High-speed image converter instrument engineering of VNIIOFI is 40 years old

Vyatcheslav S. Ivanov [a], Yuri M. Zolotarevsky [a], Vladimir N. Krutikov [b], Vitaly B. Lebedev[*c], Grigory G. Feldman [c]

[a] All-Russian Research Institute of Optical and Physical Measurements (VNIIOFI), 46 Ozernaya str., 119361 Moscow, Russia. [b] Federal Agency on Technical Regulation and Metrology, Leninsky Prospect 9, V-49, GSP-1, 119991 Moscow, Russia. [c] All-Russian Research Institute of Optical and Physical Measurements (VNIIOFI) and BIFO Company, 46 Ozernaya st., 119361 Moscow, Russia

ABSTRACT

A review of high-speed image converter instrument engineering in VNIIOFI during 40 years from the moment of Institute foundation up to this time is presented.

Key words: image converter tube, camera, high-speed processes, temporal resolution, and sweep.

1. HISTORY

An image converter method of recording and measuring parameters of high-speed processes is known for more than 55 years. The first image converter tube (ICT), namely PIM-3 where an image is swept with an electrical field was created in the Soviet Union in 1949 by M.M. Butslov (later a Head of VNIIOFI V-4 Laboratory).

The first in the Soviet Union 9-frame image converter camera based on PIM-3 ICT and intended specially for studying explosive processes was created in 1961 by Yu.A. Drozhbin (later a Deputy Director of VNIIOFI and a Head of VNIIOFI R-4 Laboratory; now he is a Chairman of the Russian (earlier Soviet) Committee on High-Speed Photography).

Fig. 1. M.M. Butslov (1914 -1973), (photo of 1970).

The first-in-the world industrial image converter camera, namely FER-2 with 20 ps limiting temporal resolution was created in the Soviet Union in the All-Union Research Institute of Optical and Physical Measurements (VNIIOFI) in 1966 [1], i.e. in the year of Institute foundation. The camera was very heavy; it weighted ~ 250 kg, had highly imposing dimensions 2200 x 450 x 710 mm3 (Fig. 2) and its power consumption was about 1 kW.

It was explained by the following: firstly, a strong magnetic field induced by a heavy solenoid power-supplied with a powerful stabilized current source was used in amplifying stages of UMI-92 ICT to focus electron beams; secondly, at that time an element base of radio electronic components (necessary for creating stabilized current sources, stabilized high-voltage sources (they are: - 15 kV, + 10 and + 20 kV in FER-2) power-supplying ICT electrodes, lamp circuit engineering of shut pulse generators (ShPG), sweep pulse generators (SwPG) and many other auxiliary pulses) had large over-all dimensions, heavy weight and high power consumption. This equipment can be located only in a powerful, heavy and cast structure. If, for example, the necessity appeared to move FER-2 from one working place to another somewhere in the laboratory, then only not less than six strong men could do this work.

*Phone No. +7 (495) 437-31-92, Fax No. +7 (495) 437-34-74, E-mail < lab-r5@vniiofi.ru >

27th International Congress on High-Speed Photography and Photonics, edited by Xun Hou, Wei Zhao, Baoli Yao, Proc. of SPIE Vol. 6279, 627908, (2007) · 0277-786X/07/$15 · doi: 10.1117/12.725059

Nevertheless, news of creating an industrially produced instrument that not only can be seen at the exhibition but also can be bought (its production has begun since 1967) and with such a high temporal resolution has quickly spread; as a result, a large queue of organizations, first of all, academic ones, having a desire to acquire FER-2 was formed. The first consumers of FER-2, apart from VNIIOFI itself, were: the Physical Institute of the USSR Academy of Sciences (FIAN), the Institute of Computer Engineering (IVT) of the USSR Academy of Sciences, and the Moscow State University. One of FER-2 samples was delivered to the University of Iyena (German Democratic Republic).

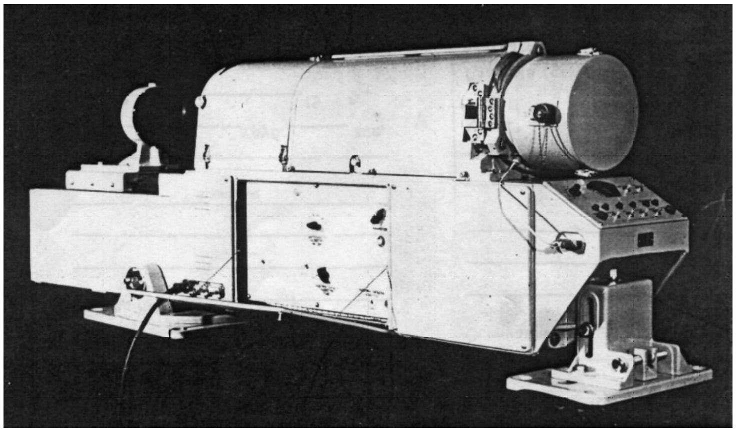


Fig. 2. The first national industrial picosecond image converter camera: FER-2 photoelectronic register.

That was a time of laser invention that was followed by a whole era of rapid development of laser technique when various lasers including lasers generating picosecond pulses appeared rapidly. But at that time none industrial oscillography had necessary temporal resolution. Only FER-2 designed in VNIIOFI had such resolution. That’s why the name of an organizer of VNIIOFI and its first director B.M. Stepanov and the names of FER-2 direct designers, first of all, Yu.A. Drozhbin, B.Z. Gorbenko and A.M. Tolmachyev as well as the name of a designer of time analyzing image converter tubes M.M. Butslov were well known to those who dealt with picosecond laser technique and generally with technique of recording and measuring parameters of various high-speed processes since a nomenclature of different instruments produced for these purposes in VNIIOFI was constantly expanded.

Fig. 3. B.M. Stepanov (1910-1990), an organizer of VNIIOFI and its first director (photo of 1980).

For the sake of justice it should be said that the high-class specialists on high-speed image converter instrumentation were not only in VNIIOFI. In FIAN this instrumentation was successfully developed by M.Ya. Shchelev and V.V. Korobkin. In the Institute of Atomic Energy there was a whole cohort of talented scientists-physicists: Ye.K. Zavoysky, S.D. Fanchenko, Yu.E. Nesterikhin, M.I. Pergament, V.S. Komel’kov, A.G. Plakhov, G.Ye. Smolkin, et al.; most of them had also an excellent engineering training. However, they created single pioneer samples (most likely prototypes that were used in physical investigations) which, indeed, showed high and often limiting for that time technical characteristics but they were unable “to satisfy hunger” of wide science and technology for such instrumentation. Only VNIIOFI has succeeded in manufacture of the first industrial cameras with picosecond temporal resolution.

Practically at the same time the Suma plant of electronic microscopes and electronic automatics began production (based on developments of the Institute of Atomic Energy) of LV-series nanosecond-range cameras called time magnifiers that were slower than FER-2. At first it was LV-01, then LV-02, LV-03 and, finally, LV-04 [2]. They differed from each othermainly by a number of amplifying stages and, respectively, by over-all dimensions, weight and power consumption that achieved several kilowatt. Structurally they represented a register in the form of a separate huge heavy module on a powerful stand with wheels in which an ICT (short focusing coils for amplifying stages had water cooling) with pre-output and output stages of pulsed control electronics and one or two (depending on the number of ICT amplifying stages) electronic racks of a ~1.5 m height with power supply sources (also on wheels) were located. The wheels provided these cameras with somewhat greater mobility in comparison with FER-2.

Fig. 4. Designers of famous FER-2 (photos of 1966, from left to right): Yu. A. Drozhbin, B.Z. Gorbenko, A.M. Tolmachev (1928-2006), D.F. Korinfsky (1921-2001), and V.A. Yakovlev.

In 1970 there was begun a small-scale serial production of LVE-1 two-channel 9-frame time magnifier [3] (Fig. 5) and FER-3 two-channel photochronograph [4] designed in VNIIOFI; they were intended for recording dynamics of generation of super powerful infrared lasers with explosive pumping that were created at that time according to a national defense program to counterbalance a similar American program of “starry wars” of SOI.

Two channels of these cameras were adjusted, with the aid of neutral filters, to different sensitivities that differed from each other by approximately two orders of magnitude and even more; it allowed to essentially increase a dynamic range of intensities of the signals to be recorded when recording the same process. The both cameras were of the same structure, had over-all dimensions 1700 x 514 x 670 mm3, weight ~200 kg and power consumption 500 W.

PIM-3 ICTs with high photocathode sensitivity extended to the infrared region (what was a unique achievement of those years) were manufactured for these cameras according to special technology in the Laboratory of Dr. M.M. Butslov.

The Voronezh plant “Etalon” has begun production of FER-5 photochronograph [5] (5 samples were manufactured) somewhat later than that of LVE-1 and FER-3; FER-5 based on UMI-93 ICT and ELU-OK type photomultiplier tube was designed according to an order of the State Optical Institute (GOI) named after S.I. Vavilov.

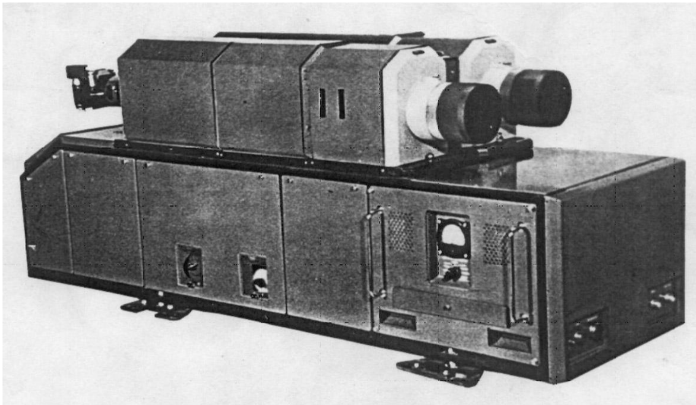


Fig. 5. LVE-1 electronic time magnifier.

This high voltage and high current photomultiplier tube which used as a sweep generator allowed to reduce "a dead time" of FER-5 triggering down to 20 ns (it was 100 ns for FER-2).

The Research Institute of Pulsed Technique of the Ministry of Middle Machine Engineering (now the Ministry of Atomic Industry) has begun development of cameras only since 1976 but exclusively for own needs of this Ministry (a leading specialist on cameras Ye.K. Slavnov).

Labor consuming character of manufacture and cost of national cameras of that time were rather high; therefore, their production was very limited. But at that time labor consuming character was not given special attention. The main thing was to achieve basic technical parameters in order to obtain required information on the recorded process. As a result, at the end of seventies of the twentieth century such a situation took place in the Soviet Union when a rapidly developing technique of pulsed picosecond lasers had no instrumentation produced by industry on a mass scale and capable to measure spatial-temporal parameters of picosecond optical pulses with 1-2 ps temporal resolution. There was needed a simple and compact camera such as an oscillograph but also technological one and not labor consuming in manufacture. It was impossible to acquire similar foreign instrumentation because of an embargo that was placed by the West KOKOM Commission that controlled deliveries of high-technological equipment from highly developed capitalist countries to socialist countries and countries of the third world.

After an unexpected untimely death of M.M. Butslov, B.M. Stepanov invited for work in VNIIOFI well-known scientists in the field of image converter and cathode-ray devices such as Drs. A.Ye. Melamid and V.A. Miller that made a great contribution to creation of new ICTs.

In the second half of the seventies of the twentieth century there appeared vacuum-tight fiber optic plates and then microchannel plates what resulted in decreasing ICT dimensions because the necessity of magnetic focusing of electron beams in ICT amplifying stages had passed away. Also due to a progress in miniaturization of a radio electronic element base the Hamamatsu Company (Japan) designed in 1978 a rather portable (for that time) photochronographic camera, namely TD C979 [6] with 10 ps limiting temporal resolution.

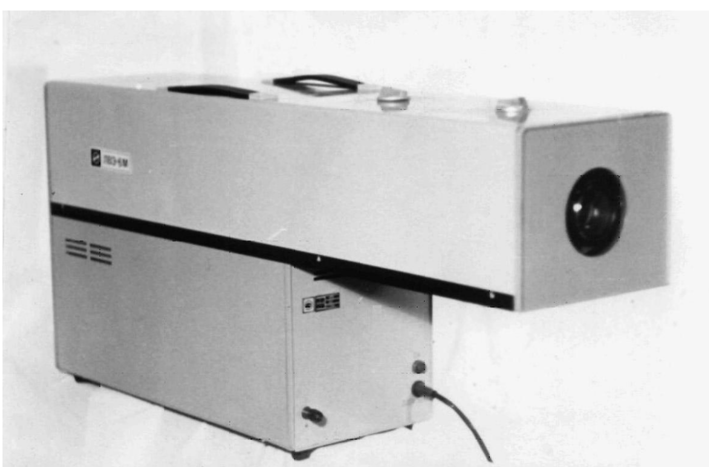


Fig. 6. Agat-SF1 camera.

It is just then, in 1978, in a critical for the Soviet Union situation that might lead to retardation in development of laser technique, an Agat-SF1 camera [7] was urgently (during half a year) designed in VNIIOFI on an initiative of its director B.M. Stepanov; its limiting temporal resolution was 2 ps what is by a factor of 5 better in comparison with Japan TD C979 camera. Agat-SFl camera dimensions (Fig. 6) were 903 x 202 x 388 mm; its weight was 30 kg; its power consumption was 100 W. It was really a hitch in image converter instrument engineering.

Since 1979 the experimental plant PROTON (in Smolensk) which was belonged to VNIIOFI has begun serial production of Agats (30 or more cameras a year). Then there was added production of FER-7 photochronographs [8], soft X-ray Agat-SF5 cameras [9] and two more new modifications of Agat cameras, namely Agat-SF3 and Agat-SF3M. During a period from 1979 to 1989 inclusive ~ 420 high-speed cameras of different types were produced in Smolensk. Agat-SF1 and Agat-SF3 were exhibited at numerous international exhibitions in the USSR and abroad: in England, German Democratic Republic, Rumania, Bulgaria, Yugoslavia and Sweden. Two Agat camera models, namely Agat-SF1 and Agat-SF3 were awarded with gold medals at the International Fair in Leipzig (GDR) in 1980 and 1983, respectively. Several cameras were delivered to foreign countries, namely GDR and Czechoslovakia.

Numerous experimental samples of high-speed and ultrahigh-speed cameras were also designed as scientific and technical work done in anticipation. Photos taken with the aid of Agat-04M camera were demonstrated at the 14th International Congress on High-Speed Photography and Photonics (Moscow, 1980); a fluctuational subpicosecond time structure of powerful neodymium laser radiation with single spikes duration from 0.2 to 0.3 ps and with 40% to 60 % contrast [10] was recorded on these photos for the first time in the world. Fifteen years have passed and only then the Hamamatsu Company (Japan) has succeeded in creating FESKA-200 camera with the same temporal resolution when a sweep coefficient was equal to 20 ps/cm. In the next model of VNIIOFI camera, namely Selena-2 a record sweep coefficient equal to 5 ps/cm was reached; it has not been surpassed by anybody in the world up to now. In this case a graphic speed of electron beam sweep on the ICT screen was equal to about seven velocities of light what provided 0.1 ps technical temporal resolution of the camera. Only the absence at that time of available femtosecond lasers with good repeatability of temporal parameters of pulses and also with energetics sufficient for stable work of RGL-2 laser spark gap used as a switch in a sweep pulse generator did not allow to measure a real limiting temporal resolution of this camera.

More detailed information on these serial cameras as well as on numerous other experimental cameras is given in a collection of scientific transactions [11] in a paper of V.B. Lebedev and G.V. Kolesov entitled “High-speed image converter technique of VNIIOFI. The results of developments obtained for a period of 10 years (1978-1988)”.

A whole family of new time analyzing ICTs and image intensifiers was created for these cameras. For Agat cameras of different modifications: time analyzing PV-001A, PV-003R, PV-006, PV-006A, and PV-006M designed by G.I. Brukhnevich, a talented disciple of M.M. Butslov, and by V.A. Miller and his disciples, namely B.D. Smolkin and A.A. Sobolev; PMU-2V microchannel image intensifier designed by V.N. Sivenkova under leadership of V.A. Miller. For FER-7, FER-11, FER-14, and FER-27: PIM-103 and PIM-104 gamma modification [12]; for X-ray cameras: open PIM-106 ICT; for LVE-6 camera: unique ultrahigh-speed multiframe PIM-107 ICT (they were all designed by G.G. Feldman).

Fig. 7. V.A. Miller (1919-1985), a well-known specialist in the field of cathode-ray devices; in VNIIOFI he was designing image converter tubes (photo of 1973).

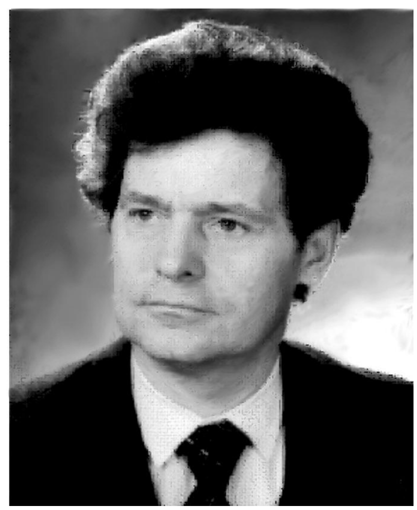


Fig. 8. G.I. Brukhnevich, a designer of image converter tubes (photo of 1970).

This is a series of one-camera modulus image intensifiers of PM type with different coefficients of image converter intensification that was started by A.O. Vardanyan, a VNIIOFI post-graduate (who is now Dr. and director of the Yerevan Research Institute of Optical and Physical Measurements in Armenia) and then was successfully continued by A.F. Myasnikov. This is both biplanar and triplanar ICTs with a 40-mm working field diameter designed by

Yu. M. Mikhal'kov and various open ICTs with MCP designed by B.N. Bragin for recording ultraviolet and X-ray radiation. This is PDM1-40 supersilicon with a 40-mm working field diameter designed for image recording systems by A.F. Myasnikov and V.P. Simonov and combined "sandwich-photocathodes" designed by G.I. Brukhnevich for the first time in the world (an antimonide-caesium cathode as an emitter of second electrons above a gold X-ray photocathode what allowed to use the same ICT in both visible and soft X-ray radiation ranges of the spectrum). By the way, it is just G.I. Brukhnevich who also for the first time in the world has designed broadband ($\geq$ 3 GHz) deflection systems with coaxial inputs for time analyzing ICTs what allowed to sharply increase a sweep speed up to the values exceeding a velocity of light in order to achieve femtosecond temporal resolution of ICTs. These systems are turned out to be universal; they were widely used and are being used now in all high speed ICTs.

Besides high-speed cameras, VNIIOFI has produced a large number of various unique experimental samples of low-noise ICTs most of which were designed by S.V. Lipatov under leadership of M.M. Butslov and then under leadership of B.M. Stepanov and V.A. Miller. Diakon-2 digital ICT with an amplifying sixty-element silicon line designed by V.N. Sivenkova under leadership of V.A. Miller also refers to a class of low-noise ICTs. V.I. Bass (on the basis of ICTs designed by S.V. Lipatov) and T.S. Vyugina (on the basis of Diakon-2 ICT) have designed corresponding ultrahigh-sensitive cameras for astrophysical investigations; practically all big observatories of the USSR were equipped with the cameras of similar type created in VNIIOFI. After a catastrophe at the Chernobyl atomic power plant V.I. Bass as a member of the group on elimination of catastrophe consequences has used one of these cameras (intended for cinematography of weak forms of northern lights) in experiments on remote control of composition of a vapor-gaseous mixture released from a damaged reactor.

It is impossible to imagine creation of ICTs and cameras listed above (this list is far from total one) without titanic work of a large association of high-class designers, opticians and technologists, chemists, skilled craftsmen – mechanicians, radio fitters and adjusters, glass-blowers and photocathode makers as well as theorists shining in VNIIOFI in this walk of life at a different time. At that time this association numbered more than one thousand people.

At that time VNIIOFI was the biggest producer of image converter cameras in the world. In so doing an extremely important national-economic task has been resolved; as a result, fundamental and applied sciences in the USSR were fully provided with the first-class diagnostic instrumentation that corresponded to a level of the best world achievements in this field of science and technology.

Fig. 9. A.F. Kotyuk, a founder of scientific metrology in VNIIOFI (photo of 1971).

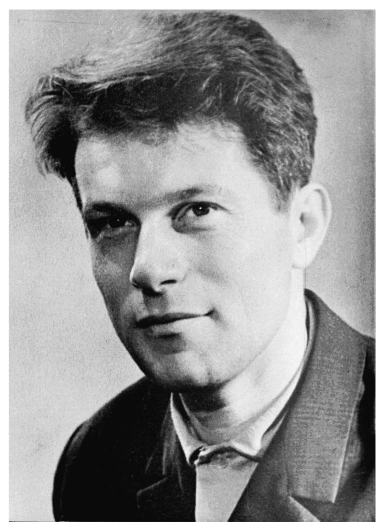


Fig. 10. G.V. Kolesov (1932-1993), «a Tsar and God» in the field of image converter cameras metrology (photo of 1970).

Formation of scientific metrology of high speed processes in VNIIOFI was started in 1971 when a professional metrologist A.F. Kotyuk began to work at the Institute (now he is a professor, Honored Scientist, academician of the Russian Metrological Academy).

In particular, under his methodical leadership there was established metrological assurance of high-speed image converter cameras in the form of the highest accuracy setup (G.V. Kolesov was its designer and scientific keeper) that allowed to guarantee normalized uncertainties of measuring spatial and time intervals as well as optical pulse durations in a pico-nanosecond time range for all types of Agat-series cameras including soft X-ray cameras. It should be said that this was done for the first time in the USSR and in the world since before that time none of producers indicated uncertainties of parameters to be measured in camera documentation.

The work of Gennady V. Kolesov, a very modest, responsive and very charming man, should be particularly noted since besides that he was a designer of many cameras himself, all cameras designed in VNIIOFI in his life-time passed through his hands when metrological parameters of cameras were investigated and their metrological certification was carried out. And now his methodical developments on metrology of image converter cameras are a reference book for continuers of his life work.

A great number of produced cameras demanded creation of a special service in VNIIOFI; for many years it was headed by B.Z. Gorbenko. This service provided putting the cameras into operation, users' training, guaranteed and post-guaranteed cameras' repair as well as, to great satisfaction of the users, often took part (together with the users) in investigations of the processes that were interested for the users at the initial stage of cameras usage.

As a result of negative events that took place in the course of reconstruction of our country economy at the beginning of nineties of the last century, potential consumers had lost financial possibilities for purchase of cameras and ICTs. Production of cameras at the Smolensk plant was fully stopped, and the plant went out from VNIIOFI. Manufacture of ICTs and design of experimental samples of new types of cameras and ICTs always performed in VNIIOFI practically had stopped too. A chain of technological processes necessary for ICTs manufacture (that always should be made at one place according to requirements of vacuum hygiene) has been broken. The association of VNIIOFI collaborators working in the field of image converter instrument engineering and numbering about one thousand people began to reduce sharply. A situation inexorably developed in direction of a full breakdown of this field of science and technology in VNIIOFI. It was clear that this large association couldn't be kept.

On an initiative of M.Ya. Shchelev, a Head of a Division of the Institute of General Physics of the USSR Academy of Sciences (IOFAN), and owing to support of this Institute director academician A.M. Prokhorov, a considerable part of VNIIOFI collaborators together with equipment was transferred to IOFAN.

The way out of this catastrophic situation in VNIIOFI was foundation in 1991 in VNIIOFI a daughter Company (BIFO Company Limited; VNIIOFI is a founder) on design and production of ICTs and cameras. Since then image converter instrumentation has been created by joint efforts of VNIIOFI and BIFO Company.

In Russia there are now 3 Research Centers which develop an image converter method of high-speed photography and, to a certain extent, compete with each other. They are: VNIIOFI together with BIFO Company, the Institute of General Physics of the Russian Academy of the Sciences and the Research Institute of Pulsed Technique of the Ministry of Atomic Industry.

Arising market relations have forced, first of all, to revise a conception of creating new image converter instrumentation. The following principle became a base of the new conception: minimum labor consuming character and cost price of design and production of instrumentation with maximal high technical and operational characteristics providing high competitivity of this instrumentation on the world market. Orientation towards the world market (a foreign market is implied) was related with insolvency of national consumers of ICTs and cameras.

The following aspects were a further detailing of this conception:

- reasonable miniaturization of instrumentation since if instrumentation over-all dimensions and weight are above a certain value, then it begins to tell on labor consuming character and, therefore, on cost price of manufacture;
- analysis of conjuncture of the needs of image converter instrumentation market with the primary aim of creating such base camera models that, for sure, will be much in demand; in so doing to lay such ideology into their structural and circuit engineering architecture that would allow flexibly to finish them off, to adapt them to scientific requirements of consumers as well as to modernize them with improvement of their element base;
- assurance of high instrumentation reliability.

One of practical realization of this conception was creation (in 1998) a base model of a portable, light and economic K008 camera [13] (Fig. 11) which was operated in both a single-frame mode (frame duration is from 10 ns to 600 µs) and a streak mode (duration is from 2 ns to 600 µs) and which provided 20 ps limiting temporal resolution.

PV-201 ICT designed by Dr. G.G. Feldman specially for K008 camera is shown in Fig. 12.

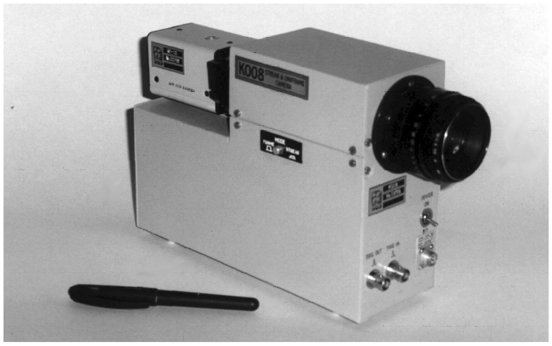


Fig. 11. K008 image converter camera.

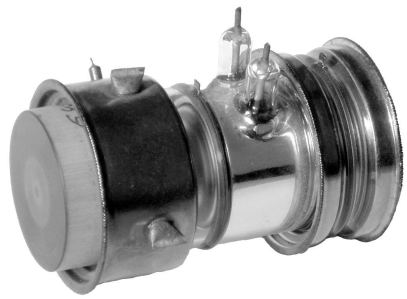


Fig. 12. Diminutive PV-201 ICT is a «heart» of K008 camera.

And up to now this camera is the very diminutive camera in the world among the cameras of such category. Its over-all dimensions are 340 x 90 x 190 mm3; its weight is 3.5 kg; its power consumption is only 8.5 W. When comparing only several characteristics of FER-2 and K008 one can see a progress that have taken place in image converter instrument engineering for these years. If in 1966 FER-2 camera that weighted 250 kg and consumed 1 kW power was a world record-holder with 20 ps temporal resolution, then in 1998 K008 camera that had the same resolution (but already far from record one) weighted 80 times lesser and its power consumption was 120 time lesser.

A latest K008 camera model capable to operate with both a personal computer and a notebook is shown in Fig. 13.

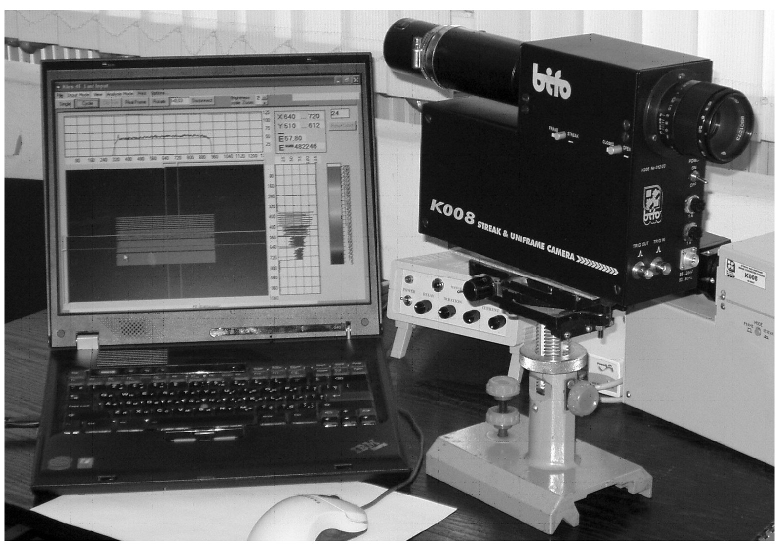


Fig. 13. A latest K008 camera model mounted on an optical table.

K008 camera has initiated creation of a new generation of cameras. Now a camera with already No.16 is being designed, i.e. K016 camera.

In all new cameras the image from the ICT output is recorded not on a film with the aid of photoattachments as it has been before in the end of the eightieths of the twentieth century but is recorded with the aid of professional digital CCD television cameras with image input into a computer and its subsequent processing according to the programs that allow to investigators to obtain necessary information quickly and in the most convenient form.

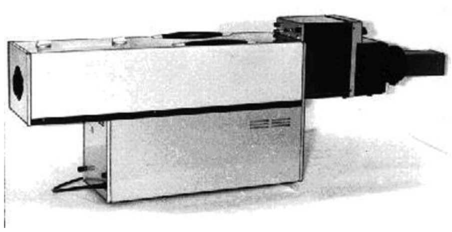
These programs also allow to level geometric and photometric image distortions in a path of image converter camera containing ICT and television camera. The distortions are caused by: a through geometric distortion appearing in glass and electronic optics; through nonuniformity of a conversion coefficient and nonlinearity of a through light-signal characteristic of the path; as well as nonuniformity of sweep coefficients in ICT. In so doing each mode of camera operation (single-frame, multiframe or streak), each sweep range, each level of image intensification , each resolved image element (pixel) in computer memory were given correcting coordinates for correction of geometric distortions and correcting coefficients of image brightness for correction of photometric distortions. This results in multifold decrease of measurement uncertainties of parameters of recorded processes and in increase of reliability of information obtained with the aid of the cameras.

2. CAMERAS CREATED DURING LAST 15 YEARS

As it was mentioned above detailed information on serial and numerous experimental cameras created in period from 1978 to 1988 years is given in a collection of scientific transactions in a paper of V.B. Lebedev and G.V. Kolesov entitled “High-speed image converter technique of VNIIOFI. The results of developments obtained for a period of 10 years (1978-1988)” [11].

Further a short review of developments carried out since 1991 (when ICTs and cameras began created by joint efforts of VNIIOFI and BIFO Company) up to the present time is given below.

2.1. K001 universal camera

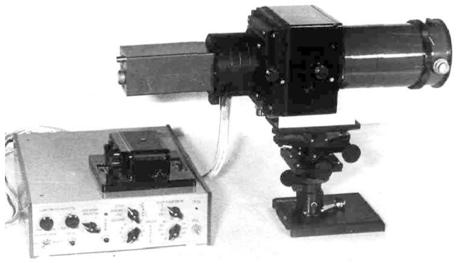


A universal K001 camera [14] (S-20 photocathode of time analyzing ICT, additional external MCP image intensifier) was designed in 1991in body of most widely produced (during a period from 1983 to 1991) Agat-SF3 streak camera (fig. 6) mentioned above in item 1. It has a three-frame mode (frame rate is $3x10^4$ - 4.4×10^9 frame/s, frame duration is 30 μs-150 ps correspondingly, 8 mm x 5 mm frame size on photocathode) and a streak mode of operation (0.4 ns – 120 μs full sweep time on 4 cm of image intensifier screen, 1 ps limiting temporal resolution). Option with open soft X-ray ICT is available. Since 1992 the camera has been used in France (in the Research Center of the Ecol Polytechnic Military University) for recording the processes of interaction of powerful ion beams and relativistic electron beams with different targets. Since 1994 it works in Californian University in Berkeley (USA) on circular electron accelerator “Advance Light Source”. In 1997-1999 it was used in the Soreq Nuclear Center in Israel. And since 1993 it has been used in the Institute of Electrical Physics of the Ural Division of the Russian Academy of Sciences (Yekaterinburg) for investigations of cathode processes in a high-current vacuum discharge [15,16].

2.2. K002 universal hard X-ray camera

A universal K002 camera [17] (MCP as photocathode of time analyzing ICT, additional external MCP image intensifier) was designed in 1991 in body of the Agat-SF3 streak camera for recording images in hard X-ray (0.1-1 MeV). It has a multi framing mode (4, 6, or 8 frames in one line, frame duration 5-100 ns) and a streak mode of operation (1 – 100 ns full sweep time on 4 cm of image intensifier screen, 200 ps limiting temporal resolution).

2.3. K003 single frame camera



This camera (S-20 photocathode and MCP inside of gating ICT) was designed in 1993 and intended for record simultaneously up to 10 spectrums (200-700 nm, 1-109 number of frames, 0.3, 1 and 3 ms frame duration, 250 Hz maximum frame rate in series, 9 mm x 9 mm frame size on photocathode) from different zones of plasma on TOKAMAK installations [18]. It was used in Russia on TOKAMAK-TCP in Troitsky Institute of Innovation and Thermonuclear Researches and also has been tested successfully on TOKAMAK DIII-D in San- Diego (USA) by American specialists of the General Atomics Company jointly with Russian specialists.

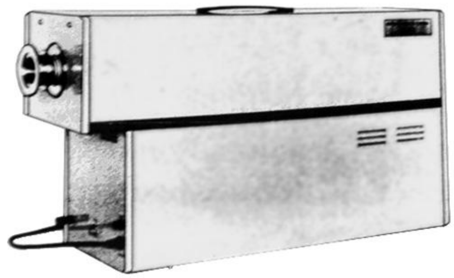
2.4. K004 and K004M universal cameras

The K004 and K004M universal cameras with S-20 photocathode designed in 2001 represent two models that are operated in a framing mode with the number of frames: 1 (frame duration is from 0.5 μs to 12 ms) and 2, 4, 6 or 9 (duration of any frame can be set in the range from 0.1 to 10 μs with a 0.1 μs step; duration of any interframe pause can be set in the range from 0.5 to 100 μs with a 0.1 μs step) as well as in a streak mode with a full sweep time from 0.3 μs to 10 ms on 4 cm of screen. The K004 camera is equipped with a time analyzing ICT containing one MCP. Since 2002 it has been used at the Institute of Electrophysical Problems of the Russian Academy of Sciences on a ballistic route for recording flight of the bodies thrown by powerful electric discharge plasma with a speed of up to the first space speed. The K004M camera ICT has two MCP. In this case a high image intensification coefficient (up to 10^6) allows to record extremely low-luminous initial discharge stages. Owing to a possibility of decreasing image intensification quickly (with delay ≤ 70 ns and gain fall time ≤ 40 ns) by a signal from a special photosensor that controls a luminous flux from the discharge, the camera can record both low-luminous and extremely bright discharge stages during the same sweep. In 2002 the K004M camera was tested on an open high-voltage (6 MV) stand at the All-Russian Electro technical Institute (Istra that is situated not far from Moscow) when recording electrical discharges in an air gap of up to a 6 m length [19]. Since 2003 this camera has been used for recording natural and trigger (artificially triggered) lightning [20, 21] at the International Center for Lightning Research & Testing (ICLRT) in Camp Blanding that belongs to the University of Florida.

2.5. K005M streak camera

The K005M camera (S-1 or S-20 photocathode of time analyzing ICT and additional external MCP image intensifier, 0.6 – 200 ns full sweep time on 4 cm of image intensifier screen, 2 ps limiting temporal resolution) is a modernized analogue of the most widely produced (during a period from 1983 to 1991) Agat-SF3 streak camera (fig. 6) mentioned above in item 1. Vacuum super-high frequency lamps previously used in fast response control electronics were replaced with semiconductor elements. One of its samples is used in the Institute of Laser Physics of the Russian Federal Nuclear Center.

2.6. K006 soft X-ray streak camera



In 1996 in the University of California in Berkeley (USA) the K006 camera (CsJ changeable slit 0.1 mm x 6 mm photocathode of time analyzing ICT, additional external MCP image intensifier, 0.4 – 200 ns full sweep time on 4 cm of image intensifier screen, 0.8 ps calculated limiting temporal resolution) based on body of the Agat-SF3 streak camera was put into operation. It was intended for recording soft X-ray radiation with quantum energy in the range of 0.1to 20 keV. The limiting temporal resolution of the camera was equal to 0.5 ps when it was tested on the femtosecond ultraviolet laser [22].

2.7. K007 streak camera with large photocathode format

This camera (S-20 photocathode of time analyzing ICT and additional external MCP image intensifier, 0.8 – 200 ns full sweep time on 4 cm of image intensifier screen, 40 ps limiting temporal resolution) was designed in body of the Agat-SF3 streak camera in 1998 for the Russian Physical-Technical Institute named after A.F. Ioffe) on the base of the PV-400 time analyzing ICT [23] with a large (40 mm x 4 mm) photocathode. ICT has a factor of image magnification (compression) equal to 0.5. The K007 camera was intended for recording super weak spectrums of TOKAMAK plasma with application of a LIDAR method.

2.8. K008 miniature streak and single frame camera

Since 1999 there have been produced more than 30, may be, the very miniature K008 cameras (in their category) in the world (S-20 photocathode, MCP inside of time analyzing ICT, 10 ns to 660 µs frame duration, not less than 12 mm x 12 mm typical frame size on photocathode, 2 ns - 600 µs full sweep time on 2 cm of ICT screen and 20 ps limiting temporal resolution) [13]. It has found a wide application in Russia and abroad [19, 21, 24-26]. It was used for recording triggered lightning in the USA, 4 cameras were delivered to Israel, 1 to Armenia [24], 1 to Slovakia [26] and 1 is prepared now for sending to India. The RU-05M CCD readout unit (1392x1032 pixel, 12 bit ADC, USB 2.0 output) coupled with ICT screen by lens is used in K008 camera now.

2.9. K009 femtosecond streak camera

The K009 camera (S-1 or S-20 photocathode of time analyzing ICT, two additional external image intensifiers, the first of them without MCP and the second with MCP, 40 ps – 4 ns full sweep time on 4 cm of time analyzing ICT screen, 20 ps jitter, 200 fs limiting temporal resolution) based on body of the Agat-SF3 streak camera was designed in 2003 for the Institute of Laser Physics of the Russian Federal Nuclear Center. The pulses with 150 fs minimum duration were recorded when this camera was tested [27]. The RU-05M CCD readout unit (see item 2.8) is used in K009 camera.

2.10. K010X miniature soft X-ray streak and single frame camera

This camera with CsJ and Au changeable slit (0.1 mm x15 mm) and frame (6 mm x 12 mm) photocathodes (MCP inside of time analyzing ICT, 10 ns to 660 µs frame duration, 2 ns - 600 µs full sweep time on 2 cm of ICT screen, 10 ps limiting temporal resolution, 5 kg weight and 10 VA power consumption) was designed in 2005. It has the same pulse control electronics that used in the K008 camera. It was tested in Russia with the help of an electron beam of soft X-ray installation, in China with the help of UV lasers (λ=248 nm, pulse duration 20 and 0.5 ns) [28] and in Israel with the help of soft X-ray produced by a powerful femtosecond laser focused on a surface of a solid target. Both of the cameras are delivered: one to China and other to Israel. The RU-05M CCD readout unit (see item 2.8) is used in K010X camera.

2.11. K011 miniature nine frame camera

The K011 camera (S-20 photocathode, 8 mm x 7 mm frame size on photocathode, MCP inside of time analyzing ICT, 9 frames with theirs durations from 0.1 to 102.4 µs and the same interframe pauses, each frame and each pause duration may be set independently one from each other with 0.1 µs step, 3.5 kg weight and 8.5 VA power consumption) was designed in 2001 at the same box as that of the K008 camera. Results of 4 pcs. K011 cameras application in Russia for researches of microwave discharges [29], discharges in water [30], discharges from an artificial cloud of charged water aerosol [31] and interaction of the plasma clouds forming as a result of two laser target irradiation [32] are presented in program of this Congress**.** The RU-05M CCD readout unit (see item 2.8) is used in K011 camera.

2.12. K012 miniature hard X-ray nine frame camera

This is a full analogue of the K011 camera but with MCP as photocathode (8.5 mm x 6.5mm frame size on photocathode). It was designed in 2002 for the Institute for Electrophysics and Electric power of the Russian Academy of Sciences and intended for recording images in hard X-ray (0.1-1 MeV). The RU-05M CCD readout unit (see item 2.8) is used in K012 camera.

2.13. K013 miniature soft X-ray streak camera

These 2 cameras with CsJ and Au changeable slit (0.1 mm x15 mm) photocathodes of time analyzing ICT (without MCP inside of time analyzing ICT but with additional external MCP image intensifier, 2 - 200 ns full sweep time on 2 cm of image intensifier screen, 10 ps limiting temporal resolution, 5 or 6.3 kg weight and 15 or 35 VA power consumption correspondingly depending on the type of applying CCD) were designed in 2004. The application of external MCP image intensifier is necessary for providing greater stability of camera through gain during its life time. The first camera (it is presented in figure) with RU-06 readout unit (cooling CCD with fiber optic input, 1160 x 1060 pixel, 18 mm x 16 mm working area and 14 bit ADC) coupled with ICT screen by the taper is used in the Institute of Laser Physics of the Russian Federal Nuclear Center and the second camera with RU-05M CCD readout unit (see item 2.8) is used in the Institute of Applying Physics of the Russian Academy of Sciences. Options with input 12 or 24 VDC supplying mains are available for camera application under conditions of super high electrical interferences.

2.14. Uniframe-05 miniature single-frame camera

Two models of this camera are intended for solving various LIDAR tasks. They were designed in 2003 exactly in the same box as that of the K008 camera. They have the spectral sensitivity range from 210 nm to 850nm, 14.4 mm x 10.8 mm frame size on photocathode, the maximum triggering frequency 300Hz (it has increased to 1 kHz now), and the frame duration that may be varied from 5 to 500 ns. The "UNIFRAME-05-01" model contains one MCP in an image converter's section and provides the spatial resolution on the photocathode being not less than 22 l.p./mm. The "UNIFRAME-05-02" model contains two MCP, provides the spatial resolution being not less than 15 l.p./mm and the maximum sensitivity that allows to work in a mode of photon counting. The "UNIFRAME-05-02" model with RU-05M CCD readout unit (see item 2.8) was used in experiments on active ultraviolet imaging. In so doing the image of reinforced-concrete building illuminated by an UV laser (λ= 355 nm, t_{pulse} = 8 ns, E = 20 μJ) was obtained with confidence at a distance of 1 km when diameter of laser beam on the building wall was 12 m [33].

2.15. Cameras that are being designed now

K014 miniature streak camera

This camera will have a time analyzing ICT with S-1 or S-20 photocathode without MCP inside of time analyzing ICT but with additional external MCP image intensifier, 2 ns - 600 μs full sweep time on 2 cm of image intensifier screen, 10 ps limiting temporal resolution, 5.5 kg weight and 35 VA power consumption. The RU-06 CCD readout unit (see item 2.13) will be used. With S-1 photocathode the camera can be used in a wider infrared region of the spectrum (up to 1200 nm instead of 800-850 nm) than the K008 camera.

K015 multiframing camera

This will be a multichannel multiframing camera consisting of separate single-frame modules (up to 9 pcs.) each of which is similar to the Uniframe-05 single-frame camera but smaller. Modules (each with an input objective) will be fixed on a common base. Option with common objective system will be available. Modules will be triggered by programmable control unit of program shooting. Each module will be based on proximity ICT (ø 18 mm) with one MCP. Option with 2 MCP will be available. The camera will have S-25 photocathode, 210 – 850 nm spectral range of sensitivity, frame durations from 0.5 ns to ~ 1 ms and the same interframe pauses, each frame and each pause duration will be set independently one from another.

K016 miniature picosecond streak camera

This will be a miniature analogue of the K005M streak camera. It will have a time analyzing ICT with S-1 or S-20 photocathode without MCP inside of time analyzing ICT but with additional external MCP image intensifier, 0.2 - 200 ns full sweep time on 2 cm of image intensifier screen and not worse than 2 ps limiting temporal resolution. The RU-06 CCD readout unit (see item 2.13) will be used.

3. CONCLUSIONS

During 40 years image converter instrument engineering in VNIIOFI had both periods of rapid development and periods of stagnation. During the years that were difficult for the Russian economy, foreign organizations were the main customers of ICTs and cameras. Deliveries to the USA, Great Britain, France, Israel, and China have saved this field of science and technology in VNIIOFI from total disappearance. Now it can be said with satisfaction about a renewal of the interest of Russian organizations to the image converter method of investigations. In spite of exceptional difficulties of the last 15 years image converter instrument engineering in VNIIOFI has survived, is being developed and its history is being continued.

REFERENCES

1. M.M. Butslov, Yu.A. Drozhbin et al., "The FER-2 high speed photochronograph with $2x10^{-11}$s temporal resolution", Izmeritelnaya Tekhnika (in Russian), (11), 21-23, 1972.
2. P.P. Barzilovich, A.S. Bruchanov, "Industrial image converter time magnifier of LV-01 – LV-04 type", *Image converter tubes and their application in science and technology. Instruments of experimental physics*, VNIIOFI scientific transactions, series B, (1), 115, Moscow, 1972.
3. E.N. Vinogradov, Yu.A. Drozhbin et al., "The LVE-1 dual channel electronic magnifier", All-Union Scientific and Technical Conference: *Current state and prospectives of high-speed photography and cinematography and metrology of high-speed processes,* Reports abstracts, 36, VNIIOFI, Moscow, 1972.
4. V.I. Averin, E.N. Vinogradov et al., "The FER-3 dual-channel photochronograph with ICT", the same as in [3], 35.
5. L.I. Andreeva, M.M. Butslov et al., "The photochronograph", Author's Certificate of the USSR, No. 299819, Bulletin of Inventions, (12), 1971.
6. A Leaflet of the Hamamatsu TV company, LTD., "Hamamatsu Temporal disperser C979", Japan, 1978.
7. V.I. Averin, B.Z. Gorbenko et al., "A new picosecond photochronographic camera", *Proceedings of the14th International Congress on High-Speed Photography and Photonics,* 135, Moscow, 1980.
8. V.I. Averin, R.G. Belgovskaya et al., "The FER-7 portable photochronograph with ICT", the same as in [7], 203.
9. V.I. Averin et al., "The Agat-SF5 X-ray photochronographic camera", Pribori I Technika Eksperimenta (in Russian), (3), 248, 1986.
10. O.M. Brekhov, V.B. Lebedev et al., "The Agat-04M experimental image converter camera with a $5.2x10^{10}$ cm/s sweep speed", the same as in [7], 253.
11. G.V. Kolesov, V.B. Lebedev, "High-speed image converter technique of VNIIOFI. The results of developments for a period of 10 years (1978 – 1988)." *Methods and means of measuring parameters of high-speed processes,* (Collection of scientific transactions), 5-36, VNIIFTRI, Moscow, 1989.
12. G.G. Feldman, "New image converter tubes for scientific investigations", the same as in [11], 61-70.
13. V.B. Lebedev, G.G. Feldman, "Super small single streak and single-frame image converter camera", *Proceedings of the 23th International Congress on High Speed Photography and Photonics, Moscow, 20-25 September, 1998,* SPIE, 3516, 85-91, 1999.
14. V.B. Lebedev, G.G. Feldman et al, "Tests and further development of universal image-converter picosecond camera", *Proceedings of the 20th International Congress on High Speed Photography and Photonics, Victoria, 21-25 September, 1992,* SPIE, 1801, 528-534, 1993.
15. M.B. Bochkarev, V.B. Lebedev et al., "Development of high voltage vacuum spark in centimeter gap", will be presented at this Congress, Paper No. 080.
16. M.B. Bochkarev, V.B. Lebedev, G.G. Feldman, "Observation of vacuum arc cathode spot with high speed framing camera", will be presented at this Congress, Paper No. 081.
17. V.B. Lebedev, G.G. Feldman, V.M. Zhilkina, "A universal camera on a time-analyzing ICT sensitive to UV and hard X-rays", *Proceedings of the 21th International Congress on High Speed Photography and Photonics, Taejon, 29August-2 September, 1994,* SPIE, 2513, 50-53, 1995.
18. V.B. Lebedev, G.G. Feldman, Maranichenko N.I., "Camera based on low noise ICT without sweep for multiframe recording of Tokamak plasma spectra", the same as in [17], 50-53, 1995.
19. V.B. Lebedev, G.G. Feldman et al., "Features of Application of Image Converter Cameras for Research on Lightning and Discharges in Long Air Gaps", *Proceedings of the 26th International Congress on High Speed Photography and Photonics, Alexandria, 19-24 September, 2004,* SPIE, 5580, 887-897, 2005.
20. V.B. Lebedev, G.G. Feldman et al., "Test of K004M Russian image converter camera when recording natural lightning in Florida", will be presented at this Congress, Paper No.036.

21. V.B. Lebedev, G.G. Feldman et al., "Test of K004M and K008 Russian image converter cameras when recording triggered lightning in Florida", will be presented at this Congress, Paper No. 035.
22. V.B. Lebedev, G.G. Feldman et al., "Development and Testing of Subpicosecond Streak Camera for Soft X-ray Measurements", the same as in [13], 74-84, 1999.
23. G.G Feldman., V. M Zhilkina., G.T Razdobarin., "PV-400 picosecond streak tube with large photocathode", the same as in [13], 487-488, 1999.
24. V.B. Lebedev, G.G. Feldman et al., "Application of K008 Camera within LIDAR for Laser Sounding of Water Width from Air", the same as in [19], 282-292, 2005.
25. V.B. Lebedev, G.G. Feldman et al., "Application of K008 Camera within Measuring Complex of Laser Diagnostics of Shock and Detonation Waves", the same as in [19], 881-886, 2005.
26. V.B. Lebedev, G.G. Feldman et al., "Application of K008 Camera in non-stationary Spectroscopy", the same as in [19], 898-904, 2005.
27. V.B. Lebedev, G.G. Feldman, A.N. Mashkovtsev, "Development and Test of Femtosecond Image Converter Camera", Metrologiya (in Russian), (Monthly supplement to scientific and technical journal: Izmeritelnaya Tekhnika), (12), 10-38, 2005.
28. V.B. Lebedev, G.G. Feldman et al., "Design and first tests of miniature K010X soft X-ray streak and single-frame camera", will be presented at this Congress as post dead line paper**.**
29. I. I. Esakov, L. P. Grachev et al., "Research of the streamer microwave discharge in a quasi-optical beam of electromagnetic wave with application of the K011 image converter camera", will be presented at this Congress, Paper No. 032.
30. V. A. Kolikov, M. E. Pinchuk et al., "High-speed diagnostics of pulsewise-periodic electric discharge in water", will be presented at this Congress, Paper No. 041.
31. A.G. Temnikov, L.L. Chernensky et al., "Application of image converter camera for investigation of discharges from an artificial cloud of charged water aerosol", will be presented at this Congress, Paper No. 033.
32. V.I. Annenkov, A.V. Bessarab et al., "Investigation of Interaction of the Plasma Clouds Forming as a Result of Two Laser Target Irradiation", will be presented at this Congress, Paper No. 038.
33. A.V. Berlizov, S.D. Pitik, G.G. Feldman, "Application of the image converter camera «Uniframe-05-02» for ultraviolet imaging", will be published in *Proceedings of the 7th International conference «Applied Optics - 2006»* which will take place in Saint-Petersburg (Russia) from 16 to 20th October, 2006.