V. V. Korobkin, B. M. Stepanov, S. D. Fanchenko, and **M. Ya. Shchelev,** *Pico-femtosecond Electron-optical Photography*. Zavoiskii and Fanchenko[1,2] established the basic principles of electron-optical chronography with a time resolution of 10 psec (10^{-11} sec) – 10 fsec (10^{-14} sec). But-slov[3] has used this principle to develop the PIM-UMI series of multichamber time-analyzing electron-optical converters in which the image is scanned by an electric field in the time-analyzing chamber and which introduce such a high degree of brightness intensification in the subsequent chambers that it turned out to be possible to record photographically each electron emitted by the entrance photocathode. These electron-optical converters have been used to photograph for the first time the development of 200–300 psec miniature sparks in the case of 10 psec combustion fronts.[4] Since the appearance of lasers, Korobkin and Shchelev[5] have successfully introduced into practice high-speed electron-optical chronography in routine studies in quantum electronics and nonlinear optics. This has resulted in the solution of many physical problems which have not been amenable to existing methods. For example, this method has been used to investigate the motion of focal points during the self-focusing of powerful laser radiation in liquids,[6] the propagation of the ionization front through successive breakdowns in the laser spark,[7] and the dynamics of lasers operating under self-mode-locking conditions.[8] These experiments have led to the development of a method for the determination of the time resolution of the electron-optical converter, based on the detection of beats between two laser modes.[9]

The mass-produced FER-2 camera with a time resolution of 10 psec[10] was developed under the direction of B. M. Stepanov in 1968. Stepanov subsequently directed work on the development of electron-optical converters with time resolutions of 100–1000 fsec. A. M. Prokhorov provided considerable help in this development work.

The application of the new generation of time-analyzing electron-optical converters with time resolutions of 500–700 fsec, namely, the "picochron"[11] (resonant microwave scanning of the image and three-electrode lens with enhanced electric field on the photocathode) and the UMI-93M[12] (broad-band deflecting system and accelerating grid next to the photocathode) has been very fruitful in the study of the picosecond structure of neodymium laser radiation under self-mode-locking conditions.[13–15] Calibration of the time resolution of the UMI-93M by mode beats gave a figure of 700 fsec.[16]

A new powerful stimulus to the development of electron-optical methods of detection has been provided by experiments on laser-controlled thermonuclear fusion in the picosecond time range. An x-ray electron-optical converter (the UMI-93SR) has been developed for these experiments[17] and has been used to resolve two successive x-ray pulses from high-temperature laser plasma, separated by a time interval of 66 psec.

In addition to further improvements in the electron-optical methods and equipment, the first steps have been made toward the digital processing of the images recorded by electron-optical converters with a view to improving the quality of the images and automating the measurement process.[18]

Pico-femtosecond optical photography, the principles of which were developed in the USSR and were embodied in a number of Soviet devices, has become widely used in other countries (England, USA, Canada, and France) and is assuming ever increasing importance in physics research. It offers a unique tool for investigations in quantum electronics, plasma physics, and biophysics, and has already led to the design of a number of interesting physics experiments. The 1–100 psec range is now being confidently explored, and the 100–1000 fsec range is approaching a similar situation. There is every hope that the various problems being encountered will be solved, and the limiting time resolution of the electron-optical converter (of the order of 10 fsec) will eventually be achieved.

[1]E. K. Zavoĭskiĭ and S. D. Fanchenko, Dokl. Akad. Nauk SSSR **108**, 218 (1956) [Sov. Phys. Dokl. **1**, 285 (1957)]; Appl. Opt. **4**, 1155 (1956); Dokl. Akad. Nauk SSSR **226**, 78 (1976).
[2]S. D. Fanchenko, Prib. Tekh. Eksp. **1**, 5 (1961).
[3]M. M. But-slov, Usp. Nauchn. Fotogr. **6**, 76 (1959).
[4]E. K. Zavoĭskiĭ and S. D. Fanchenko, Dokl. Akad. Nauk SSSR **100**, 661 (1955).
[5]V. V. Korobkin and M. Ya. Shchelev, in: Proc. Eighth Intern. Congress on High-Speed Photography, Stockholm, 1968, p. 36.
[6]V. V. Korobkin, A. M. Prokhorov, R. V. Serov, and M. Ya. Shchelev, Pis'ma Zh. Eksp. Teor. Fiz. **11**, 153 (1970) [JETP Lett. **11**, 94 (1970)].
[7]V. V. Korobkin, S. L. Mandel'shtam, P. P. Pashinin, A. V. Prokhindeev, A. M. Prokhorov, N. K. Sukhodrev, and M. Ya. Shchelev, Zh. Eksp. Teor. Fiz. **53**, 116 (1967) [Sov. Phys. JETP **26**, 79 (1968)].
[8]A. A. Malyutin and M. Ya. Shchelev, Pis'ma Zh. Eksp. Teor. Fiz. **9**, 445 (1969) [JETP Lett. **9**, 266 (1969)]; SMPTE **79**, 35 (1970).
[9]V. V. Korobkin, A. A. Malyutin, and M. Ya. Shchelev, J. Photogr. Sci. **17**, 179 (1969); Zh. Tekh. Fiz. **41**, 216 (1971) [Sov. Phys. Tech. Phys. **16**, 165 (1971)].
[10]N. G. Basov, Yu. A. Drozhbin, V. V. Nikitin, A. S. Semenov, B. M. Stepanov, and V. Ya. Yakovlev, quoted in Ref. 5, p. 33.
[11]M. M. But-slov, S. D. Fanchenko, and R. V. Chikin, in: Proc. Tenth Intern. Congress on High-Speed Photography, Paris, 1972, p. 137; Prib. Tekh. Eksp. No. 5, 202 (1973).
[12]G. I. Bryukhnevich, N. S. Vorob'ev, V. V. Korobkin, A. M. Prokhorov, B. M. Stepanov, and M. Ya. Shchelev, in: Proc. Twelfth Intern. Congress on High-Speed Photography, Toronto, 1976, p. 17.
[13]N. G. Basov, M. M. But-slov, P. G. Kryukov, Yu. A. Mat-

veets, E. A. Smirnova, S. D. Fanchenko, S. V. Chekalin, and R. V. Chikin, Zh. Eksp. Teor. Fiz. **65**, 907 (1973) [Sov. Phys. JETP **38**, 449 (1973)].

[14]E. M. Gordeev, P. G. Kryukov, Yu. A. Matveets, B. M. Stepanov, S. D. Fanchenko, S. V. Chekalin, and A. V. Sharkov, Kvantovaya Elektron. (Moscow) **2**, 205 (1975) [Sov. J. Quantum Electron **5**, 129 (1975)].

[15]V. A. Babenko, M. A. Kudinova, V. I. Malyshev, A. M. Prokhorov, A. A. Sychev, A. I. Tolmachev, and M. Ya. Shchelev, Pis'ma Zh. Eksp. Teor. Fiz. **25**, 366 (1977) [JETP Lett. **25**, 341 (1977)].

[16]G. I. Bryukhnevich, N. S. Vorob'ev, V. V. Korobkin, A. M. Prokhorov, B. M. Stepanov, and M. Ya. Shchelev, Pis'ma Zh. Tekh. Fiz. **2**, 1009 (1976) [Sov. Tech. Phys. Lett. **2**, 396 (1976)].

[17]G. I. Bryukhnevich, Yu. S. Kas'yanov, V. V. Korobkin, A. M. Prokhorov, B. M. Stepanov, V. K. Chevokin, and M. Ya. Shchelev, in: Proc. Eleventh Intern. Congress on High-Speed Photography, London, 1974, p. 554.

[18]V. N. Platonov, A. M. Prokhorov, Yu. P. Pyt'ev, A. G. Sveshnikov, and M. Ya. Shchelev, in: Proc. Twelfth Intern. Congress on High-Speed Photography, Toronto, 1976, EC-5.