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Two hump-shaped angular distributions of neutrons and soft X-rays in a small plasma focus device

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HIGHLIGHTS

- The angular distributions of neutrons and soft X-rays from a 3.5-kJ PFD were investigated.
- The distributions of neutrons and X-rays represented two humps with a dip at the central axis of the device.
- The maximum neutron yield of $2.98 \pm 0.2 \times 10^8$ neutrons per pulse was registered at 13.5 kV and 6.5 mbar.

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Plasma focus device (PFD)
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ABSTRACT

Angular distributions of soft X-rays (SXRs) and neutrons emitted by a small plasma focus device (PFD) were investigated simultaneously using TLD-100 dosimeters and Geiger-Muller activation counters, respectively. The distributions represented two humps with a small dip at the angular position 0° and reduced from the angles of ± 15° and ± 30° for the neutrons and SXRs, respectively. The maximum yield of 2.98×10^8 neutrons per shot of the device was obtained at 13.5 kV and 6.5 mbar. A time of flight (TOF) of 75.2 ns between the hard X-ray and the neutron peaks corresponds to neutrons with energy of 2.67 MeV. A similar behavior was observed between the angular distributions of neutron and soft X-ray emissions.

1. Introduction

The plasma focus device (PFD) uses a self-generated magnetic field produced by a high current flow in an ionized gas column to compress the plasma to high temperatures (~ 1–3 keV) and high densities (~ 2–3 $\times 10^{19}$ cm^{-3}) with a life time of ~ 200–300 ns to produce high neutron fluxes, X-rays, and bursts of ions and electrons (Mather, 1965; Filippov et al., 1962). A small-sized PFD typically comprises a pair of coaxial electrodes with an insulator sleeve between them, a high-voltage low-inductance power supply, and a spark gap switch for producing kilo-ampere per microsecond electric discharges. The PFD is usually operated with the inner electrode as anode and the outer electrode as cathode. At each high-voltage pulse, the plasma current sheath between the electrodes generates an azimuthal magnetic field, which produces a Lorentz force that pushes the current sheath toward the end of the electrodes. Once the sheath is driven to collapse toward the symmetry axis, the plasma surface is pushed inward, and the Lorentz force compresses the plasma to a focused column, which is bright and highly unstable. At peak compression, the magnetically confined plasma column breaks because of the development of instabilities, and a large induced axial electric field accelerates the electrons toward the inner electrode and ions in the opposite direction (Lee and Serban, 1996). In addition, when deuterium is used as working gas, neutrons from fusion reactions are also emitted. X-rays emitted from PFDs are mainly of two types: continuous and series of lines that are characteristics of the gas and the anode tip material, respectively (Lee and Serban, 1996). The experiments showed that SXRs are emitted from the pinch column, and the composition of the gas and filling pressure has the strongest effect on the amount of SXR yield in a discharge (Wong et al., 2004). In the dense plasma column region at $T_e = 1$ keV, X-ray continuum is expected to peak at $\lambda = 6.2$ Å, which is in the SXR region. In addition, as much as 4% and 10% of the capacitor energy are found to be converted into 1–1.5-keV X-rays for low- and high-energy PFDs, respectively (Zakaullah et al., 2002). The radiations of PFDs are generally anisotropic, and the investigation of anisotropy may provide useful information about the radiation generation mechanism. Lee et al. proposed a scaling relation for the SXR yield (Y_{SXR}) with capacitor energy (E) and pinch current (I_{pinch}) as follows: $Y_{SXR} \sim E^{1.6}$ for small PFDs and $Y_{SXR} \sim I_{pinch}^{3.6}$ (0.07–1.3 MA) (Lee et al., 2009a). The angular distribution of SXRs and neutrons from a 5-kJ PFD was reported by Castillo et al. (2007) using TLD-200 dosimeters and CR-39 nuclear track detectors, respectively. They found that while the highest neutron yield

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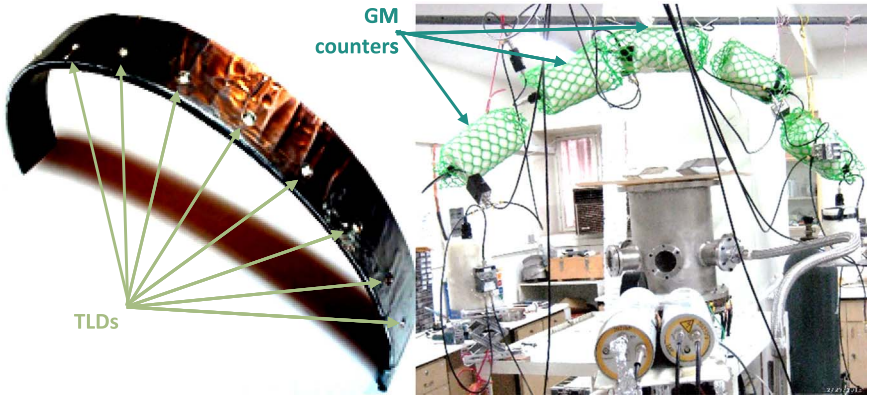

Fig. 1. Left) An array of 11 TLDs installed to the PFD chamber, Right) An array of seven GM counters and the plastic scintillation detector used in this experiment.

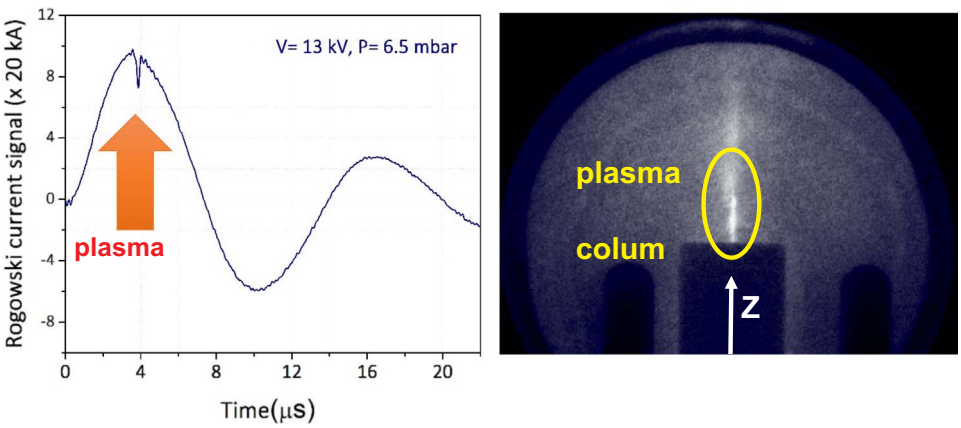

Fig. 2. Left) A typical current signal with D_2 (V = 13.5 kV, P = 6.5 mbar), Right) Visible light corresponding to this signal.

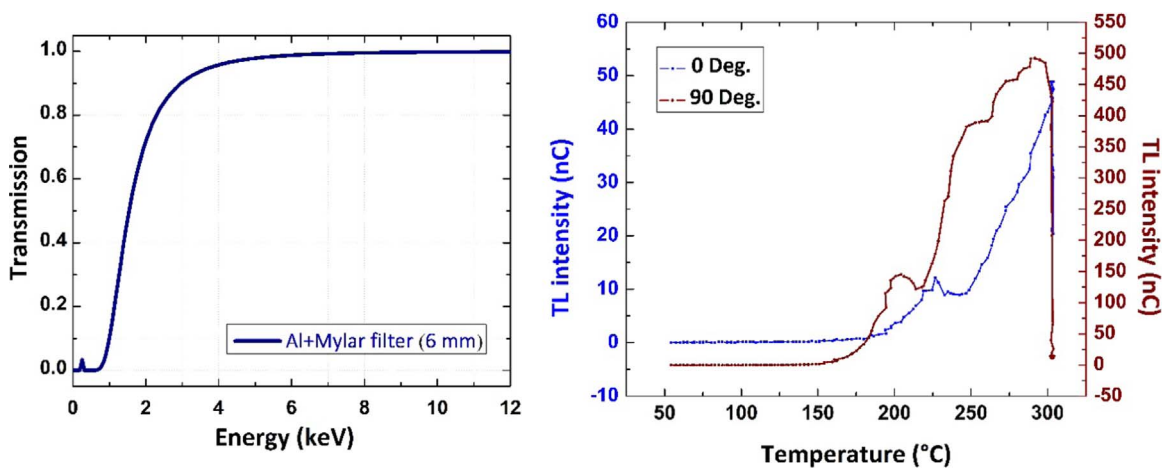

Fig. 3. Left) 6 μm Al–Mylar foil transmission curve, Right) Glow curves of TLD-100 chips after X-ray irradiation (6.5 mbar and 13.5 kV).

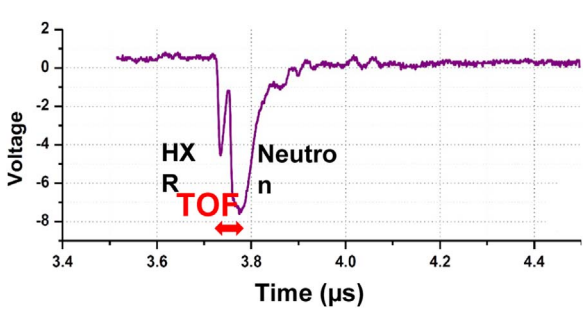

Fig. 4. A typical oscilloscope signal of HXRs and neutrons 1.7 m away from the z-axis of the device (6.5 mbar and 13.5 kV).

was obtained on the central axis of the device, the distribution of X-rays was bimodal around the axis and peaked approximately at ± 20°.

By using the Lee code for PFD, Saw and Lee determined the scaling of neutron yields with energies and currents (Saw and Lee, 2010). In their study, the neutron yield Y_n was derived as follows: $Y_n \sim E_0^x$; x = 2 at tens of kJ and also $Y_n \sim I_{pinch}^{4.5}$; I_{pinch} (0·2 − 2·4)MA , where E_0 and I_{pinch} are the capacitor bank energy of PFD and pinch current, respectively. In another study by Saw and Lee, the scaling laws for SXR yield were proposed as follows: $Y_{sxr} \sim I_{pinch}^{3.6}$ and $Y_{sxr} \sim E_0^{1.6}$ (kJ range) Lee et al. (2009b). Jalufka and Lee observed a large anisotropy in SXRs produced from a small PFD (Jalufka and Lee, 1972). They found that the angular distribution of SXRs was very similar to the electric quadrupole radiation pattern. Etaati et al. (2010) showed that the intensity of SXRs is bimodal, and Stormberg et al. (1987) showed a parabolic