Broad-band efficiency calibration of ITER bolometer prototypes using Pt absorbers on SiN membranes

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Introduction

In view of ITER, R&D efforts have been started to develop a radiation resistant detector suitable for the operation under the harsh environmental conditions expected. So far, these efforts resulted in a detector prototype based on the design of the commonly used foils with Au-absorber on a mica or kapton substrate [1], but now using Pt-absorber on SiN-membrane with Pt-resistors on the back side for each of the 4 channels. Latest developments [2] led to a version featuring an up to $12.5\,\mu$m thick absorber suitable for the detection of high energy photons as they are expected from the centre of the ITER plasma with its high electron temperatures.

The most accurate reconstruction results of the spatial distribution of the plasma radiation to support transport studies or enhance the accuracy of the evaluated total radiative loss P_{rad} deduced from the line-integrals can be achieved only if the energy resolved efficiency of the photon absorption of the bolometer detectors are known. To this aim, the absorption efficiency of the new prototype detectors has been calibrated for absorbers of two different thicknesses in a broad spectral range (3 eV up to 25 keV) by making use of the synchrotron radiation facilities of the Physikalische Technische Bundesanstalt (PTB) at the electron storage rings BESSY II and MLS. Additional measurements for the VIS (1.46 eV up to 3 eV) have been conducted in the lab.

Experimental set-up

For energies above 3 eV, the incident radiant power was measured by calibrated silicon photodiodes as reference detector with relative uncertainties of about 1%. For the measurements in the VIS (400 nm–850 nm) monochromatized radiation from a halogen lamp was focused onto the detector and adjusted to fall completely onto the absorber area in the laboratory of IPP. A calibrated laser power meter was used as reference with an uncertainty of 5%.

For all calibration measurements the prototype detectors (bolometer 1: flow chart 1100025,

waver 481, chip L with 12.5 μm thick absorber; bolometer 2: flow chart 900076, wafer 234, chip D with 4.5 μm thick absorber) have been connected to the same data acquisition hardware. It can be operated in both, calibration mode to determine the detector parameters, i.e. meander resistance R, cooling time constant τ, normalised heat capacity κ and offset of the Wheatstone-bridge U_{offs} in-situ, and in measurement mode. The respective procedures have been described in detail elsewhere [3]. The sampling time chosen for the experiments was 19.2 ms, the highest the ADC could achieve, in order to reduce readout noise as much as possible.

Before each measurement, the procedures for determining R, τ, κ and U_{offs} have been run. After acquiring the measurement signals, i.e. the time trace of the bridge voltage U_{b} for each detector channel, the detected power P_{rad} is evaluated according to $P_{\text{rad}} = A\kappa \left[\tau \frac{dU_{\text{b}}}{dt} + U_{\text{b}}(1 - \frac{B}{\kappa}) \right]$ (equation 16 in reference [3]) and a software implementation of the Savitski-Golay-filter for calculating the time derivative of U_{b}. The constants A and B depend on the properties of the electrical circuit for each Wheatstone bridge, e.g. exciting voltage of the bridge, cable resistance, etc.

Each measurement cycle was defined to last up to 30 s during which the beam illuminated the detector for 12 s by operating a shutter synchronous to the data acquisition. As the incident radiant power showed intensities as low as 0.2 μW and the offset drift is non-negligible in these cases, the background of the measurement signal showed variations which had to be taken into account for the evaluation. An example of such a time trace of the
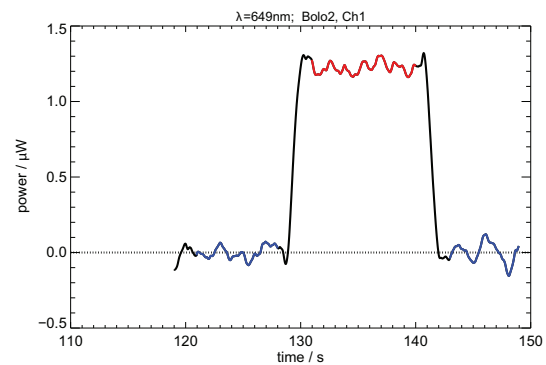

Figure 1: *Example time trace of the detected power after offset correction.*

detected power is shown in figure 1. For all measurements made, the background can be well approximated using a linear function. The parts of the time trace used to determine this function are indicated in blue. The average power P_{bolo} as measured by the bolometer is now determined by calculating the average value of the signal during the time when the shutter was open (red parts of the time trace). Those parts of the time during which the shutter opens or closes, plus an additional delay to account for the filter width of the Savitzky-Golay-filter (also applicable at the start of the measurement cycle), have neither been used for calculating the background nor the average power (black parts of the time trace). The uncertainty of the average power is determined using Gaussian error propagation and taking all input uncertainties into account.

The efficiency η for each photon energy measured is $\eta = \frac{P_{\text{bolo}}}{P_0}$, where P_0 is the incident radiant power, measured with calibrated diodes.

Measurement results and discussion

The results from scanning range and sampling time settings demonstrated that the data acquisition system used to implement the in-situ calibration procedure and the measurements is well capable of applying various range and sampling time settings which can be chosen to match the experimental conditions. Measuring low incident radiant powers helped to assess the performance of the prototype detectors and to project this to the use on a fusion experiment like ITER. According to fig. 1 the power as determined by bolometer 2 has a noise level of $\pm 0.1 \, \mu$W; the one for bolometer 1 (not shown) $\pm 0.2 \, \mu$W. Thus, under optimal conditions, the lowest power level which can be detected by the bolometers is about $0.2 \, \mu$W. Taking the surface area of the detector exposed to the radiation of $4.94 \, \text{mm}^2$ into account, this relates to a line averaged radiant power density of $40 \, \text{mW/m}^2$ which would be, in ideal conditions, the lower limit detectable in a fusion experiment when using these detectors. For more realistic conditions it is expected that this increases to $0.2 \, \text{W/m}^2$.

The efficiency of the two bolometer detector prototypes has been determined for channel 1 and 4 respectively in the energy range from $1.46 \, \text{eV}$ up to $25 \, \text{keV}$. Figure 2 shows all results within one graph. The efficiency values with the highest uncertainties correlate to measurements which had to be made at the lowest ra-
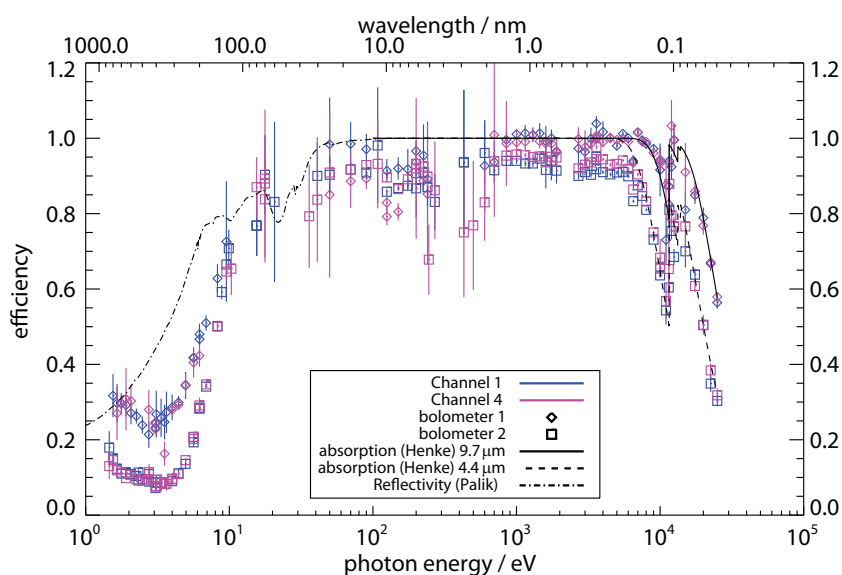

Figure 2: *Efficiency of 4 bolometer channels vs. photon energy.*

diant powers. In addition to the measured efficiency, the absorption coefficient according to [4] is drawn as a continuos line for an assumed absorber thickness of $9.7 \, \mu$m and as a dashed line for an assumed absorber thickness of $4.4 \, \mu$m. For energies below $100 \, \text{eV}$ the reflectivity of Pt under $90°$ incidence according to [5] is drawn as a dot-dashed line. These values from literature denote the efficiency of the bolometers which could be expected in an ideal case.

At $11.56 \, \text{keV}$ the sharp Pt-L$_3$ absorption edge allowed to cross-check the absorber thickness by fitting the measured efficiency to the theoretically expected absorption of X-rays in a homogeneous Pt-layer. The nominal thickness of the thin absorbers could be confirmed, however not the one of the thick absorbers. To decide whether the discrepancies between nominal and mea-

sured thickness are due to differences in the assumed Pt-density of the absorber or variations in the production process, Rutherford backscattering (RBS) measurements will be performed.

The calibration measurements clearly demonstrate that the efficiency of the bolometer prototype detectors in the range of $50\,\mathrm{eV}$ up to $\approx 6\,\mathrm{keV}$ is close to unity; at a photon energy of $20\,\mathrm{keV}$ the thick absorber detects 80% of the photons, the thin absorber about 50%. This indicates that the detectors will be providing an absolutely calibrated measurement of the plasma radiation expected from the standard ITER scenario. However, a minimum thickness, which can be determined by using literature data for the absorption coefficient of the absorber material, will be required to detect the high energetic radiation from the central plasma (up to $25\,\mathrm{keV}$, depending on the envisaged scenario).

Below $50\,\mathrm{eV}$ the photon absorption first follows the reflectance expected for Pt, but below $10\,\mathrm{eV}$ it is reduced further by a factor of 2 for the thick absorber and a factor of 4 for the thin absorber. Most probably, the different histories in production, storage and operation led to varying surface conditions which in turn influenced the result. For future detector prototypes it is envisaged to investigate possibilities for blackening the absorber in order to enhance the photoabsorption in the VIS and VUV range. However, in view of ITER it will be highly important to consider potential degradation effects of such measures.

Acknowledgements

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