ABSTRACT

In the recent years, the radiations, namely X-rays and ions, from high temperature and high density plasma have become extremely important because of their applications in diverse areas. In micro- and nano-electronics industries, the current predominant trend of shrinkage of integrated circuits demands powerful, clean and bright pulsed X-ray sources. These sources are in hunt for not only electronics industries but also for other disciplines like micro-radiography, microscopy, crystallography etc.. Likewise, the quest for plasma based ion sources has been growing phenomenally during last decades for the synthesis of novel materials. These novel materials have plenty of applications in automotive, aerospace, biomedical and electronics industries. The need of present hour is to develop compact, cost-effective and efficient plasma based radiation sources so as to fulfill industrial requirements.

The work presented in this thesis mainly focuses on how to operate the Dense Plasma Focus facility of Centre of Plasma Physics (CPP DPF) in an enhanced X-ray and ion emission mode. Four research problems are addressed in this thesis: (i) study of current sheet dynamics; (ii) investigation of X-ray emission; (iii) analysis of ion emission; and (iv) utilization of ions for material modification. Salient features of the different chapters of this thesis are described hereafter.

Chapter 1, in addition to a brief introduction to the importance of plasma physics, provides information on X-ray and ion sources and their current scenario of industrial applications. Besides, this chapter provides a short introduction to DPF device along with current sheet dynamics and other related plasma phenomena.

Chapter 2 presents the design and fabrication details of CPP DPF facility
(pulsed power driver, plasma focus tube with pumping system) along with the basic diagnostic techniques (Rogowski coil and resistive voltage divider). In addition, the discharge performance of DPF facility, which is evaluated using Rogowski coil and resistive voltage divider, is presented in this chapter.

Chapter 3 contains the study of current sheet dynamics in axial acceleration phase. In order to accomplish the study, we have fabricated a high frequency multiple magnetic probe assembly having response time of ~ 1 ns. The tiny structure of magnetic probe is well suited to sense the magnetic field associated with pulsed plasma, without perturbing the plasma severely. The magnetic probe is calibrated using a simple, novel and reliable calibration technique and the calibration factor is found to be ~ 0.34 Tesla/Volt. Our study reveals that the parabolic current sheet accelerates as it propagates through the electrode assembly reaching a rundown velocity ~ 6.1 cm/μs. The average current sheet thickness in acceleration phase is found to be ~ 3 cm. The current shedding and mass loss factors are estimated to be 32% and 40%, respectively. Our approach of deployment of high frequency multiple magnetic probe assembly for studying the current sheet dynamic is a highly effective tool for precise and accurate measurements.

Chapter 4 describes the investigation of X-ray emission in different experimental conditions. A five-channel Diode X-ray Spectrometer (DXS) and a novel X-ray pinhole camera have successfully employed to study the X-ray emission. The X-ray emission in three different anode designs (hollow, solid, and hemispherical) is compared using nitrogen and hydrogen as working gas medium. The X-ray emission is found to be strongly dependent on the anode design as well as filling gas pressure. The X-ray yield is found maximum in case of hemispherical anode and the maximum X-ray
energy of 2.2 J into 4\pi sr is obtained in hydrogen pinched plasma. The X-ray pinhole images of pinched plasma in hemispherical anode indicate a point like structure having \( \sim 500 \text{ - } 800 \mu \text{m} \) in diameter. On the contrary, other anode designs show columnar pinched structure, \( \sim 8\text{-}10 \text{ mm} \) in length with a nearly circular cross section of about 1-2 mm in diameter. Some X-ray pinhole images show hot spots and some indicate occurrence of \( m = 0 \) instabilities. The electron temperature and density of hydrogen pinched plasma is estimated to be \( \sim 1 \text{ keV} \) and \( \sim 10^{24} \text{ m}^{-3} \), respectively. Our results indicate that an appropriate design of anode enhances the X-ray yield by more than ten fold in conventional low energy DPF facility. Besides, our DPF facility is portrayed as a non-conventional X-ray radiography machine.

Chapter 5 discusses the analysis of ion emission in different anode designs. A nanosecond response Faraday cup is fabricated and employed to detect axially emitted ions. The Faraday cup operating in bias ion collector mode was used to determine the energy spectrum and flux of fast nitrogen ion beams along the electrode axis (0°) of the device. The correlation of ion beam intensity with filling gas pressure is investigated and it is observed that ion beam intensity is a maximum at a pressure of \( \sim 0.3 \text{ torr} \). We have succeeded to register the ion energy up to a lower kinetic energy threshold of \( \sim 7 \text{ keV} \), which is a value much lower than that obtained in any previous works. A multiple FC assembly is also deployed to investigate the anisotropy of ion emission at different angular positions (0°, 5°, -10°) with respect to the electrode axis. Angular distributions of fast ion demonstrate a highly anisotropic character. A distinct ion emission dip is observed at 0° whereas maximum ion emission is observed at an angle of 5°. The correlation of the ion beam intensity with filling gas pressure and the energy spectrum of ions in different anode designs are presented. The energy
spectrum of ions recorded in different anode designs at an angle of 5° shows that the maximum ion energy is ~2.2 MeV and the most probable ion energy is ~20 keV. Our first ever investigation on ion emission using hemispherical anode is of importance for developing an ion source of high fluence.

Chapter 6 portrays the DPF as an excellent ion source for material modification. Nitrogen ion beams emitted from DPF are utilized for the first time to irradiate American diamond (high purity Zirconia) specimens. Specimens of various colors are exposed to nitrogen ion beams of single/multiple shots of DPF at optimum operating condition. The colors of exposed specimens are found to change after ion irradiation. The exposed and unexposed specimens are characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and microhardness test. Cubic phase of unexposed Zirconia transforms into hexagonal phase due to the ion irradiation. The surface morphology of ion exposed Zirconia specimen indicates the removal of materials from the surface layer of specimen.

The works presented in this thesis have demonstrated the feasibility of DPF as a rich source of X-radiations and energetic ions for different new generation industrial applications.