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IMAGING OF FAST PROCESSES

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Scientific instrument engineering at Japanese congresses devoted to high-speed imaging

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Abstract. **The information about the congresses held in Japan and devoted to fast imaging processes and photonics is presented. Reports devoted to the technique and the results of applications of superhigh-speed recording instrumentation in different fields of science and technology are considered.**

Keywords: *scientific instrument engineering, high-speed processes, imaging.*

In December 2009 and September 2010 the National and International Congresses on High-Speed Imaging and Photonics (ICHSIP) were held in Japan.

About 150 – 200 participants who presented at least 50 reports attended the Congresses organised on a high scientific level. Traditionally the topics of the congresses can be divided into two major blocks. The first block consists of theoretical justification, experimental implementation and testing of instrumentation and techniques, used to image high-speed processes (HSP), including the design of gauging radiation sources. The second block is related to methods and results of using the superhigh-speed recording instrumentation in different fields of science and technology. Despite many conferences on similar applications, here we focus the attention on the reports devoted to the instrumentation.

The development of X-ray electron-optical cameras (EOCs) aimed at frame-by-frame imaging of the exploding kern of the target in laser fusion synthesis (LFS) experiments with fast ignition under the conditions of high-power X-ray exposures was considered in the reports by Azechi, Shiraga, Koga, et al. (Institute of Laser Engineering, Osaka University). Simultaneous registration of the processes of target explosion with thermonuclear fuel and the moment of injection of the heating laser radiation was provided. To investigate it simultaneously is rather difficult, mainly because the processes take place in essentially different spectral regions. To solve the problem a camera was designed for frame-by-frame shooting, providing simultaneous recording of 12 frames with the frame exposure time of 360 ps; the interval between each three frames was 80 ps, and the interval between each sequence of four groups with three frames in each group was 500 ps. The frame shooting is implemented by applying an electric pulse with the duration 360 ps to the strip line, coating the surface of the microchannel plate (MCP) (Fig. 1). The same MCP serves as a photocathode for X-ray images, since it is equally sensitive both to the soft X-ray radiation (thermal X-ray radiation from the plasma of the exploding target at its ignition by high-power nanosecond laser pulses) and to the hard ($\sim$50 keV) X-ray radiation, arising at consequent irradiation of the target with femtosecond laser pulses of petawatt power. Using the performed measurements the authors declare that they could measure the moment of injection of laser radiation (10^{15} W, 800 ps, 200 J) into the target with the precision up to tens of picoseconds with respect to the moment of the target collapse under the action of radiations from the 9-channel GeKK0 XII laser system (0.53 μm, 1.5 ns, 400 J in one channel).

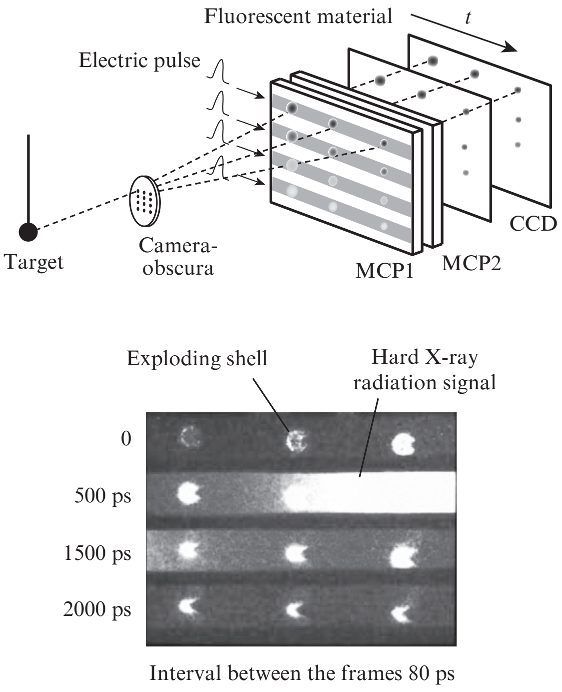

Figure 1. Principle of operation of the X-ray picosecond camera for frame-by-frame recording (top) and typical experimental results (bottom).

Apparent interest of participants was drawn by the report of Shimizu et al. (Osaka University and Hamamatsu Photonics) in which a VUV spectrometer in combination with a streak camera was considered. The system operates in the spectral region 125–850 nm, its entrance is equipped with the reflecting-type optics with Al and MgF_2 coatings. In the experiments the Nd^{3+}:LaF_3 crystal was used having the dimensions 1×1×3

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cm and polished surfaces. The crystal was placed in a vacuum chamber and irradiated with a focused radiation of the third harmonic of titanium-sapphire laser (290 nm, 100 fs, 0.6 mJ, 1 kHz). For comparison the radiation of a F_2 laser (157 nm, 1 mJ, 5 ns, 100 Hz) was also used. The electron-optical camera operating in the linear-sweep and synchronous scanning regime had an entrance window made of MgF_2. The measured wavelength of fluorescence from the tested crystal was nearly 175 nm, the decay time constant was ~7 ns.

The studies aimed at EOC construction are extensively carried out not only in Japan, but also in other countries. Thus, Smith (UK Atomic Weapons Establishment) reported the creation of a fast framing EOC (5×10^8 frames s^{-1}) aimed at recording high-intensity X-ray radiation. Image-converter tubes for this camera with the blue boundary of spectral sensitivity at 200 nm were designed by the British company Photek. The camera was used for photographical recording of processes that take place in picosecond X-ray accelerators and allowed obtaining important information about the optimal configuration of the X-ray diode and X-ray converters.

The French company Photonics presented the design of a new small-size EZ-Streak EOC. The camera operates in the range of scanning rates from 2 ns to 1 μs per screen and its maximal time resolution is 10 ps. The Photonics Company singly designs and manufactures the time-analysing image-converter tubes for this camera. Summ reported a series of German streak cameras manufactured by Optronis GmbH. The image-converter tubes for these cameras are supplied by Photek. Wai Chan told about new EOC developments for multi-frame recording at Specialized Imaging, UK.

The analysis of experimental problems, related to achieving sub-100-femtosecond time resolution in the streak regime and in the regime of photoelectron bunch formation by a non-stationary electric field [time-resolved electron diffrraction (TRED) experiments] was carried out by Schelev (A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, Russia). His information about the comparison tests of the Optoscope streak camera (Otronics, Germany) and the PS-1/S1 streak camera, designed and manufactured at the A.M. Prokhorov General Physics Institute, Russian Academy of Sciences (tests being carried out at the Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Russia) aroused great interest. The Russian facility demonstrated essentially better performance that allows high-precision measurements in a wide spectral range (200–1300 nm) with one-picosecond time resolution.

Particular interest was drawn to the original developments of superhigh-speed video cameras carried out jointly by the Japanese (Kinki University), American (Arizona University) and Dutch (Dalsa Corporation) researchers. A superhigh-speed (10^7 frames s^{-1}) video camera with 10^6 pixels per frame on the basis of backside illuminated ISIS structures, equipped with memory elements, integrated with photosensitive elements, is created (Fig. 2). The maximal sensitivity of the photosensitive matrix is less than 10 photons $pixel^{-1}$, which is achieved by introducing more than 100 CCD memory elements into each pixel, as well as by improving the geometric configuration of the matrix itself and by the use of the charge carrier multiplication technique.

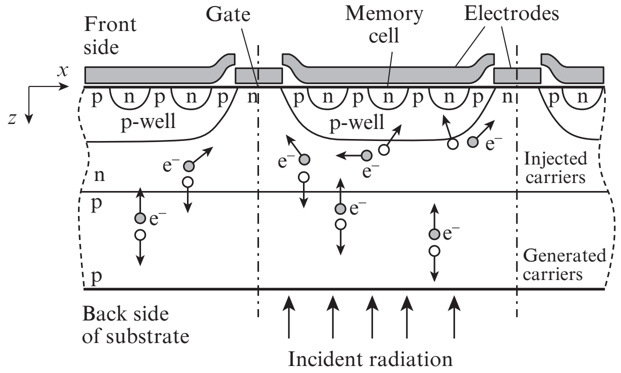

Figure 2. Cross section of backside illuminated ISIS-MV12-sensor.

The specialists from Los Alamos National Laboratory (USA) informed about the completion of construction of a unique CMOS-sensor, aimed at multi-frame proton radiography and providing 10-frame recording of proton images with the exposure time 50 ns, frame dimensions 1024×1024 pixels and dynamical range of detection 12 bit. The matrices are manufactured by Teledyne Imaging Sensors (USA). A series of video cameras based on these sensors was successfully approved during many years on the proton accelerator with the energy 800 MeV in Los Alamos. The frame sequence may be set in the interval from 250 ns to 2 s. At the frame acquisition time 70 ms the cameras can be reliably synchronised with proton beams having the duration 50 ns and the repetition rate from 0.1 to 5 Hz. Up to 1000 radiographic movies may be recorded, each of them 5–30 minutes long, the exposure of a single frame remaining equal to ~180 ns.

Sato et al. (Iwate Medical University, Japan) reported the development of a high-speed X-ray technique for diagnostics and therapy of oncologic diseases with discrimination of the X-ray radiation energy. These methods provide reduced doze of X-ray exposure of the patient as compared with presently used techniques. This is achieved by using a multi-pixel CdTe-based detector and high (up to 20 MHz) scanning frequency of the X-ray images with a multi-channel analyzer, as well as by using 2-mm-thick ZnO scintillators, providing small time of de-excitation (the decay constant smaller than 0.5 ns) and high sensitivity not only to X-ray radiation, but also to α, β, γ, neutron, HF and UV radiations. As an example, a K-edge tomogram of a rabbit heart was demonstrated, in which the coronary arteries filled with iodine-containing microspheres are seen with high contrast and the carcinogenic domains are clearly distinguished (Fig. 3). The developed instrumentation may be efficiently used for recording the images at the molecular level.

Parallel to the development of novel species of recording instrumentation the problems of designing new radiation sources were also discussed. Thus, Ochi et al. (Japan Atomic Energy Agency) reported the creation of an X-ray laser with the wavelength 13.9 nm, generating 10^{10} quanta within the solid angle 0.5 sr in a single pulse, having the duration 7 ps. To investigate the parameters of the X-ray laser, the authors designed an X-ray interferometer with double Lloyd mirrors, providing the spatial resolution 1.5 μm in the direction along the surface and 6 nm in the perpendicular direction.

A number of reports were devoted to the designing of superhigh-speed X-ray scintillators. Shimizu et al. (Institute for Laser Technology, Osaka) reported the creation of superhigh-speed ZnO scintillators, used in the experiments on synchronisation of femtosecond pulses from X-ray free-electron lasers with the pulses from other radiation sources (Fig. 4). The rise and drop of the fluorescence signal (the wavelength 380 nm) from ZnO scintillators, the material for which was grown using hydrothermal methods and was doped with iron

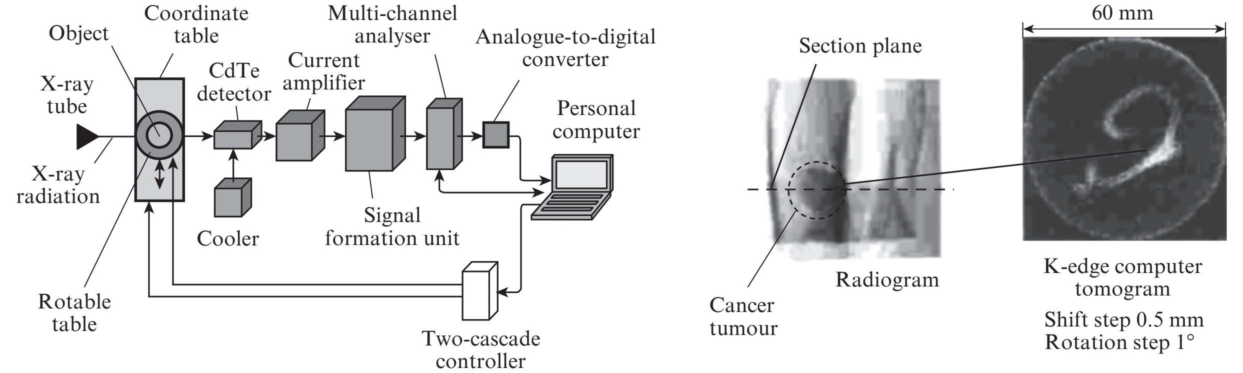

Figure 3. Schematic diagram of the system for computer tomography with discrimination of energy (left); K-edge tomogram of the rabbit heart and its magnified carcinogenic part (right).

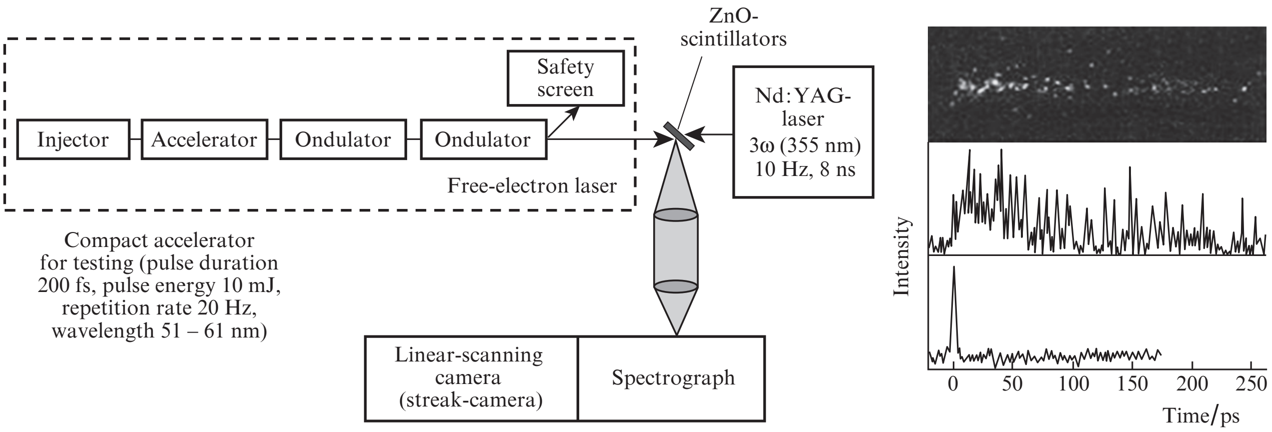

Figure 4. Schematic diagram of the setup for measuring the time-dependent response of ZnO scintillators in the VUV region and a scan of scintillation response on the streak-camera with the corresponding microdensitogram.

ions, lasted 10 and 100 ps, respectively. Due to their high luminous efficiency under irradiation by single X-ray pulses it could be found that the jitter of the X-ray pulses ($\lambda = 50 – 60$ nm) does not exceed 70 ps. These measurements were performed using EOC Hamamatsu C1587.

Sakobe at al. (Institute of Chemistry at Kyoto University) demonstrated a diffraction pattern from a crystalline gold foil (Au 001), obtained by transmitting a single electron pulse (340 keV), generated by high-power pulses of a femtosecond laser (Fig. 5). Such a method of generating high-energy electron beams in future may find wide application in the experiments on time-resolved electron diffraction.

A series of reports was devoted to the investigation of shock waves and explosion processes. Kleine (Air Force Academy, Australia) together with the colleagues from Japan and Germany reported the recording of shock waves, gas jets and liquid flows by means of video cameras with high time resolution. As an example, Fig. 6 shows a four-frame sequence of schlieren images of a shock wave, rounding a cylinder surface (the Mach number in air is 1.23, the time interval between the frames is 40 μs). In the opinion of the authors, the major obstacle in the experiments on shock wave imaging is insufficient spatial resolution of the existing superhigh-speed video instrumentation.

The congresses clearly revealed the major trends in the development of high-speed photography and photonics at present time. The development and application of methods

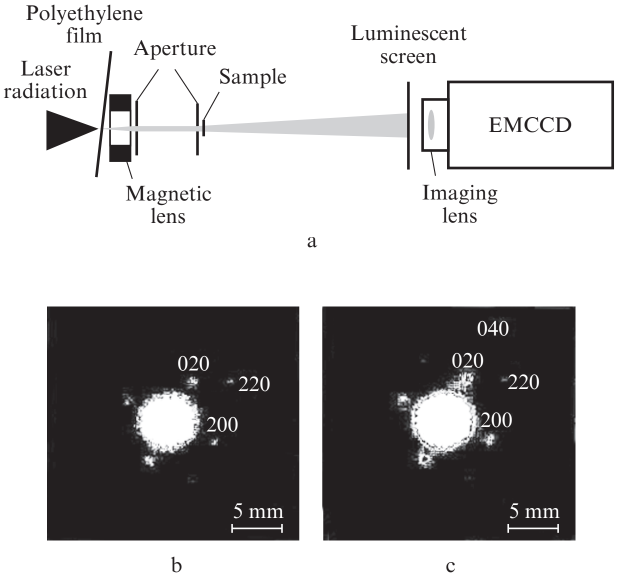

Figure 5. Schematic diagram of the setup (a) and transmission diffraction pattern from a single-crystal Au (001) in a single-frame regime (b) and in the regime of accumulation of ten frames (c). Single pulses of the third harmonic (262 nm) of a Ti:sapphire laser (170 fs, 0.15 mJ) were used. A copper photocathode is installed in the photoelectron gun.

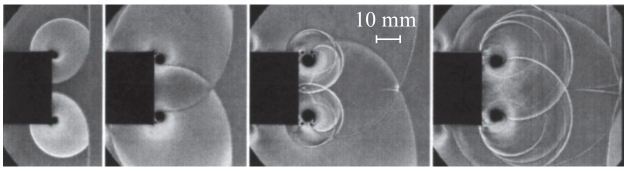

Figure 6. Four-frame sequence of schlieren images, obtained using a video camera during the diffraction of a shock wave from a cylindrical surface. The time between the shown frames is 40 µs.

and facilities of superhigh-speed imaging of fast processes at present are concentrated in the field of laser-induced fusion, accelerators, biophysics, medicine and investigation of shock waves. Note that Russia still supports high professional level in pico- and femtosecond photoelectronics. This was confirmed by awarding the International Golden Medal “High-Speed Imaging Award – VIDE et CREDE” to the author of this paper.