Synchrotron Radiation Measurement Using Diamond Detector

Amit Kumar[1]*, S. Chakraborty[1], M. Tiwari[2,3], and S. Majumdar[1]
[1]*Electronics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[2]*Accelerator Physics and Synchrotron Utilization Division, RRCAT, Indore-452013, INDIA*
[3]*Homi Bhabha National Institute, Anushaktinagar, Mumbai-400094, INDIA*

Introduction

Diamond detectors are ideal for synchrotron measurements due to their high radiation hardness, fast response time, and low noise levels [1]. These detectors operate effectively in high-flux environments, where performance of other detectors degrade significantly. The high thermal conductivity of diamond allows for efficient heat dissipation, maintaining performance under intense radiation. Additionally, its wide bandgap leads to low leakage currents, enhancing the signal-to-noise ratio, which is crucial for precise measurements in synchrotron applications.

Synchrotron radiation measurements are crucial for a wide range of scientific applications, including material science, biology, and nanotechnology, due to the high brightness, broad spectrum, and tunable nature of the radiation [2]. Accurate detection and analysis of synchrotron radiation are essential for optimizing experimental outcomes and advancing research. However, the intense radiation environment presents significant challenges, such as radiation damage, thermal management, and the need for robust performance and fast response times. Various detectors, including silicon diodes, scintillators, and diamond detectors, are employed to address these challenges, with diamond detectors standing out for their exceptional radiation hardness, high thermal conductivity, and low noise performance [1], making them particularly suited for demanding synchrotron applications.

Experimental Setup

A 5 mm × 5 mm × 300 μm single-crystal diamond detector, optimized indigenously through several processes, was mounted on a TO header. Gold wire bonding connected the top metallization of the detector to one of the header pins, while the back metallization was in contact with the ground pin [3]. The detector was securely enclosed within an aluminum housing, which featured a 3 mm aperture at the front and an SMA connector at the rear, enabling electrical connections to both the front and back metallization for signal acquisition. Frontend electronics, capable of both current and voltage mode measurement, was used in this experiment.

Experimental Method

The performance of the detector in response to synchrotron radiation was evaluated at the BL-16 beamline of Indus-II. The detector's position was precisely fixed relative to the beam exit point and aligned using a lithography film to ensure optimal interaction with the synchrotron beam. The alignment was critical in achieving accurate and reliable measurements, as misalignment results in significant errors in flux quantification or energy resolution. The experimental investigation included two distinct operational modes: current mode for flux measurement, which involved integrating the charge generated by the synchrotron beam over time to assess the radiation flux, and pulse mode for energy measurement, where individual photon events were resolved to determine the energy distribution of the synchrotron radiation.

Electronic address:* amitkumar@barc.gov.in

Measurement in Current Mode

In the current mode measurement, the charge generated within the detector was integrated utilizing a current integrator. The beam flux was varied at fixed 15 keV synchrotron energy, by slightly adjusting the crystal monochromator, and the detector's count rate was recorded. Concurrently, a reference count was also obtained from an Ionization Chamber (IC). As depicted in Figure 1, a linear variation in detector count in response to changes in flux was noted with an impressive coefficient of determination (R2=0.995). The detector has shown sensitivity of around 40 counts/photons to 15 keV synchrotrons. Consequently, the diamond detector exhibits substantial potential for monitoring synchrotron flux and exhibits potential for IC replacement.

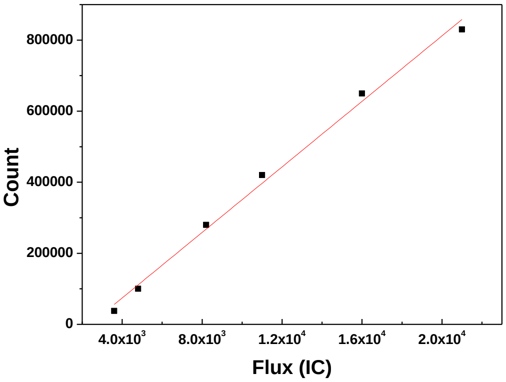

Fig. 1 Measured count Vs flux @15keV energy

During the current mode measurement, the energy of the synchrotron beam was systematically altered by varying its angle of incidence with respect to the silicon crystal monochromator. The counts recorded by the ionization chamber observed to be increased as the synchrotron energy decreased from 20 keV to 4 keV. These results followed the theoretical predictions based on GEANT4 simulations, as illustrated in Figure 2. The synchrotron flux could not be kept constant across the whole range of energy used in this experiment. The slight variation in flux may have resulted in the mismatch b/w simulated and experimental data.

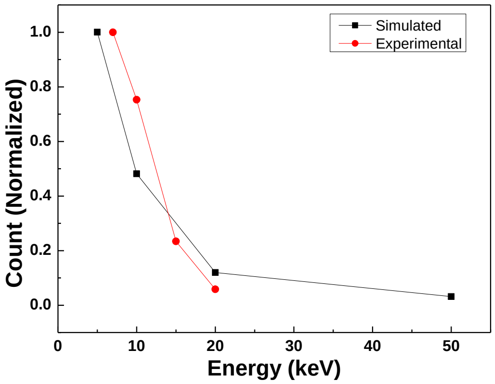

Fig. 2 Variation in count (Simulation Vs Experiment) with Synchrotron Energy

Measurement in Pulse Mode

In pulse mode operation, the detector signal was integrated using a low-noise charge-sensitive pre-amplifier, and its waveform was shaped using a CR-RC differentiator-integrator network. The resulting shaped signal was then observed on a Digital Storage Oscilloscope (DSO). Visual analysis of the signal on the DSO revealed a signal amplitude of 60 mV at a synchrotron energy of 15 keV, with noise levels below 20 mV.

Conclusion

The single crystal diamond detector has demonstrated its potential for measuring synchrotron radiation, exhibiting a linear response to variations in synchrotron flux. The reference detector, ionization chamber, showed a decreasing count with increase in synchrotron energy, aligning with GEANT4 simulation results. Future work will focus on exploring the diamond detector's potential in various synchrotron measurement experiments.

References

[1] R. Vaitkus, T. Inushima and S. Yamazaki, App. Phys. Letr., 62, 2384 (1993)

[2] Li. Zhenjie et al., NIMA. **924**, 305-308 (2019).

[3] A. Kumar and A. Topkar, IEEE trans., 65, 630-635 (2018)