The influence of light scattering on edge scanning optical microscopy resolution

T.V. Danilova[1], Y.P. Volkov[1], A.O. Manturov[1] and M.A. Yudakov[2]

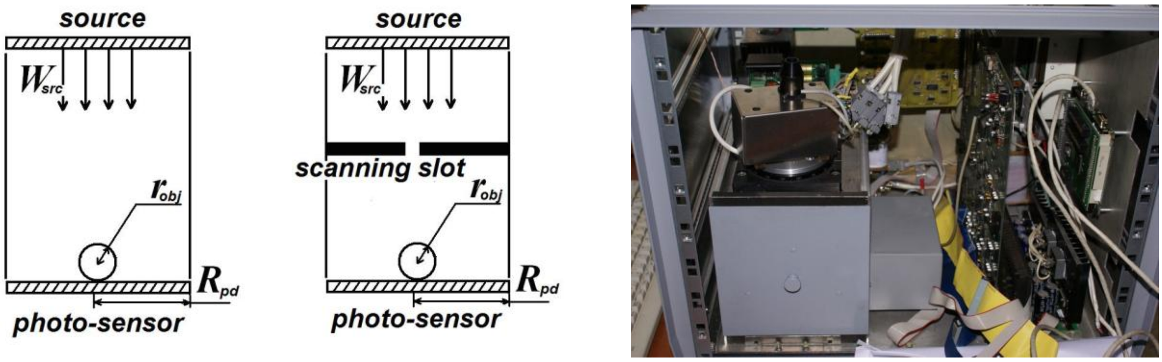
1. Faculty of Electronics and Instrument Making, Saratov State Technical University,
77 Polytekhnicheskaya Str., Saratov, 410054 Russia
2. Centre for Innovative Technologies CIT-NANO, 44 B Pervij Pugachevskij Posyolok, Saratov, 410010 Russia

_m_a_o@rambler.ru
Keywords: scanning optical microscopy, resolution, light scattering

Edge Scanning Optical Microscopy (ESOM) is a possible method for optical imaging that can achieve high spatial resolution by detecting of relative change of illuminated light intensity due to scattering by the object. Such microscopy method sees rather attractive because there is no lens system needed for image formation and there is not wavelength limit for device operation, respectively. In [1,2] the sampling optical microscope with electronically variable resolution was proposed and described. In [2] it is shown that resolution of the device is on the order of the amplitude of vibration of the knife edge. At present work we analyze the resolution limit conditioned by the light scattering for edge scanning optical imaging system that uses a moving knife edge to collect sets of tomographic projection data of two-dimensional objects. Using the Mie theory methods, we analyze the scattering of the illuminated light beam and obtain the resolution limit estimations for visible light at λ =680 nm, also as for UV light and soft X-ray illumination sources. The results of numerical estimations of the Edge Scanning Optical Microscope resolution with tomography method reconstruction of object image are presented. As it shown the spatial resolution of possible Scanning Optical Microscope can achieve 40-60 nm limit at UV illumination source (λ =206 nm). The experimental data proof these results. In order to check the obtained resolution limit estimations the experimental setup of edge scanning optical microscope was developed (Figure 1c). A tomographic filtered backprojection algorithm is implemented to reconstruct an image from the set of collected projections. The developed device works in a range of UV wavelength band (λ =206 nm, deuterium source) and shows the spatial resolution about 90 nm that meets good correspondence with obtained numerical results.

Lets describe the numerical simulation procedure that allows estimate the ESOM microscope resolution. The initial data for estimation are hardware parameters, properties of physical processes and mathematical algorithms of image obtaining. The formalized model of ESOM microscope consists of a radiation source and a photo-sensor. Simplified drawing of device is shown in a Figure 1(a). There is a hollow cylinder. Its internal surface absorbs radiation. The radiation source and the photo-sensor are allocated in opposite this cylinder. The source generates a parallel beam of electromagnetic waves. The observed object is placed between illuminating source and photo-sensor. The energy of a beam reaches object and photo-sensor from source. The object absorbs some part of the received energy and reflects other part of energy. The energy reflected by object also gets on a photo-sensor. Thus the difference between energy generated by source and energy received by the photo-sensor can characterize object. To obtain the image in these microscopes the scanning slot or edge must be placed between source and object as shown in Figure 1(b). Object is scanning by edge and photo-sensor measures the quantity of received energy on each scanning step. A set of the received values processes by tomographic algorithms. It allows to restore the object image. In its one-dimensional mode of operation, this microscope utilizes an optically opaque moving knife edge (razor blade) placed in a light beam, close to a partially transmissive object to be scanned. The transmitted, modulated light from the vicinity of the knife edge constitutes the useful signal, as it carries local information about the object. This information is extracted through photodetection and used to form an image of the object. Thus the initial data for the modeling are $\boldsymbol{W_{src}}$, $\boldsymbol{\lambda_{src}}$ – energy and wavelength of light illuminating source, $\boldsymbol{R_{src}}$ – radius of beam generated by source, we suppose that energy in beam is distributed in regular intervals, $\boldsymbol{R_{pd}}$ – radius of photo-sensor, supposed that $\boldsymbol{R_{src} = R_{pd}}$, $\boldsymbol{w_{pd}}$ – sensitivity of photo-sensor, $n = n' - i\chi$ – complex diffraction coefficient, where n' characterizes a diffraction, and χ characterizes an absorption, $\boldsymbol{d}$ – diameter of object. The object is modeled by sphere for simplification.

We assume that the beam extends as parallel and straight-line before an occurring with photo-sensor or object. The beam part is absorbed by object and other part of beam is reflected (diffused) by object. The process of beam diffusion can be described by the Mie theory because the wavelength generated by source can be comparable with the sizes of object. All the energy reflected by object not on the photo-sensor surface we consider lost. The least diameter $\boldsymbol{d}$ for which condition $\boldsymbol{W_{src} - W_{pd} \geq w_{pd}}$ is true characterizes the minimum size of object with a coefficient of diffraction n which can be visible by modeled microscope. The photo-sensor sensitivity $\boldsymbol{w_{pd}}$ we estimate here as minimum level of energy that can produce the photocurrent greater then noise equivalent current level [4]. According with it the typical photo-sensor sensitivity $\boldsymbol{w_{ph}}$ for modern Si cooled photodiodes is better then 10^{-6} W at λ_{src}= 190… 1100 nm.

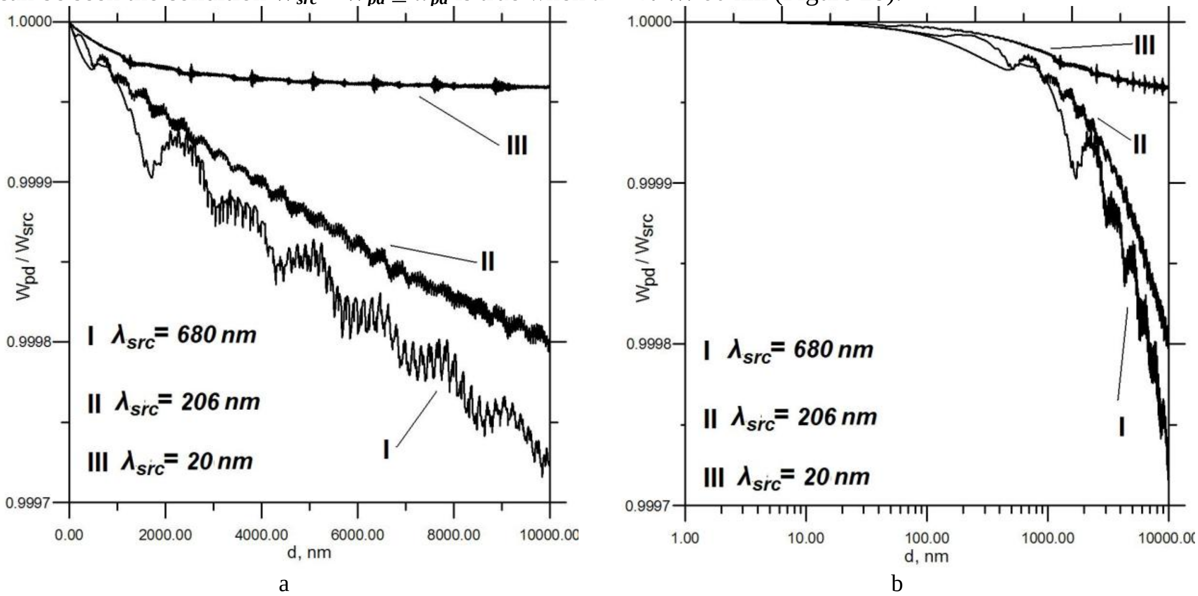


a b c

Figure 1. Scheme of edge scanning optical microscope (a,b) and measuring part of experimental setup (c)

The value of energy received by photo-sensor is defined as $W_{pd} = \int_{r=0}^{R_{ph}} 2\pi W_{pd}(r)dr$, where $\boldsymbol{W_{pd}(r)}$ – energy received by a photo-sensor on distance $\boldsymbol{r}$ from object, $W_{pd}(r) = W_{pd}^{src}(r) + W_{pd}^{obj}(r)$. This is the sum of energy received on photo-sensor immediately from source $W_{pd}^{src}(r)$ and energy reflected from object on photo-sensor $W_{pd}^{obj}(r)$. Value $W_{pd}^{obj}(r)$ is calculated as the Umov-Poynting vector: $W_{pd}^{obj}(r) = [E(r) \times H(r)]$, where $\boldsymbol{E}$ and $\boldsymbol{H}$ are magnetic and electric component of beam field reflected by object.

Above described model was used for calculating ratio of energy received on photo-sensor to energy of source $\boldsymbol{W_{pd} / W_{src}}$ (Figure 2). For calculation (the numerical algorithms that was used is described in [3,5]) we used the following meanings: $\boldsymbol{n}$ = 1.5 (glass); $\boldsymbol{R_{src}} = \boldsymbol{R_{ph}} = 2.5 \cdot 10^{-3}$m; λ_{src}= (20, 206)$\cdot 10^{-9}$m; $\boldsymbol{d}$ = 0.001… $10.0 \cdot 10^{-6}$m. As it can be seen the condition $\boldsymbol{W_{src} - W_{pd} \geq w_{pd}}$ is true when $\boldsymbol{d}$ > 40 … 60 nm (Figure 2b).



a b

Figure 2. The results of numerical simulation

1. Korpel, A., Samson, C. and Feldbush, K., "Two-dimensional operation of a scanning optical microscope using a knife edge corner", Int. Jnl. of Im. Syst. and Technol., 4, 207-213, 1992.
2. Samson.A and Korpel. A, "Two-dimensional operation of a scanning microscope by vibrating knife edge tomography", App. Opt. 95, 285-289, 1995
3. C.F. Bohren, D.R. Huffman. Absorption and Scattering of Light by Small Particles. Wiley, New York, 1983.
4. http://jp.hamamatsu.com/en/product_info/index.html
5. T.V. Danilova “Modelling of image formation and registration at photographic materials” Proc. SPIE Vol. 6164, 61640M, Saratov Fall Meeting 2005: Coherent Optics of Ordered and Random Media VI; Dmitry A. Zimnyakov, Nikolai G. Khlebtsov; Eds. Jun 2006