance measurements.

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