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Spatial and Energetic Characterization of X-Ray Emission from Inverse Capillary Discharges

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SUBJECT: Contract F61708-96-W0193 (Special Project SPC-96-4040)
DATE: 25 June, 1997

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Dear Dr. Corley,

Please find enclosed my final report on "Spatial and energetic characterization of x-ray emission from inverse capillary discharges", contract F61708-96-W0193.

Yours most sincere

Mihai Ganciu-Petcu

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Phase 1 Basic Research on Induced Gamma Emission (IGE)

Contract F61708-96-W0193

Final report

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Title of Research: **SPATIAL AND ENERGETIC CHARACTERIZATION OF X-RAY EMISSION FROM INVERSE CAPILLARY DISCHARGES**

Depletion of certain K-quantum number nuclear isomers such as [178]Hf may be achieved by up-conversion with relatively "soft" photons, having an energy of the order of tens to hundreds keV [1]. In this case the use of less expensive, tunable, lightweight X-ray machines becomes possible.

Recently, a X-ray generator providing an optimum coupling of the radiation to the active medium has been proposed. The X-rays are produced by bremsstrahlung of an intense pulsed electron beam [2, 3] cruising along the surface of a dielectric fiber (Cruise Effect) [4].

The main source of hard X rays in wall assisted discharge is the bremsstrahlung following the fast electron interaction with the walls. When the diameter of the discharge tube shrinks, one speaks about capillary discharges. While for capillaries the discharge is assisted by the capillary dielectric walls, in the case of the "Cruise Effect" (CE) the discharge is mainly assisted by an axial dielectric fiber. Consequently, we may call this system an "inverse capillary discharge"[5].

One important advantage of inverse capillary discharges is the possibility to use also the ablation plasma from the fiber surface for a better cruising of the beam. In contrast, in the case of capillary discharges, the ablation from the internal surface of the capillary determines the detachment of the electron beam from the wall and the collapsing of the channel plasma on the axis [6].

The CE can be described qualitatively by extending the ion trap model [7] of the pulsed electron beam produced in pseudospark-like discharges [8,9]. Thus, when the dielectric fiber is absent, the exceptional radial stability along many centimeters of the electron beam described in [2,3,7] is the result of counterbalancing of the Lorentz and electrostatic forces. Under steady state conditions this implies the well-known equilibrium condition:

$$n_i(x,t) = n_e(x,t)[1 - v_e^2(x,t)/c^2]$$

Here n_e and v_e stand for the electron density and velocity, respectively, at the distance x along the beam axis and at the moment t of the discharge. This equation has been deduced by assuming a homogeneous current tube and n_i denotes an effective ion density accounting for the existence of multiply charged ions [7].

Since our beam currents are below the Alfvén limit, for the slow electrons the magnetic force is small and these electrons are expelled from the axial region. Consequently, the electron

beam becomes surrounded by a thin layer of positive charge which ensures the vanishing of the electric field at the limit of the neutral plasma. The fast electrons which lose energy by collisions are still kept along the beam by the radial potential pockets due to this double layer and eventually regain energy from the axial electric field, while the secondary electrons are rapidly removed. On the other hand, the potential seen by the ions looks rather like a simple potential well, whose characteristics were inferred in [7] under the assumption of a uniform initial radial ion density and a constant electron density. For typical conditions of our experiment, in spite of the high electron space charge in which the ions are embedded during the discharge, the recombination is prohibited due to the velocity mismatch between the electrons and the ions.

The presence of the dielectric fiber can be modeled by a layer of positive charge along its surface [5]. The electric field in the proximity of the fiber is attracting the electrons in the beam. As a result, the beam is captured by the fiber and is "dressing" it. The ions in the beam, although repelled by the fiber, have enough kinetic energy in the potential well to be able to deposit on the fiber, in a dynamic equilibrium with the electrons which tend to neutralize it.

Together with the dependence on the pressure, voltage and geometrical configuration of the discharge, the X-ray emission by CE is currently investigated as a function of the dielectric material, and of its geometry and size. A few preliminary results will be presented in this report.

The experimental set-up is like the one presented in the interim report, based on a pseudospark-like system without inner bore holes with proper preionisation [10]. It uses the basic principle of the superposition of two discharges; the main one being established by applying high-voltage pulses between an open hollow cathode and an anode, and the auxiliary one creating a preliminary plasma in the cathodic region. The possibility of operating at repetition rates up to   700 Hz has been shown [11]. Typical parameters of the electron beam produced in our discharge configuration [12] are summarized in the table below:

Mean electron energy (0.6-0.76 of maximum applied voltage)	17.5 keV
FWHM of energy spectrum (0.4 of ME)	7 keV
Temporal width of the fast electron beam	10 ns
Temporal width of the beam	14 ns
Minimum beam diameter (from anodic target damage)	50 μm
Maximum beam current (~0.1 of maximum discharge current)	65 A

The lack of inner diaphragms allowed the beam to be deflected using a magnetic field provided by external coils, while keeping the focusing properties on the anode target. This was proved by the X-ray emission from the scanning point-like source thus obtained which have been monitored by autoradiography [13]. We suppose that electrons are deflected inside the cathode at low velocities during the generation of the beam, and then are accelerated at the potential applied to the cathode-anode gap. In this way it is possible to control the coupling of the beam with different targets inside the discharge tube.

The X-rays were recorded by a collimated NE102A plastic scintillator, mounted outside the discharge tube, coupled via an optical fiber to a fast photomultiplier and an Tektronix TDS350 oscilloscope. Previous observations [5] have been confirmed, namely: the X-ray emission is associated with the electron beam "dressing" the dielectric fiber and the appearance of "hot points" on its surface, and the amplitude and the duration of the X-ray pulse does not depend on the discharge repetition rate in the investigated range (up to 100 Hz).

Several types of ferrite, as well as silicon oil and lithium niobate have been studied. It has been found that the degree of "cruising" of the electron beam depends on the ferrite composition. Besides the common cylindrical geometry using thin dielectric fibers, a quasi-planar geometry has been achieved using a low conductivity ferrite cylinder of 4 mm diameter

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parallel to the discharge tube axis. Under proper preionization conditions, a 2 cm long fillamentary discharge stabilized along the cylinder surface, associated with X-ray emission. Since no damage of the ferrite surface has been observed, apparently CE provides a mechanism of X-ray generation different of that proposed in [14], a mechanism in which the preionization of the gas adjacent to the dielectric surface plays a critical role for the "cruising" effect. Indeed, we observed the CE on dielectrics of various shapes and sizes, including submillimetric ferrite particles, and also with various geometries of the discharge; in all cases the preionization of the discharge gas was a necessary condition.

The amplitude of the X-ray pulse emitted by CE along 2 cm of ferrite has been found only about 10% less than that of the X-rays emitted by the discharge electron beam totally stopped in a stainless steel anode at $45°$ relative to the beam axis. This comparison proves that X-rays are also effectively generated by fast electrons in glancing interactions along the dielectric surface, however with smaller absorption losses.

We anticipate that for a dielectric fiber as target, provided a proper plasma (laser or discharge plasma) is generated on the cruising surface the CE would work also for relativistic electrons. In this case the X-ray emission by bremstralung is main concentrated along the dielectric fiber inside a cone with an opening angle of $2/\gamma$ (where γ is the relativistic factor for the fast electrons in the beam).

Under certain conditions, a dielectric fiber containing nuclear isomers such $^{178}Hf^{m2}$ may become active medium for gamma ray emission. An X ray generator based on the scheme proposed in this work may provide an optimum coupling of the radiation to the active medium. More specifically, assuming that the nuclear isomers are concentrated along the center of the fiber and the X rays are generated around the fiber, the radiation power density at the isomers is inversely proportional to the radius of the (cylindrical) emitting surface. This hopefully would pave the way towards fillamentary hard X-ray pumping sources strongly coupled with the irradiated active media, as requested for induced gamma emission. Accordingly, for the future our research will be devoted to investigate the CE on multilayer dielectric targets at higher electron beam densities and energies.

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