PSD function a tool for near-field optical study of glass surfaces

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Abstract: Scanning near-field optical microscopy (SNOM) is emerging as a powerful tool for nanometric characterization of optical components and for ~~in~~ surface metrology. By accessing the optical evanescent field (near-field), the diffraction limit can be overcome, thereby attaining sub wavelength resolutions. In this paper we present a study on the roughness features of glass surfaces using SNOM. By analyzing the power spectral densities (PSD) extracted from the near-field optical images, we clearly demonstrate that optical near field images contain sub wavelength information that are lost as soon as the probe goes away from the near field. A shear-force driven SNOM was used to characterize the samples. The optical images obtained provide complementary information to that obtained from the topographical one.

1. Introduction

Roughness can be considered as a measure of the topographic relief of the surface, for example the polishing marks of optical surfaces and other machined surfaces [1]. Several devices exist for the characterization and measurements of rough surfaces like interference microscopes, reflectometers etc. The choice of a characterization method depends on the type of the sample and the kind of information studied (like the height profile, image of defects, power spectral density or other statistical parameters like surface roughness, correlation length etc). All these techniques of measurements provide us with information on the surface roughness and on the parameters that influence different physical or chemical processes. In general, for characterization methods like angle resolved scattering techniques, one studies the far-field of the diffracted or reflected light from the surface. However, these measurements suffer from their resolution limitation, as it is not possible to get information on sub wavelength asperities. Scanning tunneling electron microscopes (STM) or atomic force microscopes (AFM) can provide topography with better resolution and are thus a powerful tools in surface roughness characterization [2, 3, 4]. Nevertheless, these methods provide us with topographic information of the surface only. On the other hand, near-field optical methods give us additional information in the form of optical images by collecting optical near field and transforming the evanescent waves to propagating waves due to the subwavelength probe. Of the different near-field optical microscopes, the scanning near-field optical microscope (SNOM) is currently gaining popularity in micrometric and nanometric characterization of optical components and other nanoscale objects [5, 6, 7].
In this paper, we present and discuss a roughness study of glass surfaces using near-field microscopy.

Experimental procedure

Scanning Near-field Optical Microscope (SNOM) has been used for studying the optical near-field distribution, the near-field emission of fluorescent particles and the plasmons or the Eigen modes of integrated optical waveguides [7, 8]. In order to study first the roughness of our samples, a shear-force driven SNOM was used. The experimental set-up is shown in Fig. 1. The SNOM with shear-force regulation that we use is able to detect two different signals, the near-field optical signal and the interaction forces between the probe and the sample surface, also known as the shear-force interaction [5, 6]. Shear-force regulation (ShFM) is used to obtain the surface topography while the probe (an etched optical fiber) detects the optical near-field close to the surface thus providing an optical image. Furthermore, the shear force is used to keep the probe-surface distance constant and to avoid contact between the tip and the sample surface during the scanning. The shear-force effect is a mechanical damping of a vibrating tip when it moves near the surface. The probe is mounted on a dither tube, which induces lateral oscillation of a few nanometers on the fiber tip. A change in the amplitude of vibration of the fiber due to near-field damping occurs as an impedance variation in the Wheatstone's bridge. This signal is then amplified using a lock-in amplifier, the output of which is given as a feedback regulation and processed by the Nanoscope E Digital Instrument.

In the case of glass surfaces, the sample is illuminated in total-internal reflection configuration (see Fig. 2). We used a chemically etched single-mode fiber as probe for the SNOM, with an apex size of around 20nm. The ShFM allows us to obtain a two-dimensional surface profile h(x, y), recorded over a squared area $L_X=L_Y=L^2$ on the sample with $N_XN_Y=N^2$ points, where N is the number of pixels per line and L is its length. The sampling interval is given by $\Delta_X=\Delta_Y=\Delta=L/N$.

The roughness is commonly characterized by the root mean square height (*rms* roughness δ or Rq) value, when the surface asperities are assumed to have a random distribution. The *rms* height roughness [1], δ is defined by

$$\delta^2 = \frac{1}{N^2}\sum_{i,j}^{N}(h_{ij} - h_{moy})^2 \qquad \text{Eq. 1}$$

$$\text{With } h_{ij} = h\left(\frac{iL}{N}, \frac{jL}{N}\right) \text{ and } h_{moy} = \frac{\sum_{i,j} h_{ij}}{N^2}$$

The power spectrum density (PSD) $\gamma(\nu_X,\nu_Y)$ is the spatial frequency spectrum of the measured surface roughness. More specifically, the PSD function is the square of the Fourier transform of the two-dimensional topographic image [1, 10, 11]

$$\gamma(\nu_X,\nu_Y) = \left(\frac{2\pi}{L}\right)^2 \cdot \left|\hat{h}(\nu_X,\nu_Y)\right|^2 \qquad \text{Eq. 2}$$

$\hat{h}(\nu_X,\nu_Y)$ being the two-dimensional Fourier transform of the two-dimensional profile.

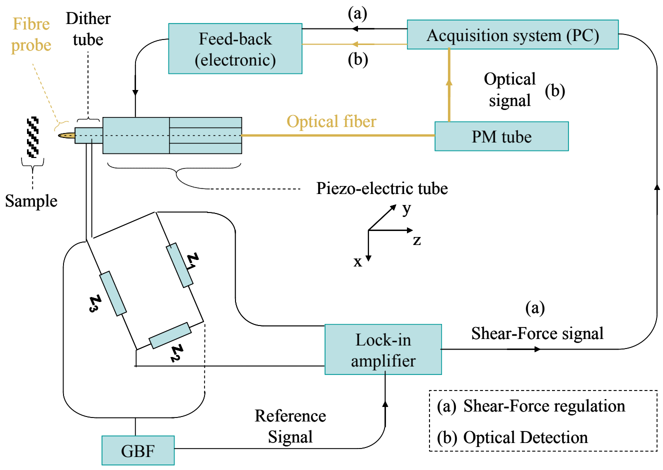

Fig. 1. Schematic set up of the SNOM with shear-force regulation and optical near-field detection

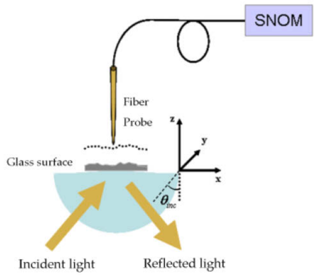

Fig. 2. Illustration of the configuration geometry for the measurement in total internal reflection

Fig. 3 shows of images of a glass surface, with on fig 4 the PSD function of the topography .

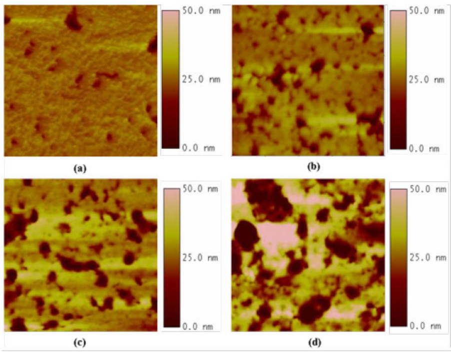

Fig. 3. (a-d) Topographic images (10x10) µm² of a typical chemically etched glass surfaces with respectively roughness around 3nm, 5nm, 10nm and 19nm resulting of different etching time process

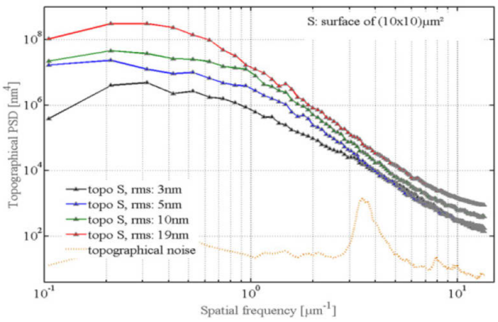

Fig. 4. Power spectral density (PSD) of topographical surfaces above (Fig. 3) with corresponding noise level

The corresponding results obtained for the SNOM measurements will be discussed and compared with the topographical results.

Discussion

In this paper we will present a study of the optical near field lying near glass surfaces using near-field techniques. The glass samples were prepared using chemical etching procedure. The etching process induced small asperities in the glass surface.

The surface statistical properties of the samples were characterized using a shear-force SNOM microscope.

We demonstrate the possibility to fabricate surfaces with various roughnesses from few nanometers to more than ten nanometers, with a good mastery of the fabrication process and roughness control. We will demonstrate that using the simple concept of roughness δ is not sufficient for characterizing the surfaces, two surfaces could have the same value of δ with different topographies, and then the best is to consider the PSD which give information on asperities contribution, for different spectral domains.

After analyzing the topography of the different samples, thanks to the SNOM, the optical near field analysis has been done by varying some parameters such as roughness and the probe-surface distance. Topographic and optical images were obtained using this technique. PSD plots were directly obtained from these images with the help of a MATLAB program. We will demonstrate by using a very simple model of a probe far from the surface, that there is a relation between the topographical PSD and the optical one. In the same way using another model for very low roughness, we will explain why the optical PSD is proportional to the topographical PSD. At list we show for low roughness that when the probe is taken away the surface, first the information concerning the higher frequencies are lost, demonstrating indirectly the presence of evanescent waves lying very close to the surface and partly collected by the probe for short distances. The evanescent waves participate to the sub wavelength resolution of the SNOM.

References

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