Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Belle-II VXD radiation monitoring and beam abort with sCVD diamond sensors

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http://dx.doi.org/10.1016/j.nima.2015.09.007

ARTICLE INFO

Keywords:
CVD diamond sensors
Radiation hardness
Diamond radiation detectors
Beam radiation monitoring

ABSTRACT

The Belle-II VerteX Detector (VXD) has been designed to improve the performances with respect to Belle and to cope with an unprecedented luminosity of $8 \times 10^{35}\ \mathrm{cm^{-2}\ s^{-1}}$ achievable by the SuperKEKB. Special care is needed to monitor both the radiation dose accumulated throughout the life of the experiment and the instantaneous radiation rate, in order to be able to promptly react to sudden spikes for the purpose of protecting the detectors. A radiation monitoring and beam abort system based on single-crystal diamond sensors is now under an active development for the VXD. The sensors will be placed in several key positions in the vicinity of the interaction region. The severe space limitations require a challenging remote readout of the sensors.

1. Introduction

The design luminosity of the SuperKEKB asymmetric e^+e^- collider is 40 times higher than that of KEKB, and it will be achieved by a sizeable decrease of the beam size, larger crossing angle at the interaction region and a moderate increase of the beam currents. All the Belle-II sub-detectors [1] have been redesigned to improve the performances with respect to Belle and to cope with the expected increase of luminosity. A large effort has been made to minimise the overall material budget for the VXD [1], the innermost tracking device of Belle II. The VXD will be composed of 2 layers of DEPFET pixels (PXD: PiXel Detector) [1] at radii 1.4 and 2.2 cm, surrounded by 4 layers of double-sided silicon strips (Silicon Vertex Detector: SVD) [1,2] at radii 3.8, 8.0, 10.4 and 13.5 cm.

As a consequence of the luminosity increase, severe beam-induced backgrounds and radiation doses are expected. The main background sources will be e^+e^- pair production in two-photon process, radiative Bhabha scattering, Touschek scattering and off-momentum particles from beam–gas interactions. Synchrotron radiation will be controlled by appropriate shielding. These backgrounds are strongly dependent on beam optics, simulations are in progress and they show that the most affected Belle-II sub-detector is the VXD and energy losses will be mainly from electrons. From preliminary estimates the PXD total integrated doses [1] may range from about 150 to 180 kGy (15 to 18 Mrad) during the projected lifetime of Belle-II at the design integrated luminosity ($50\ \mathrm{ab^{-1}}$). For the inner layers of the SVD, less exposed, a dose of about $90\ \mathrm{krad/ab^{-1}}$ would approximately integrate to 4.5 Mrad. All the DEPFET structures were irradiated up to 20 Mrad. The APV25 SVD front-end chips were tested to be radiation-tolerant above 30 Mrad.

2. Performance requirements

The primary goal of the VXD radiation monitoring system is to detect beam conditions that will be potentially damaging for the sensors or the front-end electronics. The corresponding action should be an immediate trigger signal to the SuperKEKB beam-abort system. From the experience of previous experiments (such as BaBar, Belle, and CDF), two signals can be foreseen: a fast abort for a sudden large increase in background and dose rate, and a slow abort for a smaller increase, with unacceptable integrated dose over longer periods. The secondary but important goal, for both Belle-II and SuperKEKB, is the continuous monitoring and recording of radiation doses at sensitive spots.

3. Sensors, location, cabling, package

In order to perform such a task, the sensors must be placed as close as possible to the PXD and SVD, possibly in the vicinity of and around the interaction region. The severe space limitations require a challenging remote readout of the sensors and the package itself must be as compact and shielded as possible. Belle-II monitoring system will be fully based on radiation-hard sCVD single-crystal Chemical Vapour Deposition diamond sensors with dimensions $4.5 \times 4.5 \times 0.5\ \mathrm{mm^3}$. Polycrystal pCVD sensors are less expensive, but have a lower Charge Collection Efficiency (CCE) and require a higher operating voltage. A set of 4+4 sensors will be located on an empty groove behind the beam pipe cooling manifold, upstream and downstream of the PXD at the same radius; 6+6 will be located close to the support rings of the inner SVD layers. Long (∼20 m) doubly screened coaxial cables directly connect the diamond sensors to the high voltage and current-measuring circuits. Cables must be halogen-free, radiation-hard, with appropriate shielding and grounding. Fig. 1 shows a diamond in a prototype package.

4. Electronics requirements

Assuming sensor-current/dose-rate to be 1 nA/7 mrad/s (70 μGy/s), for fast aborts the readout must have a 10 nA precision at a 10 μs response time; for slow aborts a better than 1 nA precision, at 1 s time scale. The design of readout electronics, now close to the prototype level, is done in collaboration with Electronics Division of the Elettra Synchrotron light source in Trieste. It includes current digitizers and FPGAs with digital filtering, data buffering, and programmable thresholds for the beam abort triggers. Among the other features: selectable current digitization ranges (0÷50 μA and 0÷2 mA) and several levels of running averages updated every 10 μs.

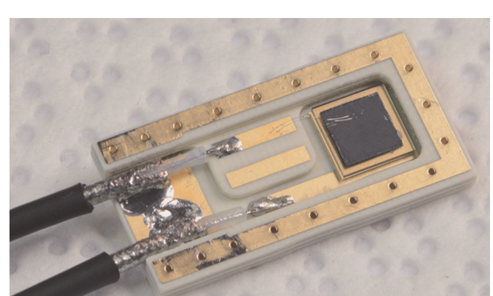

Fig. 1. A picture of the compact package hosting the single-crystal diamond.

Please cite this article as: K. Adamczyk, et al., Nuclear Instruments & Methods in Physics Research A (2015), http://dx.doi.org/10.1016/j.nima.2015.09.007

5. Characterization of first prototypes

The characterization of first prototypes, made of sCVD with Al or Au electrodes and mounted in the compact package shown in Fig. 1, has been performed in several steps: (a) I–V current–voltage characteristics in the dark, typically $\lesssim 1$ pA up to 500 V; (b) I–V with light exposure: a significant increase of the current above 1 pA must be observed; (c) CCE with single particles from a β source as a function of the voltage, with a saturation of $\simeq 100\%$ typically observed above 60 V; (d) I–V when irradiated by a β source at a given distance; in this case the measured currents increase with the high voltage and no saturation is observed; (e) current–distance behaviour when irradiated by a β source, matching the expected dependence on the inverse squared distance; (f) long-term stability when irradiated by β source at a fixed voltage and distance for periods from several hours to few days; (g) Transient Current Technique (TCT) by α source that allows to measure the electric field uniformity and carriers mobilities.

6. Conclusions

We have shortly described the radiation monitoring system of the Belle-II VXD based on 20 sCDV diamond sensors. The first tests with 4 detectors and a prototype of the readout system will begin during the first commissioning phase in 2016.

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Please cite this article as: K. Adamczyk, et al., Nuclear Instruments & Methods in Physics Research A (2015), http://dx.doi.org/10.1016/j.nima.2015.09.007