Recent status of VUV/EUV photodiodes for radiometric scale comparison

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Semiconductor photodiodes are widely used for the dissemination of radiometric scales. For the extreme and vacuum ultraviolet spectral range (i.e., wavelengths between 10 nm and 200 nm) the performance of these devices does not suffice with respect to homogeneity and stability because of the extreme surface sensitivity. For future scale inter-comparisons, suitable detectors still have to be identified.

INTRODUCTION

In the spectral ranges with wavelengths below 200 nm, synchrotron radiation based realizations of radiometric scales have been established through the last three decades using electric substitution radiometers as primary detector standards [1]. Although different detector types can be used as secondary (transfer) standards, semiconductor photodiodes are widely used, e.g. due to their handiness.

PTB maintains a scale of spectral responsivity using synchrotron radiation from the BESSY II and MLS electron storage rings and electrical substitution radiometers in the spectral ranges from UV (400 nm or 3 eV) to hard X-rays (60 keV or 20 pm). The scale is maintained by the use of different semiconductor photodiodes depending on the respective sub-range, e.g. Si np- and PtSi-nSi Schottky-, and PIN type.

VUV/EUV DETECTOR CALIBRATION UNCERTAINTY BUDGET

The calibration uncertainty and, thus, the possible accuracy of the scale of spectral responsivity, is mainly determined by the contributions listed in Table 1. Main contributions arise from the light source, i.e. the synchrotron radiation from the electron storage ring which is monochromatized by a grating- or crystal monochromator. The monochromatized radiation, however, is not spectrally pure but contains unwanted higher-order and diffuse scatter contributions. The intensity has to be monitored to normalize for the decreasing electron current stored in the storage ring and changes of the monochromator transmission over wavelength or by aging of optical components.

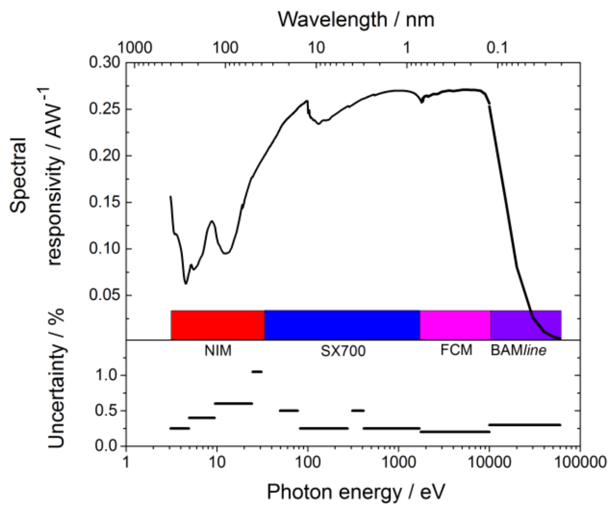

Figure 1. Scale of the spectral responsivity of semiconductor photodiodes by PTB using monochromatized synchrotron radiation at BESSY II (SX700, FCM, BAMline) and MLS (NIM, EUVR/not shown here).

Table 1. Example uncertainty budget for the measurement of the spectral responsivity of a photodiode at 60 nm using monochromatized synchrotron radiation.

Quantity	**Uncertainty contribution (*k*=1)**
ESR power	0.04
BL stability (norm.)	0.15
stray light, higher orders	0.15
photocurrent measurement	0.35
detector non-linearity	0.1
detector non-uniformity	0.2
total	**0.46**

However, the detector itself significantly contributes to the measurement uncertainty if it shows non-uniformity in responsivity over the active surface. Since the beam has a certain (sometimes wavelength-dependent) size, and the position accuracy of the detector with respect to the beam is limited, this leads to variations of the measured signal. Moreover, in the VUV and EUV spectral ranges, any detector is known to suffer from responsivity degradation (from contamination as well as from radiation-induced damage). It can occur already under illumination in the sub-microwatt radiant power regime during the calibration process. If the non-uniformity exceeds the other uncertainty contributions, the diode quality is not sufficient to act as suitable reference detector.

DETECTOR EXAMPLES

AXUV100G Si-np photodiodes have established as well-proven radiometric standard photodiodes over a wide spectral range since they entered the market decades ago. Their extremely thin top oxide layer makes them suitable also for VUV/EUV radiation, where in certain regions the absorption length is less than 10 nm. However, it got obvious very soon that in particular between 40 nm and 170 nm, already moderate irradiation causes significant (local) damage [2]. Radiation-hardened photodiodes like the SXUV100 or PtSi-nSi Schottky SUV-100 type have drawbacks e.g. a much lower responsivity. To our knowledge, there is still no commercial semiconductor photodiode which meets all relevant requirements (e.g. high responsivity, size, uniformity, linearity, radiation hardness, availability).

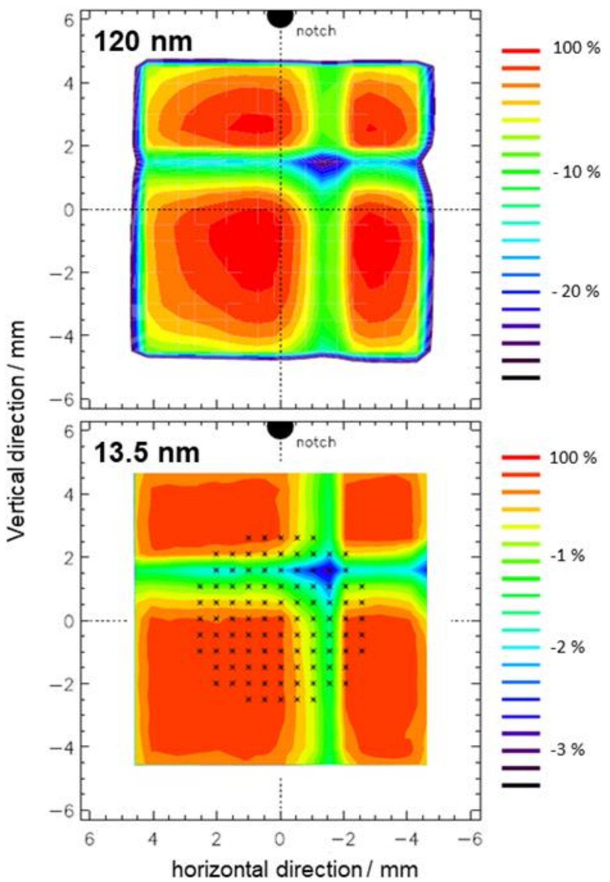

Figure 2. Relative responsivity at wavelengths of 120 nm (VUV) and 13.5 nm (EUV) of a recent example Si photodiode over its active surface area (interpolation with colour scale showing relative changes to the maximum).

Moreover, in the recent years, we observed significant quality losses (regarding uniformity, Figure 2) of some of commercially available standard detector types. Other, new types of detectors (e.g. B-Si type [3] or metal-SiC-Schottky devices [4]) showed promising results, however, still have not reached a commercial level for VUV use.

PREVIOUS SCALE COMPARISONS

In the decade before 2010, intercomparisons between NMIs took place in the EUV (10 nm to 20 nm) [5] spectral range as well as in the VUV range (135 nm to 250 nm) [6]. Although the results indicated that the scale agreement between the NMIs was well within the combined stated uncertainties, it got obvious already then that the characteristics and use of the transfer devices was the limiting factor. Going beyond these existing results, therefore, first of all requires transfer photodiodes with improved characteristics. Even a reproduction of the previous results will not be possible with the presently available detectors.

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