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Characterization of detectors for extreme UV radiation

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Abstract. Photodiodes are used as easy-to-operate detectors in the extreme ultraviolet (EUV) spectral range. The Physikalisch-Technische Bundesanstalt calibrates photodiodes in the spectral range from 1 nm to 30 nm with an uncertainty of the spectral responsivity of 0.3% or better. For the dissemination of these high-accuracy calibrations, we investigated the stability and linearity of silicon n-on-p junction photodiodes under intense EUV irradiation in ultra high vacuum. We used quasi-monochromatic direct undulator radiation or focused radiation from a bending magnet to achieve high radiant power. The maximum current in linear operation (1% relative saturation) ranges from about 3 mA for 6 mm photon beam diameter to 0.2 mA for a 0.25 mm diameter spot. The corresponding irradiance increases from 30 mW/cm² for 6 mm photon beam size to about 2 W/cm² for a 0.25 mm beam. Diodes with diamond-like carbon as well as TiSiN top layer proved to be stable up to a radiant exposure of about 100 kJ/cm^2. The observed changes of the responsivity could be explained as the result of carbon contamination of the surface and changes in the electrical behaviour at the interface between top layer and sensitive silicon region. Under UHV conditions, no indication of oxidation of the surface was found.

Introduction

The Physikalisch- Technische Bundesanstalt (PTB) calibrates radiation detectors in the EUV spectral range with an uncertainty of the spectral responsivity of 0.3% or better[i]. Photodiodes are used as easy-to-operate reference detectors. The calibrations at PTB are based on the comparison of the photodiodes to a cryogenic electrical substitution radiometer radiometer (ESR) [ii] as primary detector standard using monochromatized synchrotron radiation[iii], a quasi DC- radiation with a rather low radiant power of about 1 µW. At the customer, these diodes may be used for strongly pulsed radiation and very different radiant power[iv]. We present here investigations of the stability and linearity of the diode signal.

Experimental

At present, mainly silicon n-on-p junction photodiodes of the types AXUV (nitrided siliconoxide passivation layer) and SXUV (metal silicide passivation) form International Radiation Detectors or Au/GaAsP Schottky diodes (e.g. G1127 from Hamamatsu) are used for EUV detection. PTB uses the EUV radiometry beamline with the electrical substitution radiometer SYRES I [ii] as the primary detector standard to provide calibrations of radiation detectors over a broad spectral range from 1 nm up to 30 nm with low relative uncertainty (0.3 % at 13.5 nm, k=1)[i]. Typical results are shown in Fig. 1. The Schottky diodes have the advantage of a very low dark current und thus better signal-to-noise for low power applications. They are, however, less homogeneous because of the strong absorption in the Au- top layer (dashed line in Fig. 1). The AXUV type silicon diode shows superior homogeneity and spectrally flat response. Therefore, this type seems to be suitable as a reference detector. We, however, showed that AXUV diodes degrade during storage even with no irradiation at all[v], see Fig. 2.

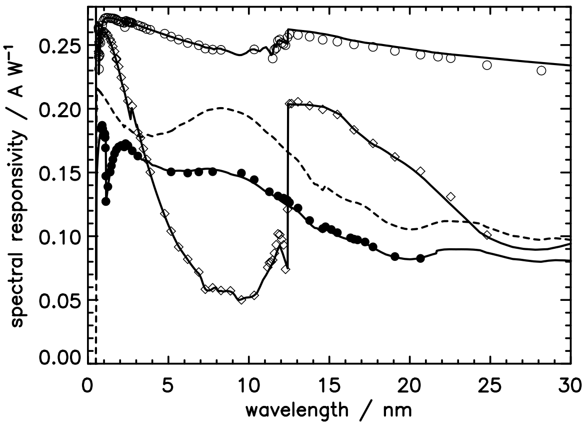

Figure 1. Spectral responsivity of three photodiodes. The upper curve (open circles) is an AXUV type diode. Data for an SXUV type diode are shown with diamonds and for a GaAsP/Au Schottky diode by solid circles. The lines represent model calculations[vi]. For the Schottky diode, the dashed line represents the responsivity that would result if the charge collection efficiency were ideal and only the Au contact layer absorption taken into account.

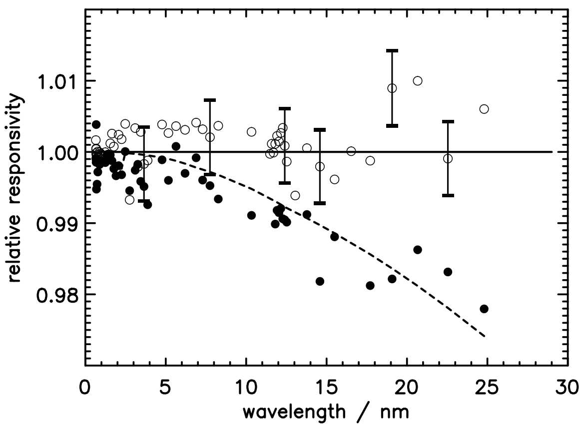

Figure 2. Ratio of spectral responsivity of an AXUV diode, six months after the initial calibration, to the responsivity measured initially (closed circles), and for an SXUV100 diode with TiSiN passivation, measured at the same times (open circles). The error bars represent the uncertainty of a single measurement with the extension factor k=2. The dashed line represents the transmittance of 0.11 µg/cm² oxygen.

The stability of silicon n-on-p junction photodiodes under intense EUV irradiation in ultra high vacuum (UHV) has also been investigated[vii]. Diodes with diamond-like carbon as well as TiSiN top layer proved to be stable up to a radiant exposure of about 100 kJ/cm^2. Although the responsivity remained unchanged within a few percent over the complete spectral range from 2 nm to 20 nm, the low uncertainty in the responsivity measurement allowed a significant spectral dependence to be revealed, see Fig. 3. Using a model for the spectral responsivity[vi], the observed changes of the responsivity could be explained as the result of carbon contamination of the surface, yielding a decrease in responsivity and changes in the electrical behaviour at the interface between top layer and sensitive silicon region. It appears that depending on the type of the top layer, part of this layer becomes either more sensitive or more non-sensitive, and also exhibits a small change in the charge collection efficiency at the interface. Under the UHV conditions of our experiment, no indication of oxidation of the surface was found.

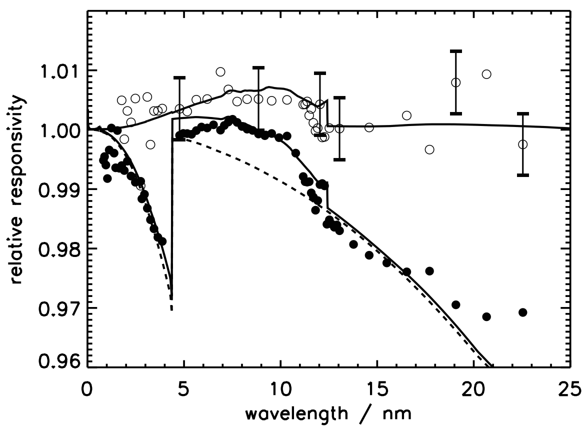

Figure 3. Ratio of responsivity after irradiation to the initial value for two SXUV type diodes. The diode coated with DLC (open circles) was exposed to 69 kJ/cm² and the diode with TiSiN (closed circles) to 143 kJ/cm². The dashed line shows absorptance of 0.57 µg/cm² carbon. The solid lines show the change in responsivity due an increase of the charge collection efficiency at the top silicon interface by 0.5 % absolutely. The error bars represent the uncertainty of a single measurement with the extension factor k=2.

The linearity of the photodiodes was tested in quasi-DC illumination using direct undulator radiation for different photon beam spot sizes[viii]. A systematic and significant variation of the maximum external photocurrent with the photon beam spot size is shown. The maximum current in linear operation (1% relative saturation) decreesed from about 3 mA for 6 mm photon beam diameter to 0.2 mA for a 0.25 mm diameter. The corresponding irradiance increased from 30 mW/cm² for the 6 mm aperture to about 2 W/cm² for a 0.25 mm aperture, see Fig. 4. The behaviour is explained by a change in the effective serial resistance with photon beam size. The values derived from the saturation measurement vary between 65 Ω for a 6 mm beam and 540 Ω for 0.25 mm. This effect can be attributed to the finite conductivity of the thin front contact layer carrying the current to the electrode. For spot sizes smaller than the diode's active area, the serial resistance scales logarithmically with the spot size.

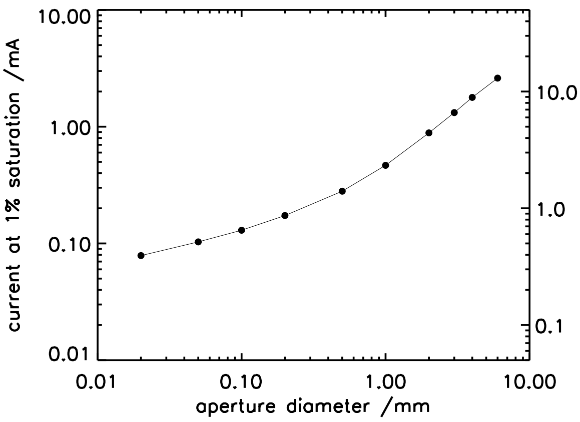

Figure 4. Relation between aperture diameter and current at 1% saturation as obtained from the relation between aperture size and serial resistance as measured down to 0.5 mm aperture size. The data for aperture sizes below 0.25 mm are calculated.

PTB at BESSY provides EUV detector calibrations with low uncertainty using an ESR and radiation of about 1 µW radiant power with high spectral purity and temporal stability. Reliable information on linearity and stability for the extension of the detector calibration to higher radiant power can be obtained at hig-flux beamlines with radiant power in the mW-range.

References

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