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NEW PHOTON BPM SETUP USING SiC DEVICES IN PHOTOCONDUCTIVE MODE

M. Colja*, G. Brajnik, G. Cautero, D. Giuressi, S. Krecic, R. Sergo
Elettra Sincrotrone Trieste, Trieste, Italy
M. Cautero, V. Di Trapani, Dipartimento di Fisica, Università degli Studi di Trieste, Trieste, Italy
G. Bonano, Università di Modena e Reggio Emilia, FIM, Modena, Italy
M. Coreno, CNR-ISM, Istituto di Struttura della Materia Trieste branch, Trieste, Italy
M. Alagia, M. de Simone, CNR-IOM, Istituto Officina dei Materiali, Trieste, Italy
E. Lagosh, M. Montagnese, W. Mühleisen, J. Pribošek, Silicon Austria Labs GmbH, Villach, Austria

Abstract

Photon beam position monitors (pBPMs) are essential diagnostic tools in synchrotron light sources, providing real-time information on photon beam stability and trajectory. Conventional designs, including photoemission blades and diamond detectors, face limitations at fourth-generation facilities, where beams exhibit sub-micron dimensions, high brilliance, and impose severe thermal loads. We present a novel pBPM concept based on intrinsic silicon carbide (SiC) sensors operated in photoconductive mode. A sensor matrix, integrated near the beamline collimator, enables distinct detection of bending-magnet (BM) and insertion-device (ID) radiation. Initial tests at Elettra demonstrate micron sensitivity, effective BM/ID separation, and real-time discrimination between positional drifts and intensity fluctuations. These results establish SiC photoconductive devices as promising candidates for next-generation photon diagnostics.

INTRODUCTION

The development of fourth-generation synchrotron light sources presents significant challenges for pBPMs. These facilities deliver photon beams with high brilliance and sub-micrometer dimensions, requiring diagnostics that combine high spatial resolution, wide dynamic range, and radiation hardness. Effective methods in earlier generations of storage rings often could be inadequate under the demanding conditions of these new machines.

A commonly used pBPM design involves crossed-blade monitors based on photoemission [1, 2]. These systems are non-invasive as they rely on detection of the beam's outer tails, however they become progressively less suitable as beam sizes decrease. In fourth-generation sources, thermal management necessitates the use of upstream apertures or collimators to remove beam tails, transmitting only the central core of the photon beam. This configuration eliminates the signal upon which blade monitors depend.

Alternative approaches, such as diamond detectors with four-quadrant electrodes, offer improved sensitivity for micrometer-sized beams and can provide good sensitivity [3]. However, their performance is strongly photon-energy dependent: at low photon energies, the diamond must be thinned to ensure transmission, compromising mechanical integrity and thermal stability. A more fundamental limitation arises when these detectors are placed downstream of a collimator. If the transmitted beam corresponds only to the flat peak of a Gaussian-like profile, any upstream beam displacement will be invisible to the monitor, regardless of the detection scheme employed.

Additionally, existing pBPMs lack the ability to discriminate between radiation originating from bending magnets (BM) and insertion devices (ID), as both contributions are spatially overlapped along the beamline. This limitation hinders precise diagnostics and beamline tuning.

To overcome these challenges, we propose and demonstrate a novel approach for the forthcoming Elettra 2.0 light source [4]: integrating a matrix of radiation-hard sensors directly onto the upstream surface of the collimator itself. This location preserves access to the full beam profile, including the tails before their clipping. The collimator, being water-cooled and structurally robust, provides a suitable platform for sensor integration in this high-radiation environment. The sensor matrix is strategically arranged such that specific regions are exposed only to BM radiation (characterized by a broad profile), while others intercept both BM and ID radiation, which is more spatially confined. This configuration allows for clear separation of BM and ID contributions and provides comprehensive information about the beam profile at the point of tail suppression.

It is worth emphasizing that pBPMs fulfill two critical roles. First, they provide valuable feedback for accelerator operators, as the electron trajectory in the ring is directly correlated with the photon beam trajectory. Second, they serve the user community by ensuring beam stability at the experimental station, reducing the risk of beam-related artifacts in measurements. Our approach addresses both requirements by providing the necessary diagnostic information without interfering with machine operation or ongoing experiments. We present the first implementation of this concept using SiC sensors operating in photoconductive mode.

SiC SENSORS

The sensors employed in this study are based on intrinsic SiC operated in photoconductive mode, analogous to the configuration commonly used for chemical vapor deposition (CVD) diamond detectors. Specifically, the 4H SiC polytype

* matija.colja@elettra.eu

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was chosen due to its wide bandgap (≈3.26 eV), high carrier mobility, and excellent thermal conductivity, making it well-suited for high-radiation, high-temperature environments [5]. In this regime, the photocurrent generated under illumination follows the well-established relation:

$$\frac{I_{ph}}{V} = \frac{eG_{ph}(\mu_n\tau_n + \mu_p\tau_p)}{l^2},$$

where I_{ph} is the photocurrent, V the applied bias, G_{ph} is the photoconductance of the sample, μ_n and μ_p the electron and hole mobilities, τ_n and τ_p their respective lifetimes, and l the inter-electrode spacing [6]. This expression indicates a linear dependence of the photocurrent on both photon flux and applied voltage.

While CVD diamond exhibits superior properties in certain aspects (such as wider bandgap and higher thermal conductivity), 4H-SiC remains a compelling alternative for pBPM applications due to its more mature fabrication processes, which translates into greater design flexibility with potentially larger detection area, lower production costs and greater scalability. In this proof-of-concept implementation, custom sensors supplied by Silicon Austria Labs (SAL) have been used, featuring an active area of 5 mm × 8 mm and a thickness of 500 µm.

Before deployment in the synchrotron environment, the SiC sensors have been characterized to assess their fundamental electrical and photoresponse properties. Initial on-bench measurements revealed high dark resistivity, exceeding several TΩ. This result guarantees minimal leakage current and low noise floor, allowing high-sensitivity photon detection. Measurements conducted with a calibrated X-ray source confirm a strong linear relationship between the generated photocurrent and the applied voltage, the photon flux and the exposed detector area.

EXPERIMENTAL SETUP

Initial proof-of-concept tests have been conducted at Elettra Sincrotrone Trieste, utilizing existing infrastructure originally designed to support legacy blade-type pBPMs, installed immediately downstream of the storage ring. These earlier systems were ultimately unsuccessful, largely due to the previously discussed limitations.

We opted to repurpose these existing pBPM holders to implement a 4 by 2 matrix (as shown in Fig. 1). However, the geometry of the legacy system required to mount the sensors on the back side of the holder assembly. As a result, only a limited portion of each sensor could be exposed to the beam, intercepting radiation near the beam's outer edges to ensure non-invasive operation. Moreover, this back-mounted configuration introduced additional thermal challenges. The sensor elements extend several millimeters beyond the cooled surface of the support, leaving a portion of each sensor thermally isolated and directly exposed to the beam. Numerical simulations indicate that these protruding, uncooled regions can reach surface temperatures of several hundred degrees Celsius under direct illumination. In contrast, the configuration foreseen for Elettra 2.0 will ensure full thermal contact between the sensors and a water-cooled collimator body, enabling more efficient heat dissipation.

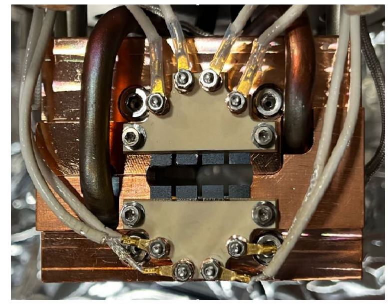

Figure 1: Developed pBPM prototype: 4×2 matrix of SiC photoconductive detectors mounted on the water-cooled holder. Signal extraction is performed via shielded cables connected to transimpedance amplifiers for simultaneous photocurrent measurement.

The pBPM holders are equipped with precise XY translation stages (perpendicular to the beam) which provided the mechanical flexibility necessary to align and position the detectors within the beam path. The photocurrent signals from all eight sensors are simultaneously measured using fast transimpendance amplifiers [7].

FIRST RESULTS AT ELETTRA

The BPM setup was installed on beamline 3.2 at Elettra, where it was exposed to synchrotron radiation originating from both the bending magnets (BM) and the U12.5 undulator (see Fig. 2). The undulator provides tunable radiation in the 17 eV to 750 eV range, and its contribution can be controlled by adjusting the undulator gap. This configurability allowed us to separately assess the detector's response to bending BM radiation alone and to the combined signal from both the BM and the ID.

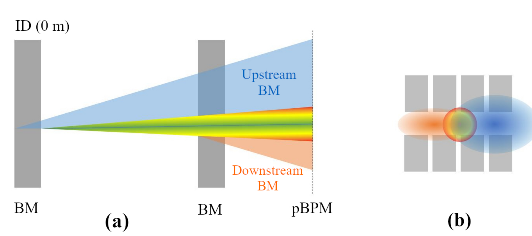

Figure 2: (a) Schematic representation of the radiation contributions from the BMs and the ID. (b) Front view of the pBPM. Central sensors intercept both BM and ID radiation, while peripheral sensors predominantly detect BM radiation, enabling spatial separation of the two components.

Initial measurements confirmed the expected spatial selectivity of the sensor array. A series of position scans were performed at different ID gaps (300 mm, 200 mm, 150 mm, 125 mm, 110 mm). As shown in the Fig. 3, the central sensor (aligned with the ID axis) exhibits a clear increase in

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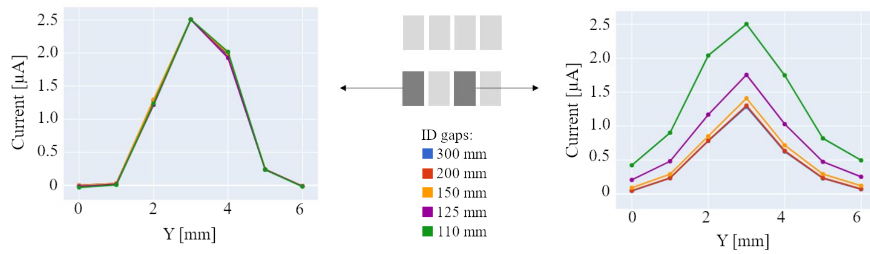

Figure 3: Photocurrent as a function of vertical beam position for different ID gaps. Outer detector (left): constant response across all ID gap values, confirming detection of BM radiation only. Inner detector (right): clear variation in signal with decreasing ID gap, reflecting sensitivity to ID radiation.

photocurrent as the ID gap is closed, indicating sensitivity to ID radiation. In contrast, the peripheral sensors show no response to gap adjustments, confirming that they are only intercepting BM radiation. This result validates the system's ability to discriminate between BM-only and combined BM+ID contributions based solely on sensor positioning.

Subsequent tests focused on the system's spatial resolution, a key performance metric for beam position monitors. Figure 4 illustrates the response of the sensor array during a controlled vertical displacement of the photon beam. As expected, the photocurrent increases on the lower sensor while decreasing on the upper sensor, consistent with the vertical movement of the beam across the detector matrix. These measurements were acquired at readout rates of 200 Hz (3.255 kHz sampling rate with 16 samples moving average filter), and the system resolution approaching the micron scale.

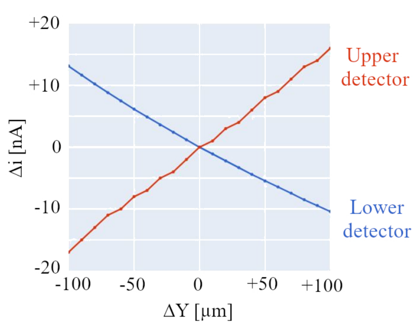

Figure 4: Photocurrent variation of the two detectors in the third column of the SiC matrix during controlled vertical beam displacement. The complementary increase and decrease in current demonstrate the system's sensitivity to vertical beam position.

A final series of measurements evaluated the detector's capability to monitor beam motion in real time and to distinguish true positional changes from mere intensity fluctuations. Figure 5 presents currents as a function of time from two vertically opposed sensors during a typical machine cycle. Initially, during the top-up phase (up to 2000 s), when the electron bunches in the storage ring are refilled, the individual sensor signals exhibit step-like increases in current. These steps are absent when using a normalized difference-over-sum (DoS) signal, indicating that no actual beam displacement occurred. Subsequently, during an orbit correction phase, both individual sensor signals and the DoS signal exhibit correlated variations, confirming an actual shift in beam position.

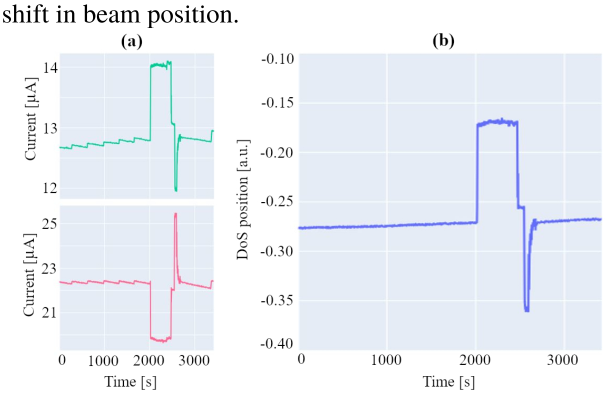

Figure 5: (a) Time-resolved photocurrent signals from the two detectors in the third column of the SiC matrix. (b) Calculated DoS signal. The normalization suppresses global intensity fluctuations (top-ups) and isolates actual beam position variations.

CONCLUSIONS

In this work we presented the first tests with pBPM based on SiC sensors, developed through the collaboration between Elettra and Silicon Austria Labs. While the results are still preliminary and were obtained using a non-ideal experimental setup, they are nevertheless highly encouraging in view of the forthcoming Elettra 2.0 light source. During the scheduled machine shutdown, considerable efforts will be directed toward addressing the most critical components, particularly the SiC sensors, with the aim of achieving improved material purity. In parallel, comparative tests will be conducted using CVD diamond detectors as an alternative. These tests will employ conventional photon sources, with the sensors mounted on a system that accurately replicates the collimator configuration planned for Elettra 2.0.

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