Rectification of SNOM-Images Taking into Account the Probe Transfer Function

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Significant enhancement of resolution in the scanning near-field optical microscopy (SNOM) is achieved by deconvolution of measured 2-D distributions using Tikhonov's method. This method makes it possible to obtain much better sharpness of images.

1. Introduction

Image deconvolution method based on the Tikhonov's theory of ill-posed problems is applied to retrieval of images distorted by the instrument transfer function influence. An actual problem in various fields of physics (radio astronomy, radar and radiometer imaging, various kinds of microscopy) is the correction of the instrument transfer function influence on measured 2-D images. Under this influence the smoothing of the real picture takes place, and even its distortion in cases when the transfer function has a complicated structure. If the transfer function is known (even approximately), it is possible to consider the inverse problem of the image rectification. This problem consists of the solution of integral Fredholm equation of the 1-st kind of 2-D convolution type, which is known as ill-posed problem. In this paper the possibility of Tikhonov's method of generalized discrepancy [1] is considered. The same approach has been used successfully in the problem of 2-D currents distribution on the superconductor film by measurements of magnetic field above its surface [2].

2. Image deconvolution

If a 2-D distribution of some physical quantity is measured, which is related to image, then the relation between the measured and the true distribution in most cases could be (at least, approximately) expressed as 2-D convolution:

$$z_{\mathrm{m}}(x,y) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} K(x-s, y-t)\mathrm{z}(s,t)\,ds\,dt \tag{1}$$

where the kernel $K(w,W)$ is the transfer function, $z_{\mathrm{m}}(x,y)$ is the measured signal, $z(s,t)$ is the true distribution to be found. The solution of (1) relative to $z(s,t)$ make it possible to retrieve the surface image with a higher resolution. It is known that the accuracy of retrieval for ill-posed equations can be determined on the basis of numerical simulation only, and these results for Tikhonov's method are presented in [3].

In the present paper this method is applied to the retrieval of scanning near-field optical microscopy (SNOM) images. The key element of a SNOM is its probe [4] shown in Fig.1. The size of the probe aperture determines the microscope resolution and the optical radiation power emerging from the probe and this size (~50 nm) is much smaller than the wavelength of light. It determines the effective width of the transfer function (kernel K) in (1), which we have to know to solve this equation. It is possible to determine this function by measurements of a small (much less than the size of aperture) test structure $z(s,t)$. This structure can be considered as δ-function, so one has from (1) $z_m(x,y) = K(x,y)$. In real measurements there are almost always suitable small structures, which can be considered as δ-functions. In such cases the smallest image inhomogeneities are similar and they repeat actually the form of $K(x,y)$. In Fig.2 one can see examples of such smallest details of the SNOM image shown in Fig.3 (left), and the corresponding kernel can be well approximated by the 2-D Gauss distribution

$$K(x,y) = \frac{4}{\pi\sigma_x\sigma_y}\exp[-4(\frac{x^2}{\sigma_x^y} + \frac{y^2}{\sigma_y^2})], \qquad (2)$$

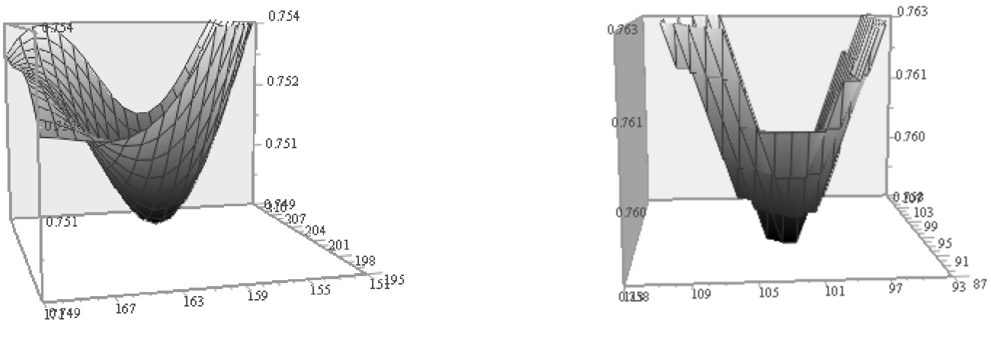

Fig.2. Two examples of smallest SNOM image details (in mV), which determine the transfer function $K(x,y)$. The pixel size is 3.3 nm.

where parameters $\sigma_x = \sigma_y = \sigma \cong 20$ pixels = 66 nm were evaluated from measurements given in Fig.2 (left). This value can be considered as the resolution of the measured image and, also, as the upper limit of the size of the probe aperture $D \leq 66$ nm that seems as a reasonable value.

2. Results of SNOM image rectification

In Fig. 3 the results of retrieval of SNOM-images are shown. It is obvious that the resolution of retrieved image is much better and the edge of the test sample is more clearly seen. The test sample was a very thin vanadium film (<10 nm) on the quartz partially etched to the substrate. The initial image was obtained with the help of the scanning near-field optical microscope "Aurora" by "Topometrix" firm, operating at wavelength of optical radiation of 488 nm; the transmission coefficient of the probe was $4 \cdot 10^{-3}$. The noise level (parameter of Tikhonov's method that determines the value of regularization parameter) was 0.03 mV.

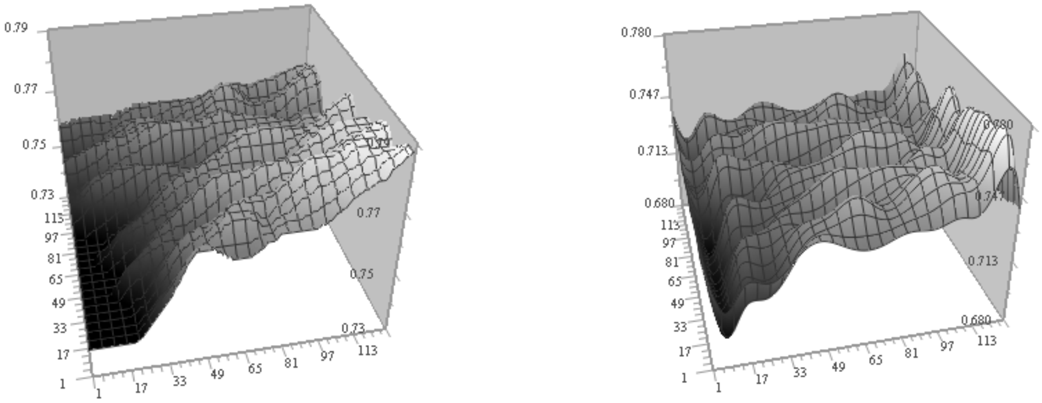

Fig.3. Initial (left) and retrieved (right) SNOM-images (in mV). The pixel size is 3.3 nm.

At this level of measurements accuracy the achieved resolution σ_r in retrieved images is at least 3 times better than the resolution in initially measured images. The achieved resolution σ_r can be determined by the smallest details of the retrieved image in the same way as the resolution of the initial image σ in (2). So, we obtain $\sigma_r \cong 22$ nm, or about 0.045 of the SNOM wavelength. In Fig.4 the measured and retrieved images are shown in a larger area.

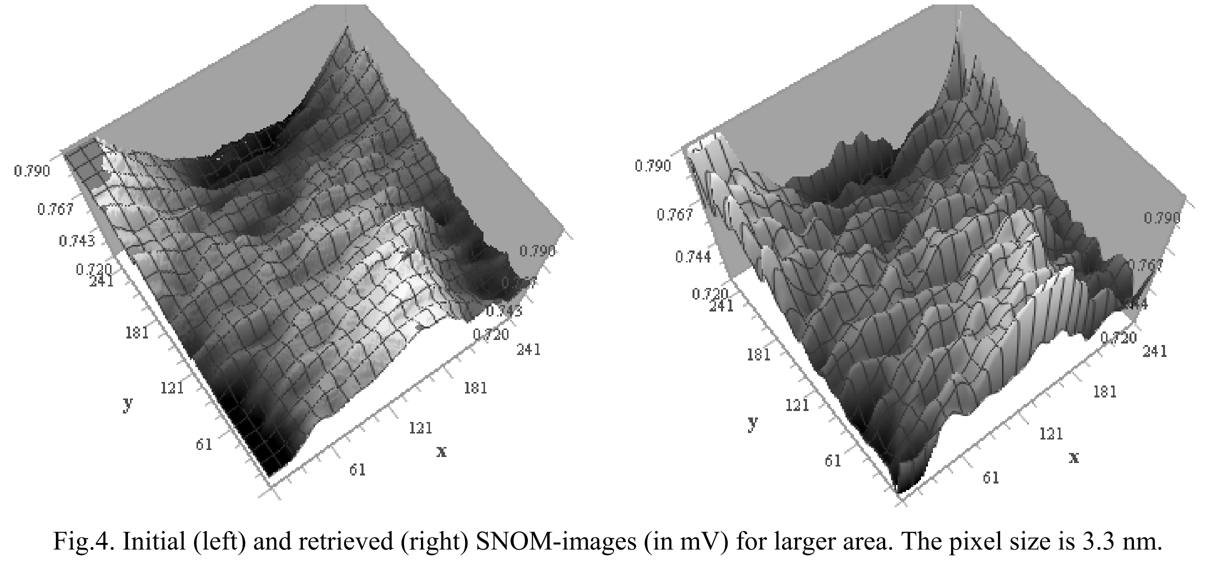

Fig.4. Initial (left) and retrieved (right) SNOM-images (in mV) for larger area. The pixel size is 3.3 nm.

Thus, we can conclude that the developed method of image rectification permits one to obtain much better image sharpness on the basis of numerical processing of measured SNOM-images. The same approach can be also successfully used in tunneling microscopy (see [5] in this issue).

Acknowledgements

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