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LABORATORY TECHNIQUES

An Apparatus for Measuring the Characteristics of the High-Speed Image Converter Cameras Operating in the Range of Soft X-Rays and Vacuum UV

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Abstract—A pumped vacuum apparatus is described that contains an electron gun with an adjustable high-voltage voltage source, interchangeable metal targets, and flanges to which the object under study is connected. The apparatus is especially designed to measure the spatial and temporal characteristics of high-speed image converter streak cameras that operate in the soft X-ray range. It can be used for research and measurements in the design of soft X-ray photodetectors and their main parts, for example, microprobe detectors, imaging devices, solid-state linear and matrix photodetectors, photoemitters operating in vacuum, etc.

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INTRODUCTION

High-speed image converter cameras (ICC) [1–3] are designed to measure the spatial and temporal characteristics of optical pulses. In these devices, an electron-optical converter (EOC) with an image scan, which is part of the camera, is used as the primary receiver. The principle of its operation is illustrated in Fig. 1.

A measured optical impulse *1* (Fig. 1a), landing on a slot photocathode, excites the flow of photoelectrons *4*, which are accelerated towards the luminescent screen *5* and focused on it. When applying the deflection system *3* synchronously with the optical pulse of a linearly increasing voltage, the electron beam impacts along the surface of the luminescent screen and causes a glow, whose brightness depends on the intensity of the optical pulse at each instant of the scan time (Fig. 1b).

The cross section of the beam has a rectangular shape, which, in contrast to the oscilloscope beam, allows one to have two coordinates, that is, temporal and spatial. The spatial coordinate provides information about the distribution of the intensity of the optical pulse along the gap.

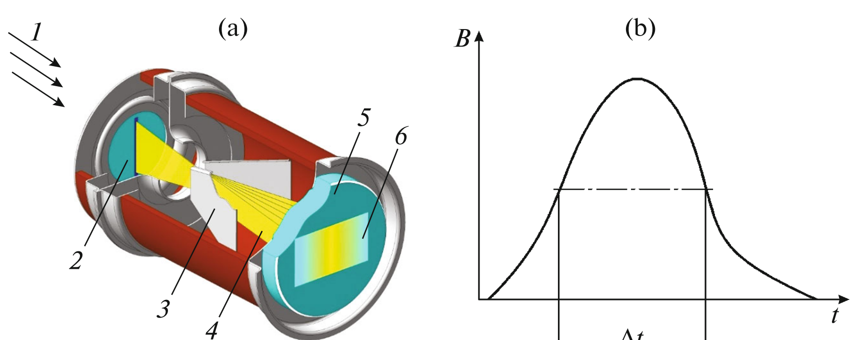

Fig. 1. The principle of operation of the electron-optical converter: (a), time analyzing electron-optical converter (*1*, input optical pulse; *2*, slot photocathode; *3*, deflecting system; *4*, electron beam; *5*, luminescent screen; *6*, time scan of the image of the optical pulse); (b), the dependence of the screen brightness *B* on time *t* (Δ*t*, the duration of the optical pulse at half maximum).

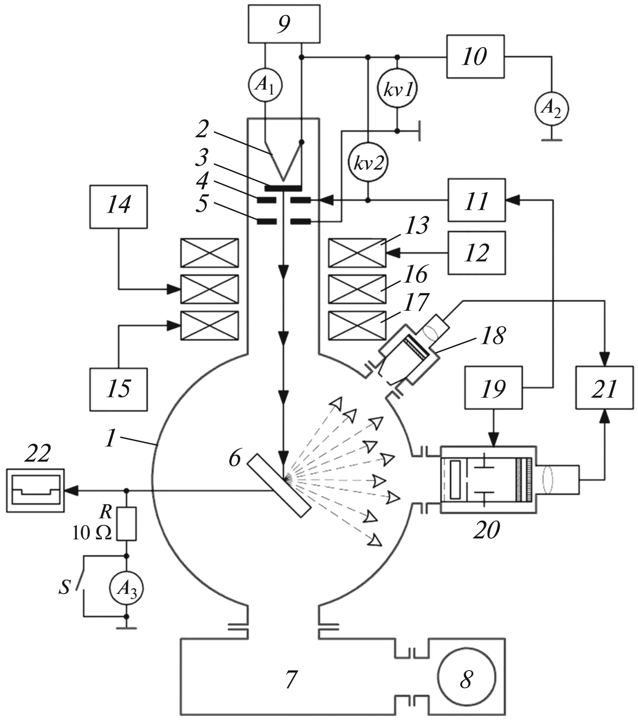

Fig. 2. A diagram of the device. *1,* a vacuum chamber; *2,* cathode heater; *3*, cathode; *4*, modulator; *5*, anode; *6*, target; *7*, turbomolecular pump; *8*, fore-vacuum pump; *9*, cathode heater power supply; *10*, adjustable (0–50 kV) cathode power supply *3*; *11*, modulator control unit *4*; *12*, focusing coil power supply *13*; *14*, *15*, power supply deflecting coils *16* and *17*; *18*, observation channel; *19*, a pulse generator for starting a modulator control unit (*11*); *20*, the studied object (ICC) or measuring device; *21*, computer; *22*, an oscilloscope for controlling the pulse current of the target; A_1, ammeter for monitoring the current of the cathode heater *2*; A_2, milliammeter to control the direct current of the cathode *3*; A_3, milliammeter to control the direct current of the target *6*; *S*, toggle switch; *R*, measuring resistor; *kv1*, kilovoltmeter voltage control at the cathode of the gun; *kv2*, kilovoltmeter voltage control between the cathode and the modulator.

The image of the pulse scan on the screen is read by a matrix photodetector and entered into a computer for processing and storage. Usually, the ICC includes an input optical system (IOS), electronic power and control units, and a reading system.

The spectral sensitivity range is determined by the type of photocathode. Photocathodes of various types can cover the optical range from 200 nm to ~2 μm. Tube, LED, or laser light sources, lenses, and other optical elements, spectral devices, etc. are usually used for measuring technical characteristics in the optical range.

We developed a pumped-out vacuum unit with an X-ray source to measure the parameters of a high-speed ICC, similar to [4–7], operating in the range of vacuum ultraviolet (UV) and soft X-ray radiation.

A DESCRIPTION OF THE APPARATUS

The scheme of the experimental apparatus is shown in Fig. 2. The vacuum chamber *1* is pumped out by pumps *7* and *8* up to $\sim 10^{-3}$ Pa. It has an electron gun formed by the cathode *3*, modulator *4*, and anode *5*. The gun is equipped with a magnetic focusing coil *13* and a pair of magnetic deflection coils *16* and *17*, which allow the formation of a grounded target in the center *6* an electronic spot with a diameter of about 3 mm. The control block *11* of modulator *4* allows one to use the gun in both constant and pulsed current rectangular shape. The amplitude and duration of the pulse current of the target can be controlled using an oscilloscope *22*. The vacuum chamber *1* is equipped with flanges to which the observation channel *18* is connected and the ICC *20*, as well as vacuum control sensors (not shown in the diagram).

A planar brightness amplifier with a microchannel plate (MCP) is installed in the observation channel *18*. The obscura camera is located before the MCP X-ray image of the electron spot on the target *6*. The pinhole is closed by a thin Be-foil filter that protects the microcircuit from electrons that are elastically reflected from the target. The MCP has a high sensitivity to soft X-ray radiation and can enhance the current up to $\sim 10^3$ times or more. The image at the output of the brightness amplifier is recorded by a CCD camera. This allows one to visualize the image of the elec-

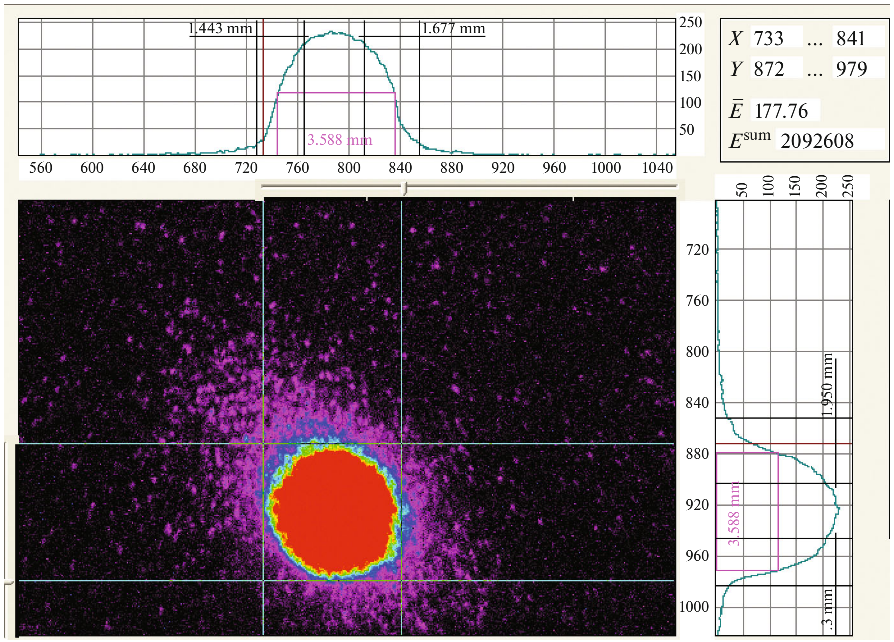

Fig. 3. An X-ray image of an electron spot on a target. The spot diameter is 3.6 mm. Above and to the right is a radiation intensity profile. E in two coordinates.

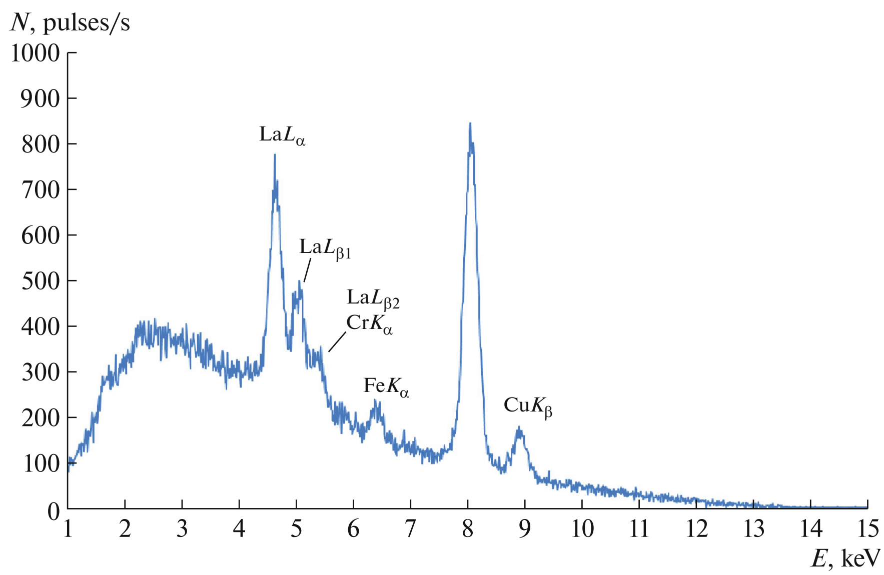

Fig. 4. The radiation spectrum of the target at an accelerating voltage of 13.8 kV, exposure, 300 s.

tron spot and control its diameter and position on the target (Fig. 3). The target material is copper. Use of other materials is possible.

THE SPECTRAL CHARACTERISTICS OF THE TARGET RADIATION

X-ray spectra were measured at an accelerating voltage of 13.8 and 7.1 kV and a current of ~2 μA. A water-cooled copper washer was used as the target. The target was irradiated with an electron beam with a diameter of ~5 mm. The angle of incidence of the electron beam on the target was 45° and the angle of selection of X-ray radiation was 45°. The X-ray detector was made by the Amptek semiconductor company (XR-100CR) with Peltier cooling. The energy resolution on the Mn line is 190 eV. The thickness of the beryllium window is 25 μm. A collimator with a diameter of 1 mm and with a thickness of 1 mm made from a copper plate is installed at the input window of the detector. The energy range for recording these detectors is 1–30 keV.

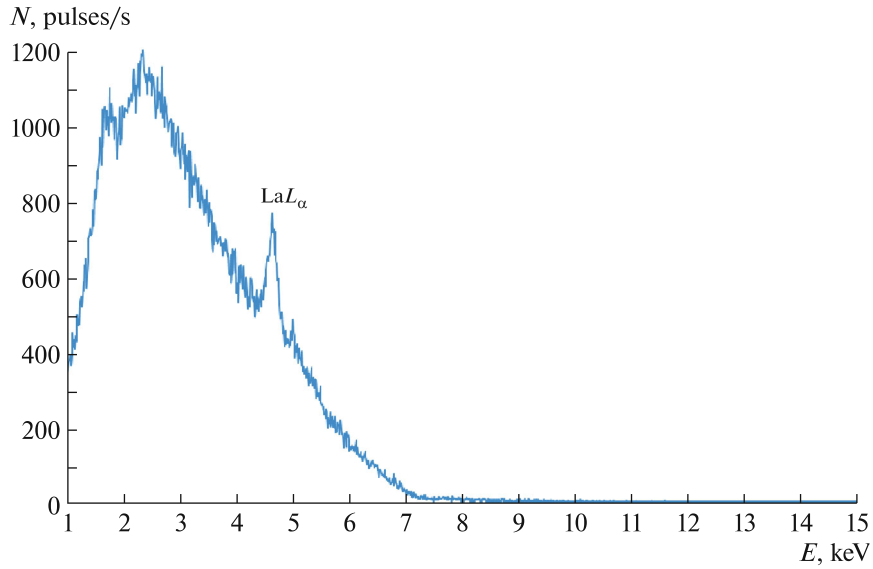

Fig. 5. The radiation spectrum of the target at an accelerating voltage of 7.1 kV, the exposure time is 300 s.

The power and control of the detecting unit was carried out using a Kolibri analogue–digital signal converter made by Green Star (Moscow), which includes a digital signal processor, high-voltage and low-voltage power sources, an amplifier and an interface module. Connection via the RS-232 serial port is used to transfer the measurement results to an external computer for further processing. Data recording and subsequent interpretation of the obtained spectra were performed using the Amtertek PXRF program.

The measurement results are presented in Figs. 4 and 5. In Fig. 4 the characteristic lines of copper (K_α and K_β) from the target are shown, since the excitation energy of these lines (8.048 and 8.905 keV) is much lower than the applied potential (13.8 kV). The presence of peaks of iron, chromium, and lanthanum is associated with the excitation of structural elements of the apparatus. A decrease in the applied potential leads to a partial "disappearance" of the spectrum due to a lack of energy, which is clearly seen in Fig. 5.

The apparatus allows the use of an external radiation source for measuring the characteristics of the ICC, for example, in the ultraviolet range. For this, the observation channel *18* (Fig. 2) is removed, and the apparatus flange is closed with a vacuum-tight window from a material that transmits ultraviolet radiation. In place of the X-ray target, a mirror is placed that reflects the optical radiation onto the photocathode of the EOC

Fig. 6. The external view of the K010X ICC.

Fig. 7. The appearance of the PV-204XM X-ray EOC with an open entrance.

(a) (b)

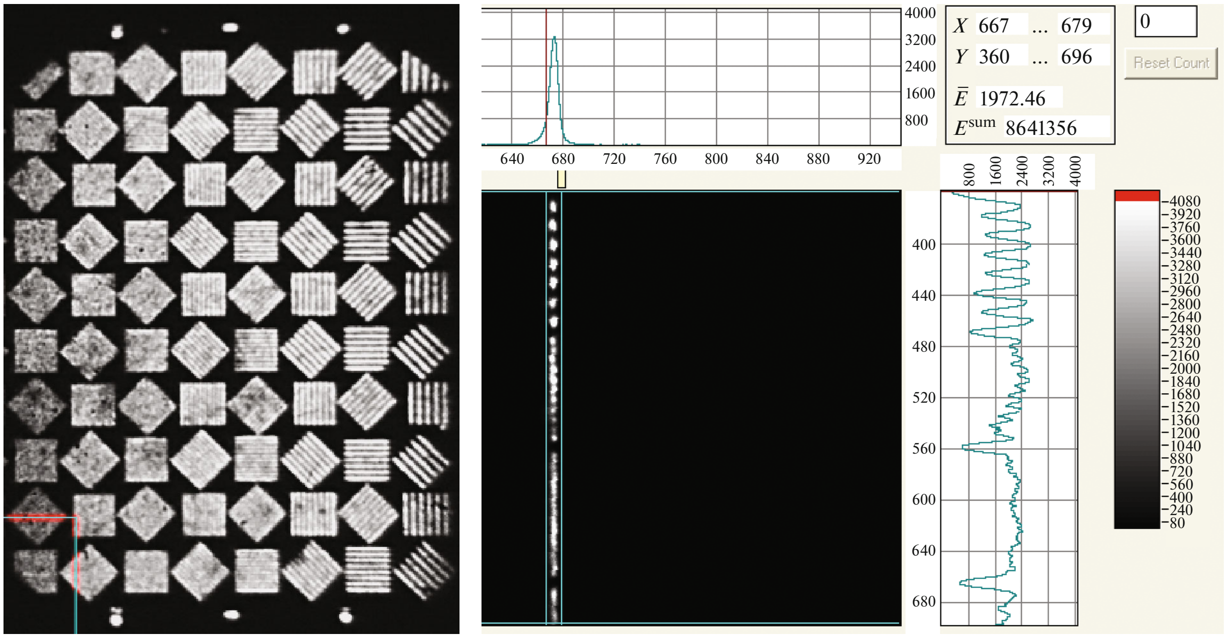

Fig. 8. Images: (a), the frame test object (CsI photocathode on beryllium foil, frame duration, 655 µs, spatial resolution in the center is 12.5 pairs of lines/mm); (b), the slit test object (CsI photocathode on the vaporization, frame duration 215 µs, three ranks with a spatial frequency of 5, 10, and 15 pairs of lines/mm are distinguished).

STUDY OF THE MAIN CHARACTERISTICS OF HIGH-SPEED X-RAY ICC

The main characteristics of the ICC include its spectral range, spatial resolution, limiting time resolution, frame duration (for the frame mode), linear sweep coefficient, and its heterogeneity.

Using the described apparatus, the main characteristics of the K010X ICC [4] (Fig. 6) with PV-204XM EOC [7] are shown in Fig. 7.

The K010X ICC is designed to operate in the soft X-ray range. A standard vacuum flange is installed at the entrance of the EOC, with which it connects to the vacuum chamber and is pumped with it to a pressure of no less than 10^{-3} Pa. The design of the PV-204XM EOC allows the installation of interchangeable photocathodes that operate in the light. CsI or Au deposited on a 100 nm thick parylene substrate or 5–10 µm thick beryllium foil are used as the photosensitive materials.

The distance from the target of the apparatus to the photocathode is 350 mm. This distance, along with the diameter of the X-ray source of 3.6 mm, ensures sufficient uniformity of the spatial irradiation of the photocathodes.

The spatial resolutions in single-frame mode and in linear sweep mode are measured using two test objects that are installed close to the photocathode. One of these is a frame (analogue of the standard test object of GOI no. 4) with a spatial resolution of 6 to 25 pairs of lines/mm, the other is a slit test object, with four ranks with a spatial resolution of 5, 10, 15, and 20 pairs of lines/mm. The test objects are made of copper foil with etched strokes. Figures 8 and 9 show the images of these test objects recorded by the ICC

Images obtained with the ICC were recorded by a CCD camera included in its construction and transferred to a computer for processing and archiving (Figs. 8 and 9).

When determining the limiting time resolution (a temporal hardware function), a vacuum tight MgF_2 window was installed on the flange of the observation channel, whose short-wavelength transmission limit is ~110 nm. Photocathode backlighting is carried out by a UV laser. The pulse duration is 500 fs ($\lambda = 248$ nm). Figure 10 shows the temporal hardware function of an image converter camera in the ultraviolet range. The half-width of the hardware function was 12.6 ps, which corresponds to the data of [7].

CONCLUSIONS

The apparatus described above can be used not only for measuring the characteristics of a high-speed X-ray ICC, but also for research and measurements on the design of devices of the ultraviolet range, soft X-ray range and their main parts, for example, microprobe detectors, imaging devices, solid-state linear and matrix photodetectors, and photoemitters that operate in a vacuum.

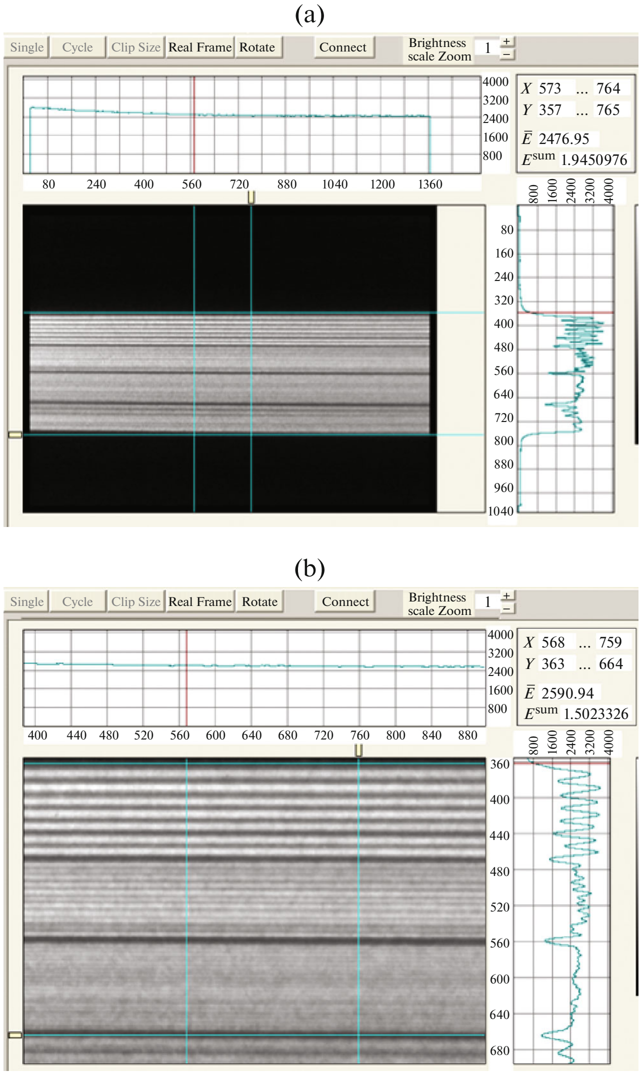

Fig. 9. A scan image of the slit test object (CsI photocathode on a vaporization, scan duration 200 µs): (a), full image; (b), a scan fragment (the first 2 ranks of the test object with a spatial resolution of 5 and 10 pairs of lines/mm and at the limit of 15 pairs of lines/mm are confidently resolved).

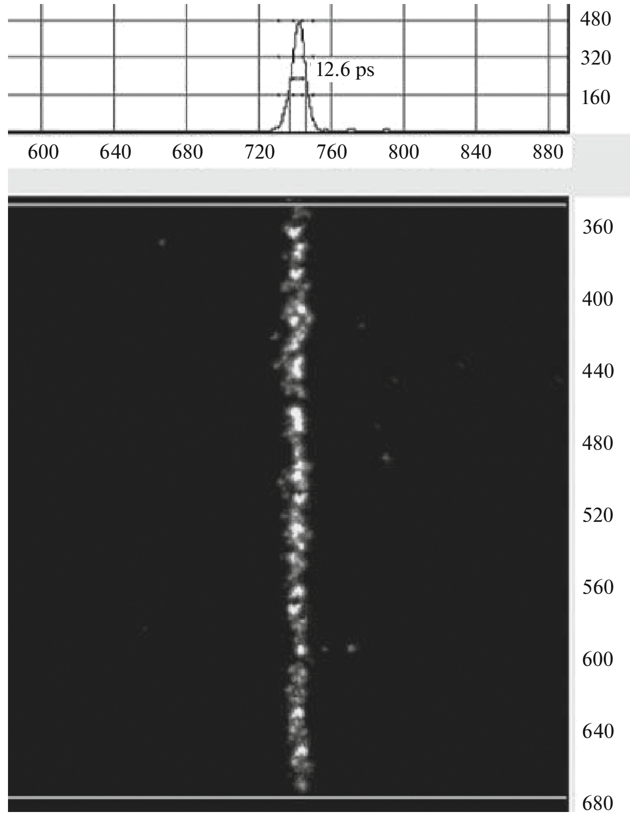

Fig. 10. The response of the K010X ICC at a 500-fs pulse of a UV laser (λ = 248 nm).

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