Confocal Scanning Microscope for Nuclear Photoemulsion

Yu. A. Batusov, Yu. S. Kovaliev, and L. M. Soroko
Joint Institute for Nuclear Research, Dubna
e-mail: yuabat@nusun.jinr.ru
Received on January 19, 2007

Abstract—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 the physics of the short-lived particles.

PACS numbers: 21.10.Tg, 29.30.Kv, 29.40.Rg, 68.37.Xy
DOI: 10.1134/S1547477108040109

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, 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 very 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 $\Lambda$ particles inside the nucleus, as well as supernuclei with $\Lambda_c^+$ and $\Lambda_b^+$ 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.

Finally, an interest has arisen anew to the problem of the submicronic structure of a 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 pointlike photodetector. At every instant of time, only one microscopic part of the three-dimensional (3D) object is illuminated and detected. The

Fig. 1. Principal scheme of the confocal scanning transmitting optical microscope: 1—pointlike light source; 2—illuminating objective; 3—object; 4—imaging objective; 5—pointlike detector; 6—moving (x–y) stage; 7—moving z stage; 8—computer memory.

\footnote{The text was submitted by the authors in English.}
3D-image of the 3D-object is stored in the computer memory.

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 a 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 the product of two amplitude spread functions, that of the illuminating objective \( g_1(x, y, z) \), and that of the imaging objective \( g_2(x, y, z) \):

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

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.

The principal scheme of the reflected confocal scanning microscope, which was used in our experiments, is shown in Fig. 2. A general view of this microscope, SOLAR TII, is presented in Fig. 3. The wavelength \( \lambda = 0.4416 \, \mu m \), the angular aperture of the objective \( \Omega = 0.9 \), the magnification is \( \times100 \), and the field of view is \( 10 \times 10 \, \mu m \). We also used the microobjective, which was provided with the annular aperture.

The view of the particle track in the nuclear photoemulsion layer 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 \( 90^\circ \), then the optical resolutions \( \Delta x_2^{\text{opt}} \) and \( \Delta z_2^{\text{opt}} \) will be

\[
  \Delta x_2^{\text{opt}} = \Delta z_2^{\text{opt}} = \frac{\lambda}{4}. \tag{3}
\]

So, for \( \lambda = 0.4 \, \mu m \), \( \Delta x_2^{\text{opt}} = \Delta z_2^{\text{opt}} = 0.1 \, \mu m \).

By means of the confocal scanning microscope SOLAR TII with an open aperture, we have detected an array of 27 microtomograms of a single silver grain in the nuclear photoemulsion (Fig. 5). The depth step \( \Delta z \) was 100 nm, and the transfer scanning steps \( \Delta x \) and \( \Delta y \) were 66 nm.