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Study of X-ray emission from plasma focus device using vacuum photodiode

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ABSTRACT

A newly fabricated vacuum photodiode (VPD) is used to measure time resolved X-ray emission and electron temperature from plasma focus device operated in hydrogen medium. The VPD signals are compared with the PIN diode signal and observed to be of similar in nature. The acquired signals from VPD are deduced to measure electron temperature and X-ray radiated power for four different anode tips (cylindrical, diverging, oval and converging). The electron temperatures are found to be 0.64, 1.5, 0.60 and 0.55 keV for cylindrical, diverging, oval and converging anode tips respectively in hydrogen plasma. The X-ray radiated powers are observed to be varying with respect to the shape of the anode tips and it is found highest in case of converging tip and lowest for the diverging one. Results indicate that VPD could efficiently be employed as an X-ray diagnostics in plasma focus device.

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1. Introduction

The plasma focus (PF) device is an intense source of pulsed X-rays [1] in addition to its ability of emitting the charged particles [2] and neutrons [3]. As a source of pulsed X-ray, it has been demonstrated as a potential candidate for various applications such as X-ray lithography [4], X-ray flash radiography [5], X-ray backlighting [6] etc. These applications of PF device have prompted the researchers to work for development of the PF device as an intense X-ray source and simultaneously the research works on the emission properties of X-rays from PF under different experimental condition have also been continued. Furthermore, the PF has been used as a source of radiation to develop and test different material properties [7] and X-ray diagnostics tool [8] for fusion reactor like ITER.

The important aspect of vacuum photodiode (VPD), for which it is considered as one of the X-ray diagnostics tool for fusion reactor [9], is its robustness and ability to withstand in the extreme and harsh environment of fusion reactor. The sensitivity of its counterpart semiconductor detector decreases due to the damages occurring from the interaction of energetic charged particles and neutrons bombardment [10,11]. In addition to this, the VPD has an edge over the semiconductor detector like PIN diode for its simplicity and low cost. Moreover, natural sensitivity of VPD falls in a wide wavelength region, which is not accessible by other detectors [12].

Despite of having the advantages as stated above, it can be mentioned that the VPD is a less explored diagnostics to characterize the X-ray emission from PF device except few reports on time resolved X-ray measurement [13,14]. Commonly, the semiconductor detectors are used in PF device to characterize the X-ray emission [15]. This is because of the fact that the VPD's efficiency is better towards higher vacuum device ($\leq 10^{-5}$ mbar) as compared to PF device (≥ 0.1 mbar) [16]. It is noteworthy that in a relatively high-pressure plasma device like PF, the photoelectron absorption in the background gas medium is higher, resulting low output signal accompanied by dominant noises for a conventional cylindrical VPD. However, we have been able to optimize the design criteria of a conventional cylindrical VPD to develop it as a suitable detector to acquire X-ray signal from PF [8]. Even then, it will be worthful if this detector can be shown to measure X-rays from PF device and the significance of our approach is given below.

The studies on VPD have been carried out by many researchers for a long time all over the world and most of the research activities are related either to its design, development, working principle or acquisition of the temporal evolution of UV and ultra soft X-rays [12,17,18]. Though a very little work has been carried out with this detector as a diagnostic to measure some parameters related to the electromagnetic emission from the plasma, it is important to test the performance of this detector further as a diagnostics tool. Gott et al. [19] used VPD for soft X-ray ITER plasma tomography. Chandler et al. [17] used filtered X-ray diode detector to measure time dependent X-ray flux from highly energetic Z accelerator with a measured peak power of 200 TW. All the works were carried out in a low-pressure plasma reactor ($< 10^{-5}$ mb). As mentioned above, Bailey et al. [13] have reported

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to obtain the total yield of X-ray emission from PF device. However, the measurement of electron temperature from PF device, using VPD is tricky and has not been carried out by any researchers and the reason for this is the poor efficiency of detector in higher-pressure plasma device like PF. However, with our newly designed detector, we have been able to measure electron temperature from PF device and have successfully extended our diagnostics to measure X-ray power from PF device for the first time. In this experiment, we have made an effort to observe the variation of emission parameters with respect to different anode tips. The whole work has the importance in the context of VPD's candidature for future X-ray diagnostics in fusion reactors and the obtained data have the additional importance for showing the variation of emission properties of X-rays of PF device with respect to the anode shapes.

2. Experimental set-up

The experiment is carried out in a 2.2 kJ Mather type plasma focus device energized by a high voltage energy storage capacitor (7.1 μF, 40 kV, 40 nH). The schematic of the experimental system is shown in Fig. 1. The device embraced with an evacuated chamber and a coaxial electrode assembly. The central electrode is called anode surrounded by twelve squirrel-cage type electrode called cathode. The detailed electrical and mechanical parameter can be found elsewhere in [20]. In the present experiment, we have operated the PF device with four different shaped anodes namely

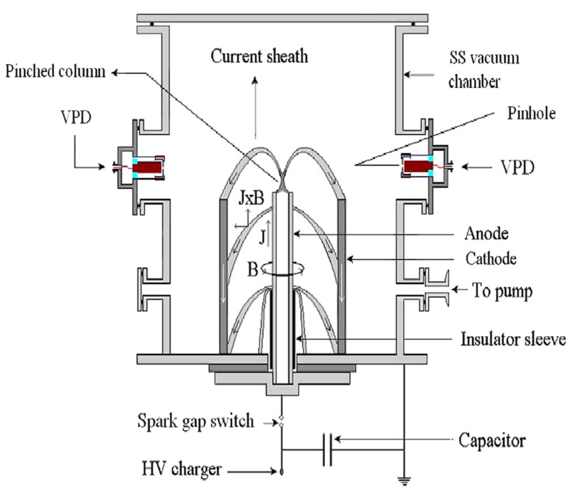

Fig. 1. Sketch of the PF Device with VPD.

diverging tip, oval tip and converging tip in addition to the conventional cylindrical tip anode as shown in Fig. 2. A couple of fast response (~0.3 ns) identical VPDs are fitted across the side port of PF device to measure the time resolved X-ray emission. The VPDs used in the experiment are simply homemade. A schematic of VPD is shown in Fig. 3. It is basically a coaxial two electrode system, consists of an Aluminum photo-cathode of diameter 10 mm and length 27 mm, which is surrounded by a SS cylindrical anode of inner diameter 13 mm and length 28 mm. The photo-cathode and anode are separated from each other by a Teflon insulator. An aluminum circular disc having a pinhole of diameter 1.5 mm at the center is fitted in front of the photo-cathode as photoelectron collector. To filter out the unwanted radiations and particles before reaching the photo-cathode, a beryllium (Be) foil is used in front of the pinhole. The whole electrode assembly along with the aluminum disc is fitted to a SS flange of suitable size so that it can be coupled to one of the ports of the PF chamber. A negative biasing voltage (100 V) is applied to the photo-cathode from a regulated DC power supply (556 High Voltage Power supply, Ortec) during experimentation, while the anode was kept grounded. The details about its construction and working condition has already been described somewhere else [8].

We have drawn information on the electron temperature, X-ray radiated power etc. from the VPD's signal for different experimental condition by operating the PF device with the above mentioned four different anode shapes. The results obtained by the VPD are supported by pinhole images of the pinched column for different anode shapes. To crosscheck the reliability of the X-ray signal acquired by VPD, a PIN photodiode and a pinhole camera was also used in another side port (not shown in figure). We used Be foil of thickness of 5 μm and 10 μm as filtration foil to study the X-ray emission from PF device. The transient discharge current across PF is monitored by a Rogowski coil, which measures the time derivative (dI/dt) of current flowing near the coil. A fast response, 1.5 GHz, 4 channels digital oscilloscope of Yokogawa (DL9240) is used to monitor the signal of the detectors.

3. Results and discussion

The results obtained for the study of X-ray emission characteristics, by employing the VPD assembly for four anode designs of PF, are found to be different for each anode design. The difference in X-ray emission properties with respect to the anode shapes is obvious as the optimized operating pressure is different for each anode shape. The optimized operating pressures of the PF device for good focusing are found to be around 0.6–0.7, 0.1–0.2, 0.7–0.8 and 1.0–1.2 Torr of hydrogen gas for cylindrical, diverging, oval and

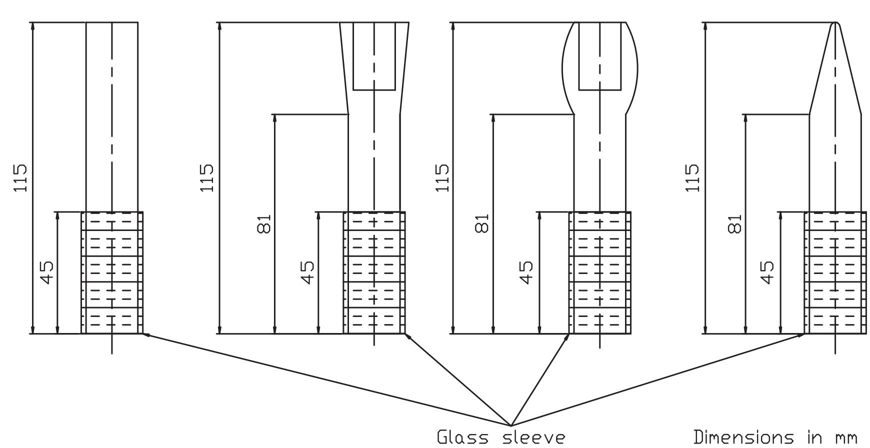

Fig. 2. Schematic of four anode designs.

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