Light polarization and intensity behaviour in aperture cantilevers with carbon tip created by focused ion beam

T V Mikhailova¹, Yu E Vysokikh²,3, S Yu Krasnoborodko²,3, A S Kolomiytsev⁴ and A A Fedotov⁴

¹V.I. Vernadsky Crimean Federal University, 295007 Simferopol, Russia
²Scientific and Technological Centre of Unique Instrumentation of the RAS, 117342 Moscow, Russia
³MTEON Ltd, Moscow, 124617 Zelenograd, Russia
⁴Southern Federal University, 344006 Rostov-on-Don, Russia

visokihy@gmail.com

Abstract. Modern atomic force microscopy (AFM) techniques and their combination with other methods give us a possibility to investigate the same samples from the new side at nano-scale. One of very promising combinations is polarization near field microscopy integrated into AFM tool. It allows one to make topography imaging by standard AFM tool and optical magnetic structure imaging by magneto-optical method simultaneously. Moreover, this combination gives synergy effect on both methods by improving their weak sides: elimination of magnetic influence of magnetic force microscopy on the sample, on the one hand, and overcoming the diffraction limit of the magneto-optical microscopy, on another hand. The cantilevers play a very important role in this combination of the methods since they interact with the surface and allow focusing the laser beam to the sample in near field mode. The geometry and other parameters of cantilevers are determined as a result of the combined methods implementation. Authors investigate the new type of carbon-tips aperture cantilevers for AFM and high resolution magneto-optical combination.

1. Introduction

Nowadays, atomic force microscopy (AFM) allows investigating not only morphology and physical properties [1,2] of the samples, but also optical data could be collected by the combination of AFM and near-field scanning optical microscopy (NSOM) methods. This combination allows one to study optical properties of the sample and morphology of same area simultaneously, which is important for new magnetic materials investigation [3-5]. One of the modern techniques obtained from such combination is polarization near-field optical microscopy, which allows performing polarization depended measurements with high spatial resolution [6].

There is a number of probes created for NSOM. Historically, optical fibre probes were used for this purpose, but they have the limitations of spatial resolution, light throughput, and reproducibility [7]. One of the modern types of the probes for NSOM methods is silicon cantilevers. Authors propose to use focused ion beam technology to get carbon hollow pyramid tip on a silicon cantilever for creation high reproducible aperture cantilevers with high light throughput and high spatial resolution [8]. In this paper, authors study light polarization and intensity in aperture cantilevers with carbon tip created by focused ion beam.
2. Experimental

Images of Bi-substituted yttrium iron garnet (Bi:YIG) thin films were obtained using magneto-optical polarization near field microscopy (Fig. 1).

Carbon-tips cantilevers were made by focused ion beam to investigate light polarization and intensity behaviour. Authors propose a new technology of aperture cantilever creation. Tipless silicon cantilevers NSG-11 (TipsNano) were used for creation a new type of probes. Ion beam etching and ion beam assistance deposition were implemented using Nova NanoLab 600 tool. Gallium liquid metal was used as ion beam source. Round shape hole with diameter of 5 μm was created by ion beam etching. After the hole creation, carbon pyramid formation started. The trajectory of the ion beam was determined to deposit carbon in an orderly manner from the base of the cone (5 μm in diameter) to its tip. As a result, a hollow tip with a height of about 5–6 μm was formed. Scanning electron microscopy images of the carbon-tips cantilevers were obtained (Fig. 2).

Produced carbon-tip aperture cantilevers with aperture sizes from 83 to 264 nm were investigated by means of NTEGRA (NT-MDT) including AFM and NSOM methods. Optical images of apertures of the carbon-tip cantilevers (bottom illumination scheme) were collected (Fig. 3).

3. Results and discussion

Optical images were obtained by laser scanning (by mirror) of apertures of the carbon-tips cantilevers. Possibility to focus light spot to the aperture cantilevers is demonstrated (Fig. 4). Disturbances occurring in different sizes of aperture are investigated. It is shown that it may be caused by nonuniformity carbon rings due to some errors in technological process.
Figure 3. Optical images of apertures of the carbon-tip cantilevers (bottom illumination scheme): (a) 264 nm; (b) 90 nm.

Figure 4. Optical images obtained by laser scanning (by mirror) of apertures of the carbon-tips cantilevers: (a) 264 nm; (b) 90 nm.

Figure 5. Polarization rotation in carbon-type aperture cantilevers. Red lines and arrows show polarization position of initial laser beam. Blue lines and arrows represent the polarization of light passed through the cantilever aperture. Aperture size: (a) 83 nm and (b) 90 nm.
Figure 6. Coefficient of light transmittance/aperture size(nm) dependence.

Polarization rotation in carbon-tips aperture cantilevers was measured. The biggest value of polarization rotation was determined for cantilevers with the smallest aperture size: 35° and 21° for 90 and 83 nm aperture size, correspondently (Fig. 5).

Coefficient of light transmittance vs. aperture size(nm) dependence was calculated. Carbon-tips cantilevers (blue circles) showed good light transmittance compared to commonly used aperture type cantilevers (marked by red circles).

4. Conclusion
New carbon-tips aperture cantilevers for polarization near field microscopy were investigated. It was shown that these cantilevers allowed obtaining appropriate laser spot for near field microscopy, but disturbances appeared in some cantilevers should be eliminated by more precision technological process and changing pyramid geometry. Light transmittance coefficients of new type cantilevers were estimated to show good results compared with commonly used aperture cantilevers. Polarization rotation measured for different apertures showed necessity of analyser prealignment depending on cantilever aperture geometry and size.

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