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# Near-field scanning optical microscopy studies of thin film surfaces and interfaces

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**Abstract**

In this article, the results of the modeling of topography related artifacts appearing in near-field scanning optical microscopy measurements are presented. The results obtained for near-field scanning optical microscope operation in reflection mode with off-axis far field detector position are compared with experimental results. It is shown that the chosen numerical method – Finite Difference in Time Domain method (FDTD) – can be used for efficient modeling of main topography related artifact. It is also seen that the far field detector position can have large influence on the resulting reflection mode optical images.

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*Keywords:* NSOM; FDTD; Image artifacts

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## 1. Introduction

Both the general scientific interest in nanoscale physical properties studies and the rapid development of opto-electronic devices yields interesting questions concerning various imaging and analysis possibilities having nanometric resolution. Near field scanning optical microscopy (NSOM) is a promising and still developed experimental technique that combines scanning probe methods resolution with imaging and analysis possibilities of optical microscopes [1].

Near-field optical microscope is often referred as an instrument being capable to produce optical images (e.g. reflection or transmission) comparable to the classical microscopy, but having much better resolution. However, quantitative analysis of optical images obtained using NSOM technique is not usually performed as there are too many issues unclear from the experimental point of view. First of all, the exact shape of NSOM probe (including its aperture) is not known and cannot be easily determined during the measurement. Moreover, the electromagnetic field distribution within the probe and in the near-field region is also unknown. Finally, topographical artifacts that arise from varying near-field electromagnetic distribution over rapidly changing sample topography are very often observed.

Despite of these facts, the possibility of performing quantitative optical analysis with resolution beyond the diffraction limit is still very attractive. Therefore, there are many approaches in the literature how to deal with the mentioned problems and create method that could be used for reliable high resolution optical analysis [2,3].

One of the largest problems in interpretation or further quantitative analysis of optical data obtained by means of NSOM is its relation to the local surface topography, real fiber geometry [4,5] and position of the far field detector. This effects can be easily seen while imaging steep slopes or edges on the sample (here, it can be easily predicted) or while imaging surface exhibiting random roughness. Sometimes the topography artifacts can completely obscure the optical information contained in the data.

In this article, we present results of complete electromagnetic modeling of the NSOM geometry, including its probe formed by fiber with small shielded aperture, tip-sample configuration and far field result going to the photodetector. All the material and geometrical parameters are

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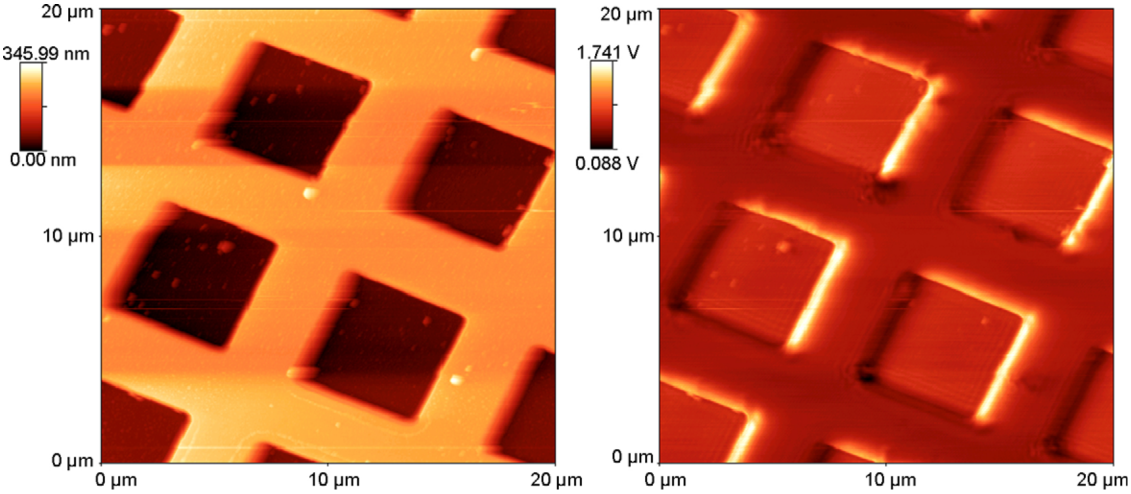

Fig. 1. NSOM topograhy (left) and reflection image (right) obtained on calibration grating.

related to concrete NSOM measurements and are therefore corresponding to the real situation. The effect of different positions of far field detector in reflection NSOM experiment is discussed.

## 2. Preparation of samples and the experimental arrangement

For NSOM measurements, Aurora 2 NSOM instrument (Thermomicroscopes) was used. Standard metal shielded fiber tips with aperture between 80–100 nm were used for the measurements. All the images were acquired in reflection mode.

As a sample, we used standard calibration grating ($SiO_2$) as a simple example of object forming topographical artifacts. Both clean grating and grating coated by a thin gold film (designed for scanning tunneling microscopy analysis) were measured using the NSOM instrument. A typical image of NSOM measurement data obtained on this sample is presented in Fig. 1. Both the morphology and reflection optical image are presented. Note that the far field detector is located at the left side relative to the presented image.

Atomic force microscope (AFM) measurements were performed by Explorer AFM (Thermomicroscopes) using standard non-contact tips and working in the non-contact mode. These measurements were used for acquiring the calibration grating morphology with higher precision than using NSOM probe.

Geometry of used NSOM fiber tips was measured using scanning electron microscope Jeol JSM-6460.

## 3. Electromagnetic field modeling

For modeling of the propagation of the electromagnetic field within the NSOM geometry we have used Finite Difference in Time Domain method (FDTD), which is probably most universal tool for the computational electrodynamics. Within FDTD we solve Maxwell equations numerically in a leap-frog scheme (E and H components consecutively) with a proper placement of the field vector components in space and proper

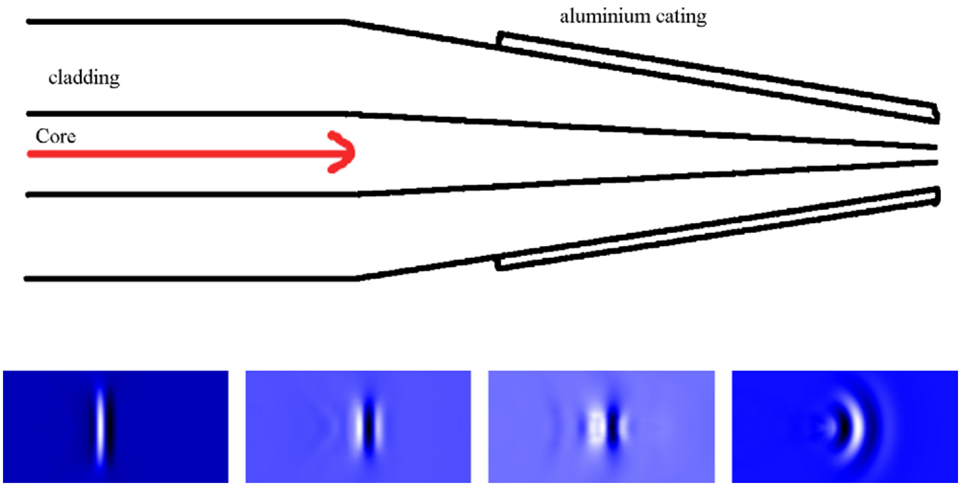

Fig. 2. Geometry of the computational domain for the fiber modeling (step 1, cross-section) and results of the electromagnetic field intensity modeling for short pulse passing through fiber for four different locations at the fiber—cylindrical fiber, uncoated cone fiber, aluminum coated cone fiber, fiber aperture.

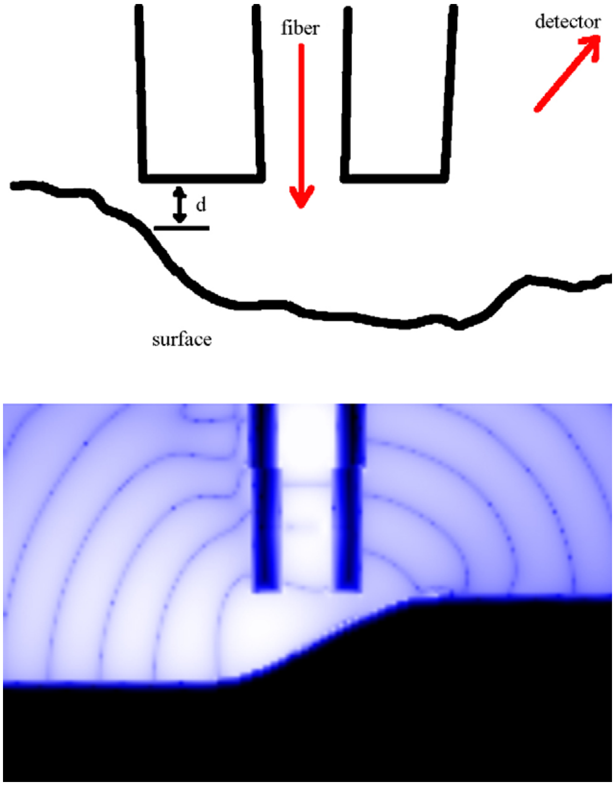

Fig. 3. Geometry of the computational domain for the complex NSOM geometry modeling (step 2, cross-section) and results of the electromagnetic field intensity modeling for one position of NSOM probe close to the step on surface.

discretization. The years of development of the FDTD methods resulted on many methods for including different materials (metals, dielectrics, dispersive materials, nonlinear materials, etc.) and sources (planar sources, antennas). For further details, see e.g. Ref. [6].

We have used the following FDTD extensions:

- uni-axial perfectly matched layer (UPML) to allow waves to leave computational domain;
- conformal modeling of the material boundaries;
- near to far field transform (NFFF) for evaluation of the far field limit of the electromagnetic field distribution [7];
- computational domain stepping in one dimension to model structures elongated in one direction.

For modeling our NSOM geometry, we have used the following two steps:

(1) Optical fiber probe analysis based on geometry obtained using scanning electron microscope and data-sheet material properties of fiber; computed in space of $20 \times 3 \times 3$ wavelengths ($\lambda$), space discretization of $\lambda/20$, using stepping in one dimension and conformal modeling. This geometry is illustrated by a cross-section presented in Fig. 2. In this way we have computed the field inside NSOM probe.

(2) Probe-surface geometry analysis using the NSOM probe fields computed in step 1 and AFM topography of the grating surface; computed in space of $4 \times 4 \times 4\lambda$, space discretization $\lambda/40$, using NFFF computation of the far field limit. The second step geometry is illustrated by a cross-section presented in Fig. 3.

Second step was repeated for all the predefined positions of tip above sample to obtain simulated NSOM image, while tip was always at the same distance from surface. The modeling therefore followed the NSOM movement over the surface.

## 4. Results and discussion

In Fig. 4 A, an image of morphology of calibration grating used for atomic force microscope calibration is presented. The area that was used for NSOM image computation is presented here too by a selection.

In Fig. 4, a series of modeled NSOM images of part of the grating presented in Fig. 3 is presented. Note that only first of these images (Fig. 4B) corresponds to position of far field detector used in the experiment. The rest of images correspond to situation when detector is placed at the opposite side of the NSOM microscope (Fig. 4C), and at both the left and right side (Fig. 4 D and E, as seen from the real detector position).

From the modeled NSOM images presented in Fig. 4 it can be seen that the basic topography related effects observed within the experimental measurements can be efficiently modeled using the

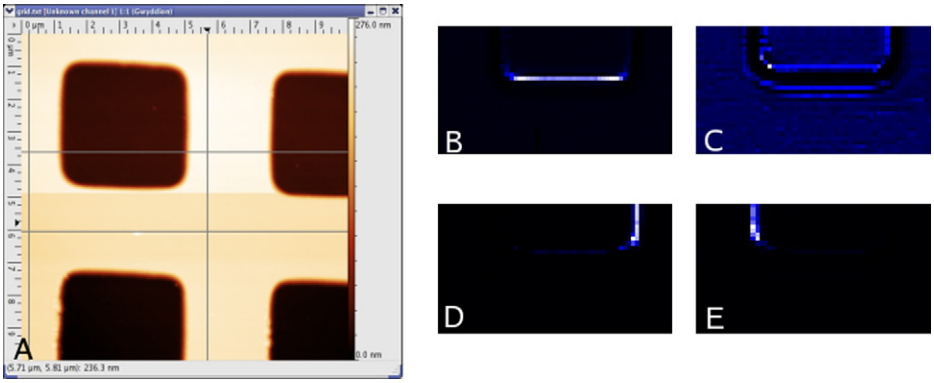

Fig. 4. (A) Simulated part of the calibration grating shown on AFM image and (B–E) simulated NSOM reflection images for four different positions of far-field detector: (B) top, (C) bottom, (D) left, (E) right.

FDTD method. These effect include namely small probe-sample distance variation while scanning over steep edges (as the whole NSOM probe follows surface topography, not only its apex) and far-field detector position. It is seen that the far-field detector position is the main source of directional topographic artifacts. For the NSOM setups that use off-axis far field detector for reflection measurement, this effect must be taken into account therefore.

Note, that in principle there is also a third source of artifact for the mentioned experimental setup. The probe itself can be damaged and its radiation can in principle be strongly directional. In this experiment we have used new NSOM probes to minimize this effect. The modeling results for different geometries of broken or non-ideal probes will be presented in our forthcoming paper.

## 5. Conclusion

In this article results of near-field optical microscopy artifacts modeling were presented. The two main sources of artifacts in reflection NSOM were simulated and compared to the experimental data. These sources include effect small probe-sample distance variation while scanning over steep edges and off-axis far-field detector position influence.

For the modeling the real parameters used for the experiments were used. Geometry of the NSOM probes was determined using scanning electron microscopy and morphology of the surface was determined using atomic force microscopy. The NSOM modeling was performed using Finite Difference in Time Domain method (FDTD) within volumes having dimensions in range of several wavelengths.

It was shown that the far field detector position has a deep influence on the optical images acquired in the reflection mode. This influence can be sometimes even larger than the effect of varying the tip-sample distance while scanning over steep slopes.

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## References

[1] M.A. Paesler, P.J. Moyer, Near-Field Optics, Theory, Instrumentation and Applications, John Wiley & Sons, 1996.

[2] B. Hecht, B. Sick, U.P. Wild, V. Deckert, R. Zenobi, O.J. Martin, D.W. Pohl, J. Chem. Phys. 112 (2000).

[3] J.L. Kann, T.D. Milster, F.F. Froehlich, R.W. Ziolkowski, J.B. Judkins, J. Opt. Soc. Am. A 12 (1995).

[4] B. Hecht, H. Bielefeldt, Y. Inouye, D.W. Pohl, J. Appl. Phys. 81 (1997).

[5] K.D. Weston, J.A. DeAro, S.K. Buratto, Rev. Sci. Instrum. 67 (1996).

[6] A. Taflove, S.C. Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method, second ed., Artech House, Norwood, MA, 2000.

[7] O.M. Ramahi, IEEE Trans. Anten. Propagat. 45 (1997) 1263–1271.