SNOM characterization of a potential low cost thin gold coated micro-structured grating using a commercial CD substrate

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Received 8 December 2014; accepted 1 July 2015

In this work near-field optical measurements of a corrugated grating coated with a 30 nm thick gold film are presented. The grating was made using the polycarbonate corrugated substrate of a commercially available recordable CD as template. This has been proved to be a versatile and low cost technique in producing large 1.6 μm period gratings. The study was carried out using a Scanning Near-Field Optical Microscope (SNOM) working in both collection and reflection modes at two different wavelengths, 532 nm and 633 nm. The results illustrate that the intensity patterns of near-field images are strongly polarization-dependent, even showing different periodicity of the localized fields for orthogonal polarization states. When electric field of the light is polarized parallel to the grooves, the periodicity of the SNOM images is coincident with the grating period, whereas when the light is polarized perpendicular to the grooves the SNOM pattern shows a periodicity twice that of the corresponding topography of the grating. Numerical simulations of the SNOM data based on a two-dimensional Finite Difference Time-Domain (2D-FDTD) model have been realized. The results of the simulations are in good agreement with the experimental data, emphasizing the need of performing numerical simulation for the correct interpretation of SNOM data.

Keywords: ***FAVOR DE PROPORCIONAR***

PACS: ***FAVOR DE PROPORCIONAR***

1. Introduction

The origin of the scanning near-field optical microscopy (SNOM) is based on Synge's original idea [1]. Synge proposed in 1928 that the resolution limit imposed by diffraction could be overcome by illuminating a sample through a pin hole of, say 100 nm aperture, located a distance from the sample less than or equal to the pin hole diameter. It was not until 1986, after the development of Scanning Tunneling Microscope (STM) that Pohl and colleagues developed its optical equivalent, now known as SNOM [2]. The modern version uses a metal coated optical fiber with a tip of nanometers dimension through which the surface of the sample is illuminated. The intensity of the reflected or transmitted light from the sample is then detected in the far-field condition using conventional microscope optics. In the case of using the SNOM in the collection mode, the sample is illuminated uniformly from the back surface and the fiber tip is used to detect the transmitted light field a few nanometers from the surface of the sample. The SNOM microscopy has the added advantage of simultaneously obtain information on the topography of the sample (by means of an Atomic Force Microscopy, AFM) and the intensity distribution of light in the near field. This powerful combination has led to this technique to be one of the most powerful tools in nano-photonics studies [3,4].

This article demonstrates the power of the SNOM technique on the direct observation of the intensity distribution of light in the near field for the study of corrugated surfaces, and illustrates the potential of producing large and low cost micro-structured grating using commercially available recordable compact discs. The production of low cost, large effective area corrugated structures with high homogeneity is an important aspect in the commercialization of micro- and nano-photonics devices [5].

The complexity of interpreting the SNOM patterns requires the use of numerical simulation techniques. Thus, experimental results have been modeled using Finite Difference Time-Domain (FDTD) simulation techniques in two dimensions [6]. The results show a good accordance with experimental data, demonstrating the versatility and power of this simulation numerical technique in the interpretation and analysis of SNOM data.

2. Experimental

The diffraction grating used in this work was made from a blank recordable compact disc, CD-R. The physical structure of a CD consists of a single polycarbonate plate which contains one single spiral track distribution of approximately rectangular cross section coated by a thin layer of photosensitive polymer and covered with a reflective metallic layer, usually aluminum. The process of removing the metallic coating is relatively simple and is carried out mechanically. First, a strong sticky tape is firmly pressed onto the metallic surface of the disc, and then the tape is pulled away with the metallic cover. The photosensitive polymer is removed then with a mixture of ethanol and water. Finally, large and high quality corrugated samples of any size or dimension can be cut from the substrate (about 4 cm^2 for this study). After cleaning the surface of the sample with ethanol and water mixture, a thin film of gold about 30 nm thick is evaporated on the corrugated surface. The thickness and rate of deposition of the gold layer was monitored in situ by a quartz microbalance [7].

Both SNOM and AFM topography images were obtained using a Nanonics Imaging Ltd. model MultiView 2000 TM operating in either reflection or collection mode. Two illuminative wavelengths; 532 nm (doubled Nd:YAG) and 633 nm (He-Ne laser) were used. Hereafter we will refer to the topographic images as AFM, whilst near field optical measurements will be cited as SNOM images. For data processing we used the program WSxM 5.0 [8]. In reflection mode, the sample is illuminated by the laser light through the SNOM fiber with a tip diameter of 100 nm, and the light scattered by the corrugated surface sample is collected through a 10× objective and directed to an avalanche photodiode. In the collection mode, the sample is illuminated from its back smooth surface, and the transmitted light from the corrugated surface is collected by the SNOM fiber tip. The collected light is then sent through an optical fiber to a photomultiplier. The samples were analyzed by using linearly polarized light with two different polarization directions: light with its electric field vector parallel to the corrugated tracks direction, and light having its electric field perpendicular to the tracks.

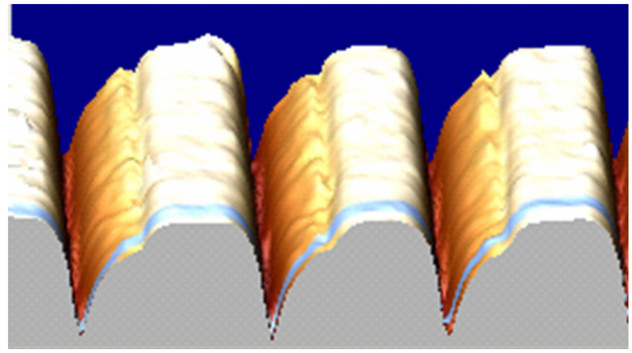

FIGURE 1. AFM image of the metalized CD corrugated surface.

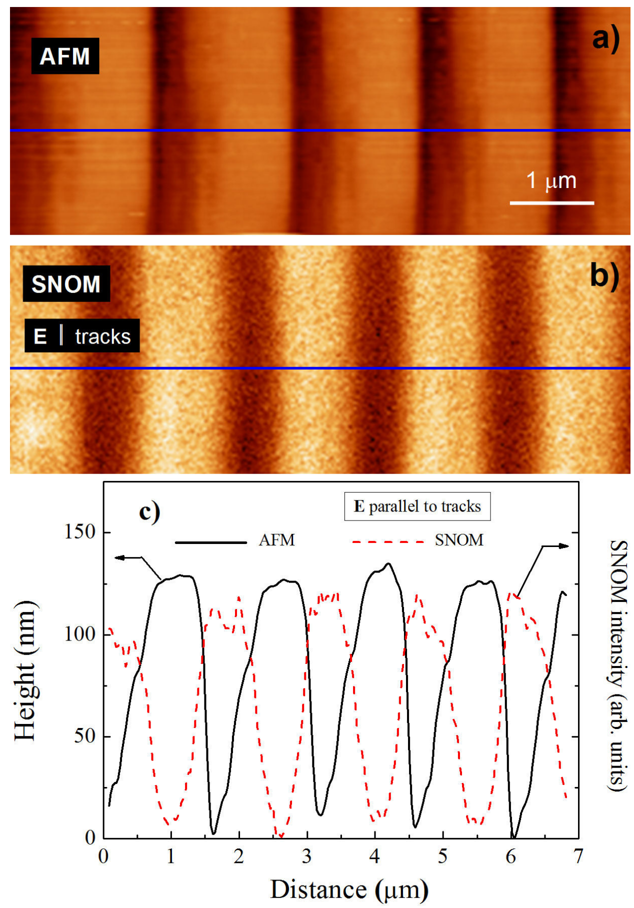

FIGURE 2. a) AFM image of the metalized CD surface. b) SNOM image obtained in the collection mode recorded simultaneously to the AFM image, for 532 nm light polarized along the tracks direction. c) AFM and SNOM light intensity profiles along the blue lines marked in Figures 2a and 2b.

3. Experimental results and discussion

Figures 1 shows the AFM image of the corrugated structure with the 30 nm thin film gold deposition. A periodicity of 1.6 μm with an average depth of the track of $\sim$120 nm and 600 nm wide are observed. These values are in accordance with parameters of commercial compact discs.

AFM images and polarized near-field SNOM of the corrugated structure, both taken simultaneously from the same region, are presented in Figs. 2a and 2b, respectively. The SNOM data were obtained under collection configuration by using linearly polarized 532 nm laser light with its electric-field vector parallel to the tracks.

It is clear from the figure that the period of the grating measured by AFM is coincident with the period shown in the images from SNOM measurements. Nevertheless, the modulation pattern of both images are shifted one respect the other. To make clear this fact, Fig. 2c shows the profiles corresponding to the lines marked in Figs. 2a and 2b, which corroborates a similar periodicity of SNOM data respect to the topographic structure of the corrugated sample taken by AFM. Also, the light intensity peaks are located at the center position of the grooves, while the minima are situated at the maxima of the metalized grating structure.

SNOM measurements were also performed by using light linearly polarized perpendicular to the tracks. The intensity map, shown in Fig. 3b besides the AFM map in Fig. 3a, reveals a double periodicity for the SNOM image as compared with the AFM image. This fact is more clearly seen in Fig. 3c, where the height profile and the SNOM intensity pro-

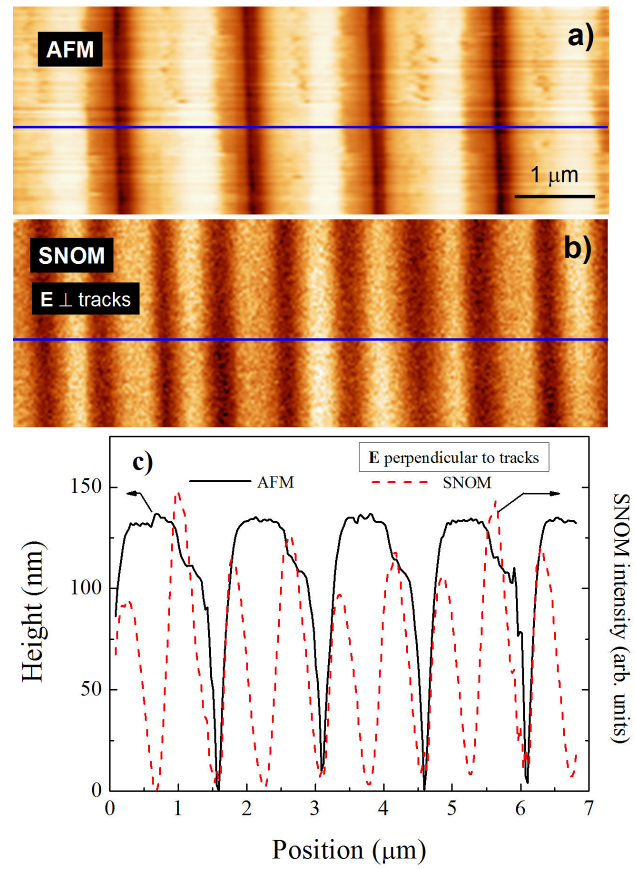

FIGURE 3. a) AFM image of the metalized CD surface. b) SNOM image obtained in the collection mode recorded simultaneously to the AFM image. c) AFM and SNOM light intensity profiles along the lines marked in a) and b). SNOM image was recorded with the electric field polarization perpendicular to the tracks route using the 532 nm wavelength source.

profile along the lines marked in Fig. 3a and 3b are plotted. Apart from the double periodicity of the SNOM profile, the minima of the SNOM signal are located at the position of the maximum and minimum height of the corrugated structure.

The strong polarization dependence of the near field found in these structures has been also observed in CD grating structures using a gold particle as the sensing probe [9]. The authors showed that the scattered light from the gold particle probe is strong at the groove edge, giving rise to split peaks for p-polarization (perpendicular to the tracks). Also, SNOM measurements of thin metallic multi-slits on dielectric substrates have been reported [10]. For p-polarization, a double periodicity of the SNOM pattern respect to the 0.76 μm period grating of the multi-slits array was found. In this case, the marked distinct behavior found between orthogonal polarizations was attributed to the excitation to surface plasmon polaritons. All these results, beside the results presented in this paper, indicate that polarized-SNOM is highly recommended to model the optical/topographic structure of the sample under consideration. In addition, numerical modeling of the light propagation through the structures is imperative for the correct interpretation of the SNOM patterns.

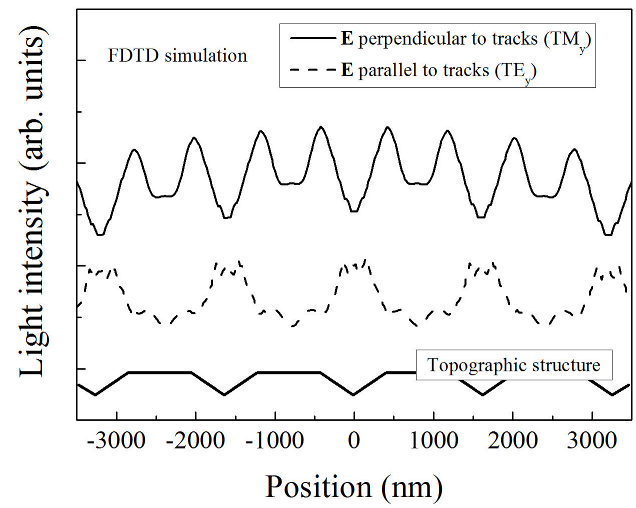

FIGURE 4. FDTD simulations of the SNOM light intensity profiles. Continuous line: electric field polarization parallel to the tracks direction. Dashed line: electric field polarization perpendicular to the tracks direction. At the bottom, the simulated topographic profile is drawn.

Along this line, numerical simulations of the light propagation through the corrugated metallic structure have been carried out by using a 2-Dimensional Finite Difference Time-Domain (2D-FDTD) model [6]. The model includes the treatment of dispersive materials and metals. The refractive index of the dielectric substrate is assumed to be $n = 1.45$, and the optical properties of the gold film has been modeled by using the Drude model, with $\varepsilon_p = 9.5$, $\omega = 8.95$ eV and $\Gamma = 0.069$ eV [11]. The simulated topography of the corrugated surface is shown at the bottom of Fig. 4, with the geometric parameters taken from the AFM measurements, besides a metallic layer of 30 nm. The FDTD simulations reproduce the configuration used in the SNOM experiments. In particular, a quasi-plane monochromatic wave is launched from the substrate, propagating to the corrugated surface. Once the light pattern in the whole computational window reaches its steady state, the near field intensity is recorded following the profile of the corrugated substrate. The implementation of PML at the boundaries of the computation region assures confident numerical results. The simulations were performed using both linearly polarized light along the tracks (TE$_y$) and perpendicular to the tracks (TM$_y$).

Figure 4 shows the results of the simulation for both polarizations using a continuous wave excitation at a wavelength of 532 nm. Essentially, the simulations reflect closely the experimental observations.

In the case of the parallel polarization, the profile has the same periodicity as the modeled grating. Also, the peak positions are located at the height minima of the structure. For light polarization perpendicular to the tracks direction, the FDTD calculation shows a double periodicity compared to the grating periodicity, and minima of light intensity are located at the centre of the top of the structure and between the grooves. These numerical results are coincident with the experimental results observed by SNOM.

In conclusion, this work has shown that corrugated structures of commercially available CDs can be potential large surface area templates for low-cost photonic elements. These metalized structures can be characterized by means of the SNOM technique, where the use of polarized light is an important experimental aspect to be considered. Finally, FDTD simulation is a powerful and fundamental numerical tool for the correct interpretation of SNOM data.

Acknowledgments

This work has been partially supported by Ministerio de Ciencia e Innovación (project TEC2010-21574-C02-01) and Comunidad de Madrid (P2009/TIC-1476), Spain. E. Camarillo G. recognizes to DGAPA-UNAM support for a sabbatical year at UAM.

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