МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

CONFOCAL SCANNING MICROSCOPE FOR NUCLEAR PHOTOEMULSION

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The application of the confocal scanning microscope to the objects in the nuclear photoemulsion is described. An array of 27 microtomograms of *single* silver grain is shown. The cross sections of the same particle track of diameter 1 μm, detected by means of the confocal scanning microscope with open and annular apertures, are presented. It was shown that the confocal scanning microscope opens indeed new opportunities for the nuclear photoemulsion technique to get previously inaccessible information for physics of the short-lived particles.

Описывается применение конфокального сканирующего микроскопа к объектам, находящимся в ядерной фотоэмульсии. Приведен массив из 27 микротомограмм *одиночного* зерна серебра. Представлены поперечные сечения одного и того же следа частицы диаметром 1 мкм, которые были получены при помощи конфокального сканирующего микроскопа с открытой и кольцевой апертурами. Показано, что конфокальный сканирующий микроскоп открывает в действительности новые возможности метода ядерной фотоэмульсии и пути получения ранее недоступной информации для физики короткоживущих частиц.

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New power accelerators of the particles of energy up to 10^{11} eV allow one to accomplish the investigations of the interactions of the relativistic nuclei with matter by means of the laboratory facilities.

Among many experimental techniques the nuclear photoemulsion provides extremely high spatial resolution. To detect selectively straight-line particle tracks with predominant orientation in space, some new optical microscopes were constructed [1, 2].

Meanwhile, some principal problems remained nonresolved in the nuclear emulsion technique. For example, such a problem arose in the course of observation of the events with extremely many secondary particles, approximately 150. Here we observe a «shadow effect», which obscures completely the vertex of the event, and excludes the information about short-lived particles. Just from this information, we can investigate new hyperfragments with Λ particles inside the nucleus as well as supernuclei with Λ_c^+ and Λ_b^+ hyperons and fragmentation processes in the course of decay of the relativistic nuclei in flight.

The second problem is the electric charge of the secondary nuclei observed in such exotic processes. To increase the precision of this estimation, we must know the structure of the cross section of the particle track besides its width.

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Finally, an interest has arisen anew to the problem of submicronic structure of *single* silver grain of the particle track. The drawback of the conventional optical microscope consists in the fact that we can see only a shadow projection of silver grains. The internal or submicronic structure is absent because of bad spatial resolution.

In this paper, we show that all these problems can be resolved by means of the confocal scanning microscope, which has never been used up to now for this aim.

A confocal scanning transmitting optical microscope, shown in Fig. 1, is provided with two microobjectives, the illuminating and the imaging ones, and with a point-like photodetector. At every instant of time, only one microscopic part of the three-dimensional (3D) object is illuminated and detected. The 3D-image of the 3D-object is stored in the computer memory.
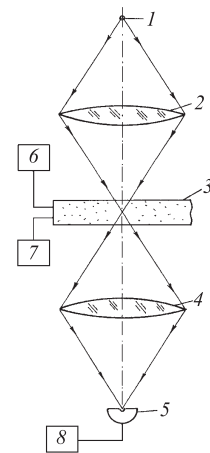
Fig. 1. Principal scheme of the confocal scanning transmitting optical microscope: *1* — point-like light source; *2* — illuminating objective; *3* — object; *4* — imaging objective; *5* — point-like detector; *6* — moving (*x–y*) stage; *7* — moving *z* stage; *8* — computer memory
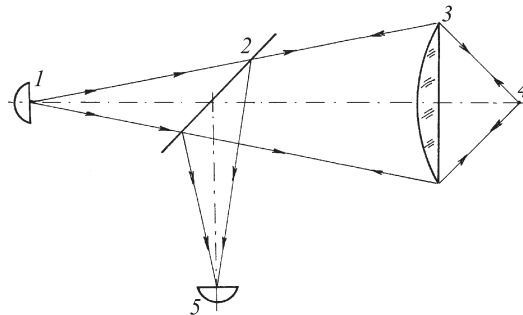
Fig. 2. Principal scheme of the reflected confocal scanning microscope: *1* — point-like light source; *2* — semitransparent mirror; *3* — objective; *4* — object; *5* — point-like detector

The performance of any microscope is described by the point spread function $g(x, y, z)$, so the amplitude of the image $u(x, y, z)$ can be written as 3D-convolution $\otimes$ of the amplitude transmittance $t(x, y, z)$ of the 3D-object with point spread function:

$$u(x, y, z) = g(x, y, z) \otimes t(x, y, z). \tag{1}$$

The amplitude point spread function of the confocal scanning transmitting microscope is equal to the product of two amplitude spread functions, that of the illuminating objective $g_1(x, y, z)$ and that of the imaging objective $g_2(x, y, z)$:

$$g(x, y, z) = g_1(x, y, z) \cdot g_2(x, y, z). \tag{2}$$

Due to this, the lateral and axial spatial resolutions of the confocal scanning transmitting microscope will be about twice as good as in the equivalent optical microscope.

Fig. 3. General view of the SOLAR TII confocal microscope

Fig. 4. View of the particle track in the nuclear photoemulsion layer at fixed z coordinate, detected by means of the confocal scanning microscope SOLAR TII
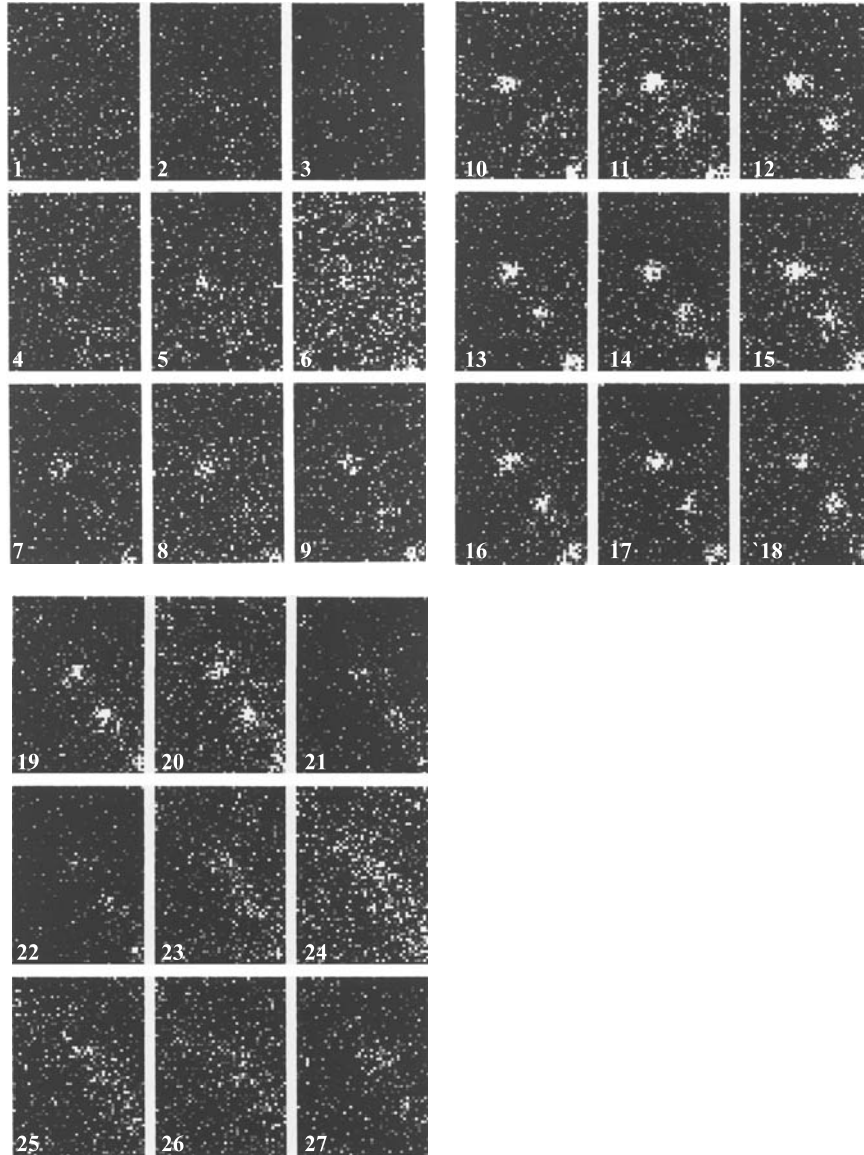
Fig. 5. Array of 27 microtomograms of *single* silver grain in the nuclear photoemulsion layer, detected at depth step $\Delta z = 100$ nm, and at the transfer coordinate steps $\Delta x = \Delta y = 66$ nm. The wave length $\lambda = 0.4416$ μm. Open aperture of the objective

Principal scheme of the reflected confocal scanning microscope which was used in our experiments is shown in Fig. 2. General view of this microscope, SOLAR TII, is presented in Fig. 3. The wave length $\lambda = 0.4416$ μm, the angular aperture of the objective $\Omega = 0.9$, the magnification is $\times 100$, and the field of view is equal to 10×10 μm. We also used the microobjective which was provided with annular aperture.
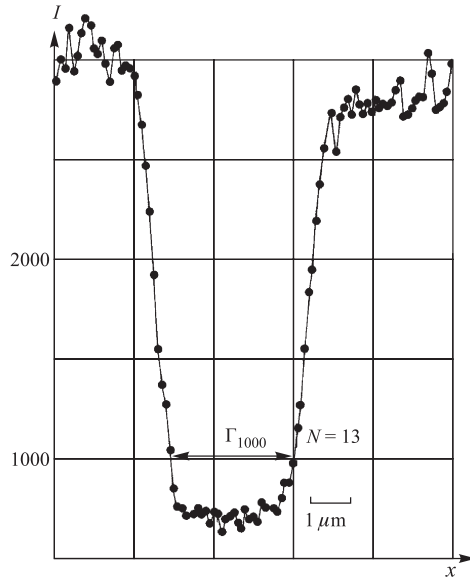
Fig. 6. The transfer intensity plot of the cross section of the particle track with width of the order of 4 μm in the reflectory mode of scanning
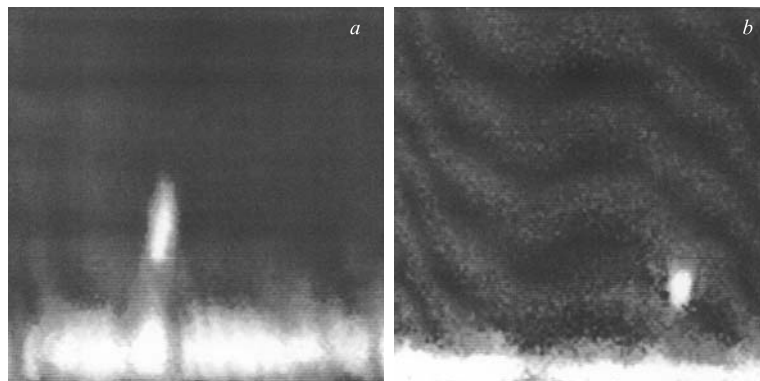

Fig. 7. Two cross sections of the particle track, obtained at different apertures: *a)* open aperture; *b)* annular aperture

The view of the particle track in the nuclear photoemulsion at fixed z coordinate, detected at open aperture, is shown in Fig. 4.

The analysis of the confocal scanning microscope provided with microobjective having annular pupil was done in [3–5]. The transfer resolution and the depth resolution are about twice as high as in the confocal scanning microscope with open pupil. If the angular aperture of the microobjective is equal to 90°, then the optical resolutions Δx_2^{opt} and Δz_2^{opt}
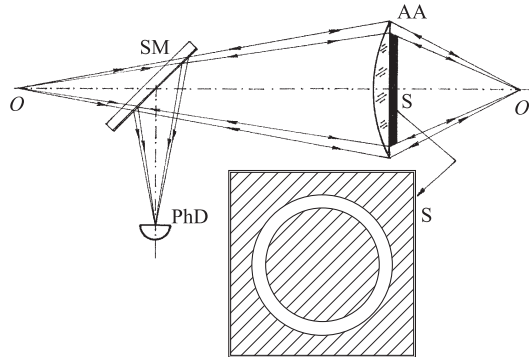
Fig. 8. The optical scheme of the confocal scanning microscope with annular aperture

will be equal to

$$\Delta x_2^{\mathrm{opt}} = \Delta z_2^{\mathrm{opt}} = \frac{\lambda}{4}. \tag{3}$$

So, for $\lambda = 0.4$ μm, $\Delta x_2^{\mathrm{opt}} = \Delta z_2^{\mathrm{opt}} = 0.1$ μm.

By means of the confocal scanning microscope SOLAR TII with open aperture we have detected an array of 27 microtomograms of *single* silver grain in the nuclear photoemulsion (Fig. 5). The depth step Δz was equal to 100 nm, and the transfer scanning steps Δx and Δy were equal to 66 nm.

The transfer intensity plot of the particle track with width of the order of 4 μm is shown in Fig. 6.

The cross sections of the particle track with diameter of the order of 1 μm, which were detected by means of the confocal scanning microscope with open (*a*) and annular (*b*) apertures, are shown in Fig. 7. The optical scheme of the experiment *b* is presented in Fig. 8.

SUMMARY

We have shown experimentally that the confocal scanning microscope opens indeed new opportunities of the nuclear photoemulsion technique to get previously inaccessible information. It provides submicronic spatial resolution. It suppresses the «shadow effect» in the vertex region of the event with a very high number (~ 150) of the secondary particles. It gives supermicronic estimation of the internal structure of *single* silver grain.

REFERENCES

1. *Astakhov A. Yu. et al.* Meso-Optical Fourier Transform Microscope — a New Device for High Energy Physics // Nucl. Instr. Meth. A. 1989. V. 283. P. 13–23.

2. *Astakhov A. Yu. et al.* Dark-Field Scanning Confocal Microscope for Vertical Particle Track in Nuclear Emulsion. JINR Commun. E13-99-342. Dubna, 1999.

3. *Wilson T., Sheppard C.* Theory and Practice of Scanning Optical Microscopy. London: Acad. Press, 1984.

4. *Sheppard C. J. R., Wilson T.* Image Formation in Confocal Optical Systems. SPIE 232, Book II. 1980. P. 197–202.

5. *Gu M., Sheppard C. J.* Three-Dimensional Imaging in Confocal Fluorescent Microscopy with Annular Lenses // J. Mod. Opt. 1991. V. 38. P. 2247–2263.