Research into Spectra of X-ray Emission from Solid Cathode Medium During and After High Current Glow Discharge Operation

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Abstract

X-ray emissions ranging from 0.6 to 10.0 keV with a dose rate up to 0.1 J/s have been detected in experiments with high-current glow discharge. The experiments were carried out on the high-current glow discharge device using H_2, D_2, He, Kr, Ar and Xe at pressure up to 10 Torr, as well as cathode samples made from Al, Sc, V, Ti, Ni, Nb, Zr, Mo, Pd, Ta, W, Pt, at current up to 500 mA and discharge voltage of 1500 – 4500 V. Two emission modes were revealed under the experiments: 1. Diffusion X-rays was observed as separate X-ray bursts (up to 10^5 bursts a second and up to 10^6 X-ray quanta in a burst); 2. X-rays in the form of laser microbeams (with up to 10^4 beams a second and up to 10^{10} X-ray of quanta in a beam; angular divergence up to 10^{-4}; duration of the separate laser beams $\tau = 3 \cdot 10^{-13}$- $3 \cdot 10^{-14}$ s; and individual beam power 10^7 to 10^8 W). The emission of the X-ray laser beams occurred when discharge occurred and within ~100 ms after turning off the current. The X-ray spectra were recorded on film with the curved mica crystal X-ray spectrometer. The X-ray emission spectrum from the Pd and other cathode material consists of spectral bands with energies ranging from 0.6 keV up to 10.0 keV.

1. Introduction

Experimental results detecting excess heat nuclear reaction products in the high-current glow discharge cathodes prove that there exist certain conditions and mechanisms that lead to the initiation of Low Energy Nuclear Reactions (LENR) in the condensed medium of the solid cathode. The formation of excited levels with energies ranging from 1.0 to 3.0 keV and lifetimes up to several milliseconds is assumed to be a necessary condition for LENR to proceed in the cathode solid medium (with the density up to 10^{27} atom/m^3). This may be achieved by devising a mechanism for conversion of 0.5 – 3.0 keV plasma ions flux initial energy into 0.5 to 10.0 keV high-energetic excitation of a solid nuclear electron system. Presumably such a conversion takes place in the cathode solid exposed to bombardment by the discharge plasma ions. This process is evidenced by intensive X-ray emission during glow discharge and after glow discharge current switch off. The energetic and temporal characteristics of the X-rays are determined by the energy and lifetime of the excited energetic levels in the cathode solid medium.

2. Experimental device

The measurements were carried out using a glow discharge device consisting of a water-cooled vacuum chamber and the cathode and the anode assemblies (Fig. 1). The cathode design allowed the placement of cathode samples made of various materials on a water-cooled surface. The experiments were carried out using a high-current glow discharge in D_2, H_2, He, Kr and Xe and the cathode samples are made of Al, Sc, Ti, Ni, Nb, Zr, Mo, Pd, Ta, W.

The X-ray emission detection was carried out by X-ray pinhole, thermo-luminescent detectors, and a scintillation detector with a photomultiplier. The energy spectrum of the X-ray emission was recorded with a curved mica crystal spectrometer. The cathode samples made of Pd and other metals were placed on a cathode-holder above which there is a window for the penetrating radiation output from the cell. The window was shielded by 15 μm-thick Be foil to protect the detectors from visual and ultraviolet radiation. Various detectors were installed by the window to measure the output penetrating radiation (Fig. 1).

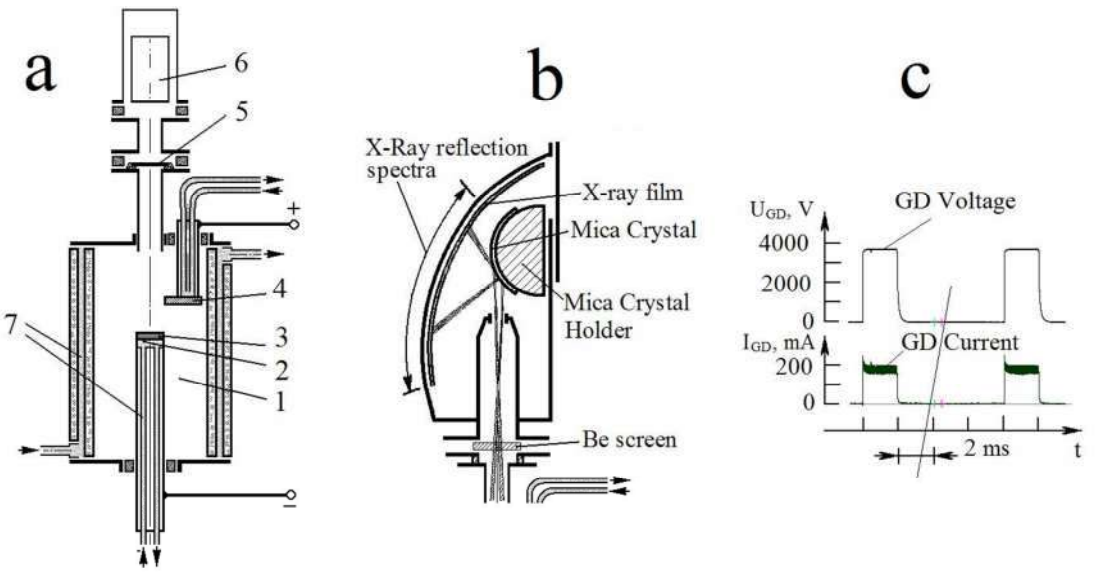

Figure 1. Schematic representation of the experiment. a. Glow discharge device, 1 – discharge chamber, 2 – cathode holder, 3 – cathode sample, 4 – anode, 5 – Be foil screens, 6 – X-ray detectors different kind (pinhole, TLD detectors, scintillator- photomultiplier, spectrometer), objective, 7 –cooling water; b. X-ray spectrometer, c. Glow discharge voltage and current oscillograms.

The glow discharge device power supply is designed to feed the glow discharge with a pulse-periodic direct current and permits the generation of the desired current forms of various pulse lengths and pulse periods, and to obtain the required current voltage. The power supply produced direct pulse-periodic current with a rectangular pulse shape (Fig. 1c). In different experiments the pulses duration varied from 0.1 ms up to 2.0 ms, and the period was from 0.3 ms up to 100 ms. The glow discharge conditions were following: current (amplitude) was from 30 mA up to 300 mA, voltage 1500 – 4300 V.

3. Experimental method and results

3.1. Pinhole method and results

The high intensity of the X-rays made it possible to obtain an optical image of the X-ray emission area with an X-ray pinhole. The X-ray measurements were confirmed by experiments with a transverse 0.3 T magnetic field induced upon the emission X-ray flux.

3.2. TLD detector method and results

To estimate the intensity and evaluate the mean energy of the soft X-ray emission in the glow discharge, thermo-luminescent detectors (TLD) based on crystalline Al_2O_3 and covered by Be foils of varying thickness were used. TLD measurements revealed that X-ray radiant intensity from the cathode increase exponentially with the increase in the glow discharge voltage (Fig. 2).

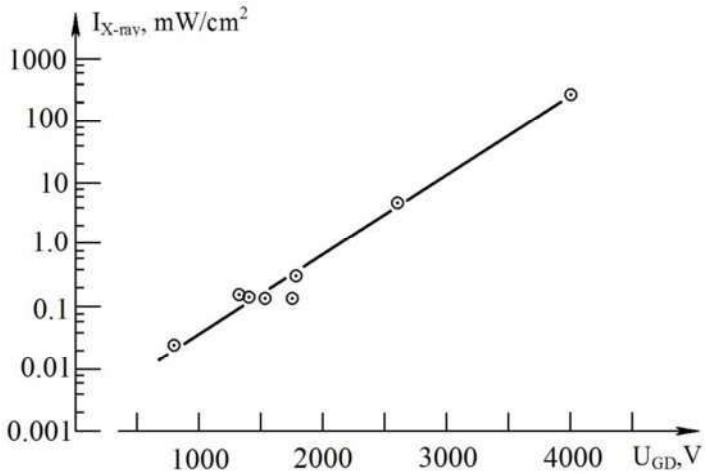

Figure 2. X-ray radiant intensity in relation to the glow discharge voltage.

3.3. Scintillation photomultiplier method and results

The temporal characteristics of the penetrating radiation were determined with scintillation detectors with photomultipliers (PM). Two modes of radiation emission were observed in the experiments: 1. Diffusion X-ray emission (Fig. 3a) and 2. X-ray emission in the form of laser beams (Fig. 3b). The diffusion X-ray emission occurs mainly during the current running in the form of flashes and conforming to the law $1/r^2$.

The generation of X-ray emission in the form of laser beams begins when glow discharge parameters increase (including current impulse duration time, current density and discharge voltage). The laser beams are observed as powerful flashes (Fig. 3b). The X-ray laser beams consist of the separate beams of a small size (up to 10^9-10^{10} photons, assuming that the system scintillator-PEM is operating in the linear field). The emission of X-ray laser beams occurs during discharge and up to 100 ms and more after turning off the current. Under certain discharge parameters the generation of X-ray laser beams lasts only milliseconds after turning off the discharge current (up to 20-30 beams after each current pulse).

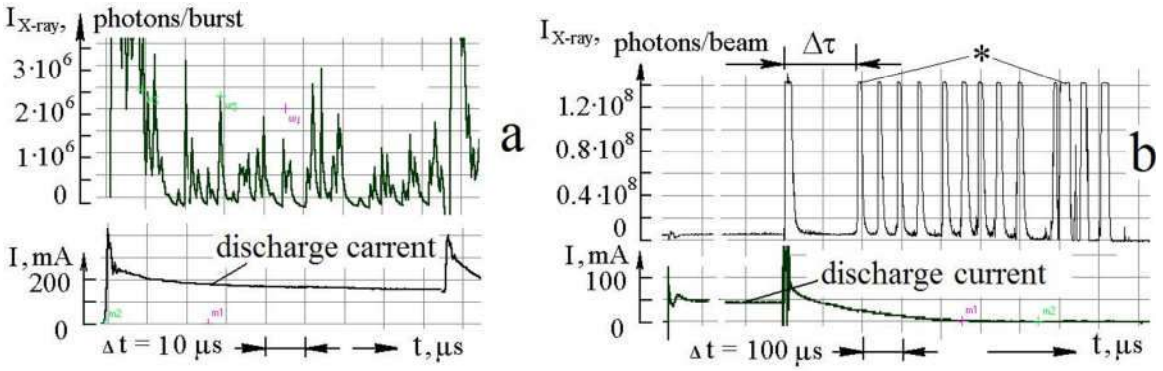

Figure 3. The typical oscillograms of the X-ray emission signal from the system scintillator – PM. The cathode sample is Pd, D2 discharge. a – diffusion mode, b – form of laser beams; . * - the pulse peak was cut a discriminator of amplifier.

3.4. The X-ray emission temporal characteristics

X-ray emission as a function of time was studied with scintillator photomultiplier detectors.

X-ray laser beam emissions were detected after passing the trailing edge of the glow discharge current pulses (Fig. 4). The different values of the time delay were recorded in experiments. The temporal characteristic of X-ray beam emissions was made for the following conditions: time zero corresponds to the trailing edge time of the discharge current pulse; and the number of X-ray beams was counted for each value of the time delay. The temporal characteristic of X-ray beam emissions show that the time delay has fixed values with a ± 2 μs deviation.

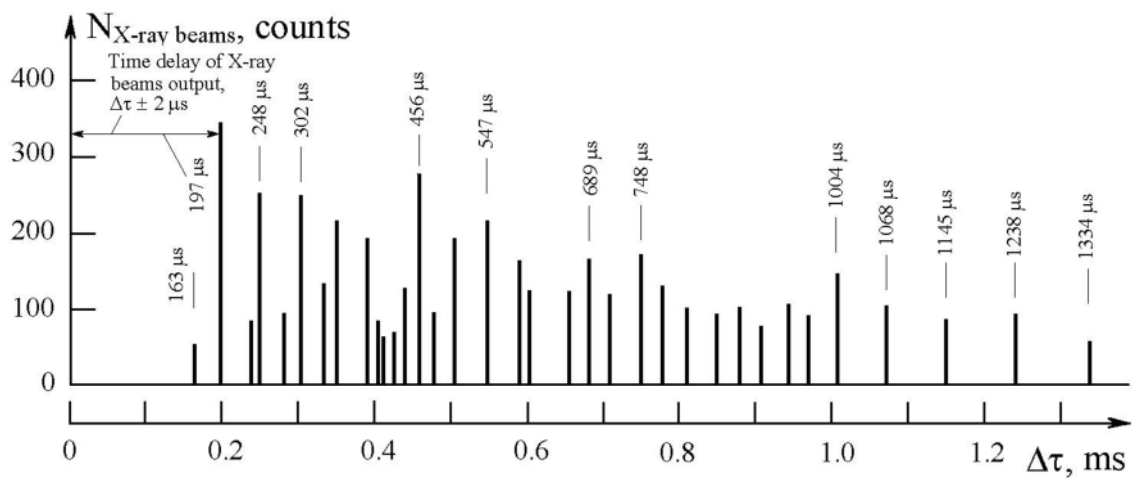

Figure 4. Temporal characteristic of X-ray beam emissions. The cathode sample is Pd, D_2 discharge, current 50 mA.

3.5. The X-ray emission spectra registration

The X-ray emission spectra were measured using the curved mica crystal X-ray spectrometer (the mica crystal holder is 50 mm diameter), with the spectrum being registered on X-ray film. The film includes the refraction spectra, the direct X-ray lighting, and reflection spectra, with

reflection spectra used for data processing. The direct X-ray lighting limits the reflection spectra in the high energy area. The wavelength and the energy of the X-ray were determined according to the expression:

$m\lambda = 2d \sin\theta$; $E_{X\text{-}ray} = 1.235/\lambda$.

Where m is the spectrum order; λ stands for the X-ray emission wave length in nm; 2d is the constant of the mica crystal lattice (2d = 2.0 nm); and θ represents the reflection angle. The spectra were repeatedly recorded during the glow discharge operation and after the glow discharge current switch off (for up to 20 hours afterwards). The spectra pattern includes bands, dark and light spots (consisting of multiple tiny dark and light dots) and separate dark and light small spots. The bands and spots were located in spectral areas specific for a given cathode material used. The registered energy of the X-ray emission bands and spots (the energetic position of the bands and spots within the spectrum) was dependent upon the cathode material used. The registered X-ray spectra in experiments was similar to characteristic X-ray spectra.

It was assumed that the diffusion component of the X-ray emission was registered on the spectrum as a series of bands.

The laser beams were recorded as dark spots and in case of the emission beam high density they turned white (solarization of the photoemulsion). The “solarization” is produced by a photographic negative in response to high energy density irradiation.

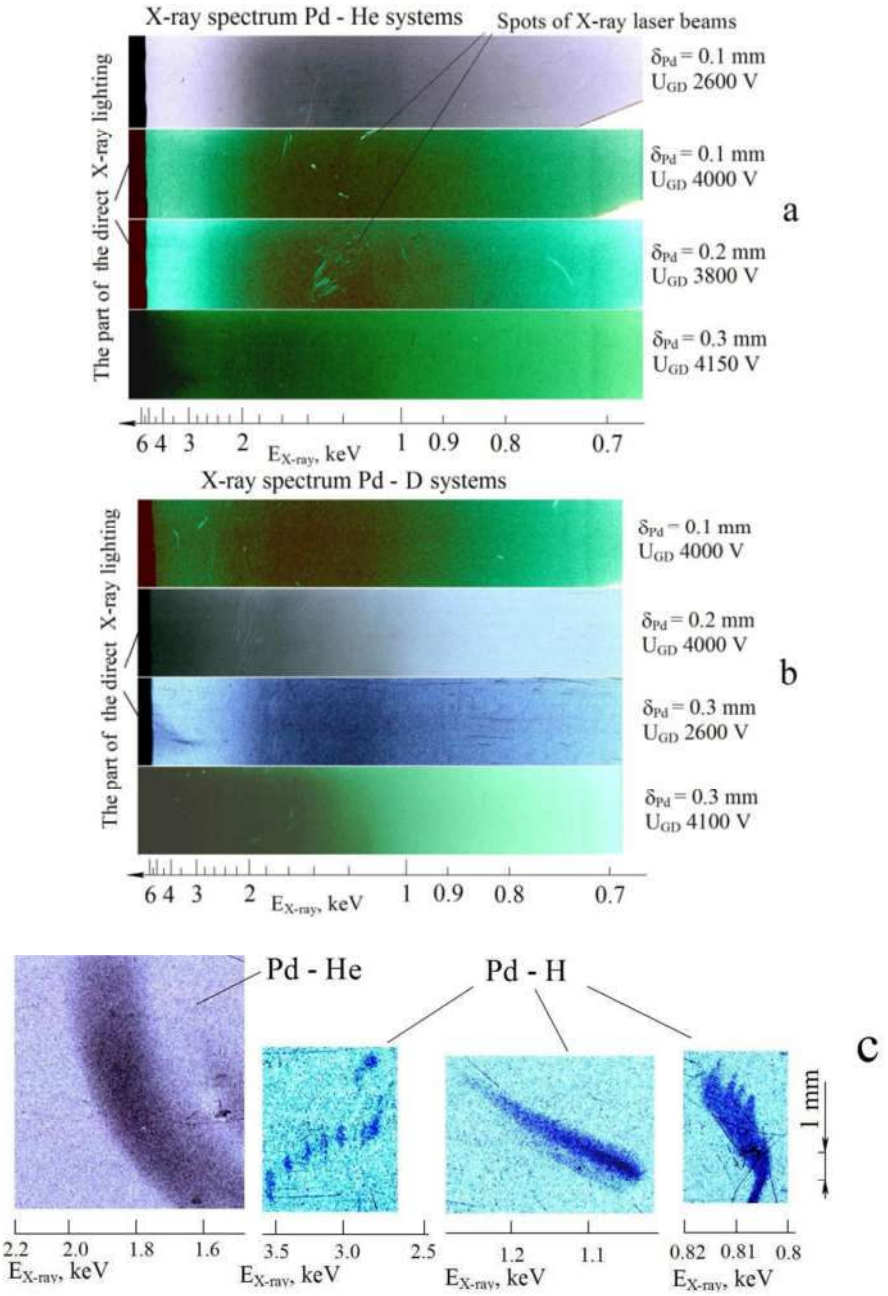

Figure 5. X-ray energy spectra. a, b – during the glow discharge operation, c – after the glow discharge in the spot modes.

4. Conclusion

Apparently, some long-lived excited levels with energies up to several keV are formed in the cathode solid-state medium when its surface is exposed to bombardment by the discharge plasma ions. These levels are characterized by fixed discreet values of energy and lifetime. The X-ray emission results from re-excitation of these levels.