Intense x-ray emission from moderate-current low-energy laser-triggered vacuum discharge

Low inductance vacuum spark discharge initiated by laser pulses or electrical trigger is an attractive x-ray source of energy ranging from a few keV to few hundred keV. Hard x-ray emission from these devices (which typically involve discharging a capacitor of 20-30 μF, charged to 10-20 kV with stored energy of $\geq$ 1 kJ, and peak discharge current of $\geq$ 100 kA) comes due to micro-pinching of the plasma in the discharge gap to a high temperature of 1-10 keV and at high density ~ $10^{22} - 10^{23}$ cm^{-3}. It will be interesting if such a hard x-ray source operates as a low energy compact device. Recent experiments performed at Laser Plasma Laboratory, RRCAT in collaboration with P.N.Lebedev Physical Institute, Moscow, have shown intense multi-keV x-ray generation in a low-energy ($\leq$ 20 J, electrical) moderate-current (~ 10 kA) vacuum discharge initiated by short duration (multi-picosecond) laser pulses.

A schematic of the experimental set-up is shown in Fig.1. The vacuum diode consists of a planar titanium plate as a cathode and a conical point-tip titanium anode, kept at a separation of ~ 3 mm. The anode was biased to a voltage up to +20 kV using a dc power supply and a low inductance 100 nF capacitor. The inductance of the discharge circuit was ~ 0.15 μH. The whole set-up was kept inside a chamber evacuated to a pressure of ~ 5 x 10^{-5} torr. The discharge was triggered by producing a plasma on the cathode using laser pulses of ~ 5 mJ energy, 27 ps full-width at half-maximum duration from an Nd:glass laser (wavelength: 1.054 μm). The laser beam was incident on the cathode at an angle of 45^0 to the cathode normal.

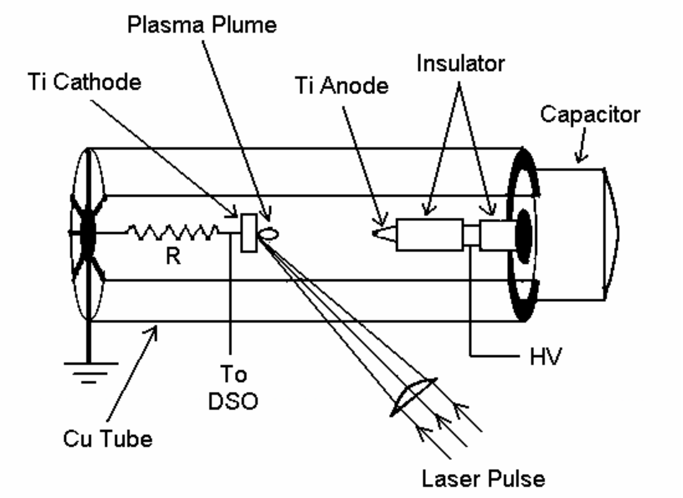

Fig.1 Schematic of the experimental set-up.

Intense K-shell (K_α: $h\nu \approx 4.51$ keV) x-ray emission was observed from the titanium anode tip due to its bombardment by the accelerated electrons extracted from the expanding cathode plasma. This x-ray emission occurs in the form of two or three pulses, each of 20-30 ns duration, occurring up to ~ 100 ns from the time of triggering. The number of K_α photons is estimated to be $\approx 6 \times 10^{10}$ photons per shot, comparable to that for the nanosecond pulse laser-driven vacuum diode x-ray source [Ref.1]. An evidence of a much harder x-ray component ($h\nu > 100$ keV) was also seen from the flooding of microchannel plate detector filtered through 10 mm thick copper disc. Hence the discharge gap was imaged at a lower anode voltage of ~ 5 kV using an x-ray pin-hole camera filtered with a formvar filter of 0.3 μm thickness (photon energy for 1/e transmission ~ 100 eV). The image of the discharge gap (Fig.2) clearly shows pinching of the plasma near the cathode. This pinching effect occurring in the cathode plasma jet expanding with a free boundary is different from the high-current discharges in which the pinching occurs in the plasma column bound by the electrode surfaces. Detailed measurements of hard x-ray emission are being carried out.

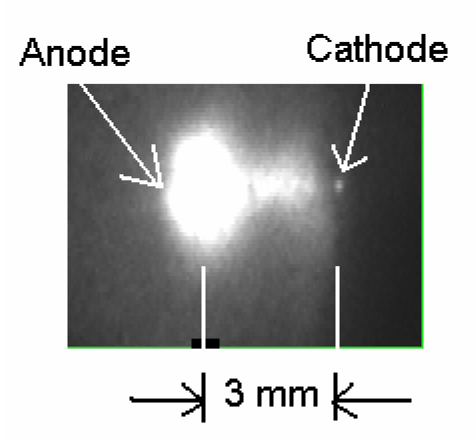

Fig.2 Pin-hole image of the discharge gap.

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