ADVANCED METHOD OF SCANNING PROBE MICROSCOPY IMAGE RESTORATION

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ABSTRACT

The scanning probe microscopy techniques share the problem with finite tip dimensions. If the surface geometry is known, it is quite easy to determine the tip shape (in certain circumstances) and subsequently use deconvolution for image restoration. The case when there is no need to subsequent tip shape determination scan is described in this paper. The knowledge of surface geometry allows us to determine accurate tip shape. The employed approach is a variation of Villarrubia's tip characterizer one. Additionally, it allows determine regions on restored image where the uncertainty of the surface reconstruction is too high.

1. INTRODUCTION

Nowadays the microscope is an important tool for device or material characterization and most recently also for surface modification. Resolving power of conventional optical microscope is restricted by diffraction of light hence other methods for sample observation with higher resolution were introduced. These methods also posses their resolution limit.

The scanning probe microscopy technique *SPM* is a large group of microscopy techniques, where the probe is scanning over the sample and creates the image of e.g. topography, reflection, electric conductivity etc. point by point [1]. Quality of the scanning probe, in particular the tip, is the crucial factor that influences the resulting image. In the case of topography image, the tip sharpness is important. Some topography distortion caused by blunt tip can be eliminated using offline data processing.

2. SNOM FUNDAMENTALS

The scanning near-field optical microscopy *SNOM* is one of the *SPM* techniques. Compared to other kinds of microscopy, *SNOM* uses optical fiber probes, its lateral resolution is lower, but provides some extra information upon sample. Considering Fig. 1 measurement configuration, the topography, reflectivity signal and electric response of sample can be measured simultaneously. Laser light is coupled into fiber and locally excites the sample. Reflected light is detected by photomultiplier *PMT* and electric response is measured using lock-in amplifier/voltmeter. Topography measurement is based on shear forces feed-back scheme, see Fig. 2. The fiber glued onto the quartz tuning fork is excited in transverse vibrations on resonance frequency by piezodriver . Electrical outputs of quartz have a voltage response due to the mechanical oscillation. This voltage response is a feedback signal that bears with the magnitude of fiber oscillation and the probe *z* motion is driven by its implication. The oscillations are damping as the probe approaching the sample. The tip sharpness influences the mechanical resonant frequency and the magnitude of oscillation.

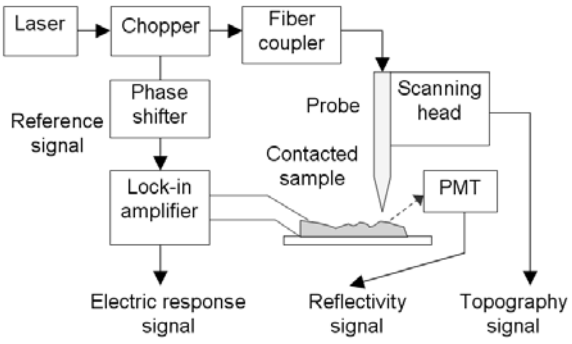

Figure 1 Measurement configuration

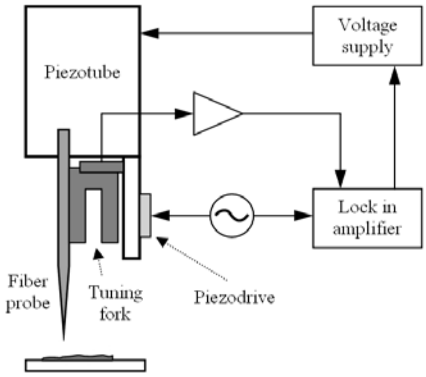

Figure 2 SNOM feedback system

3. ARTEFACTS

Let us consider that nonlinearity, hysteresis, creep and cross-coupling do not affect the scanner features. Then the image resolution depends only on the tip sharpness. Therefore a topographic image is a result of the sample and tip shape convolution. Image distortion appears in the case when a tip is larger than the scanned object on the sample surface. Scanning process using sharp tip and blunt tip is drawn in Fig. 3. Solid line is the shape of the surface and measured topography (using two different tips) is presented by dashed line.

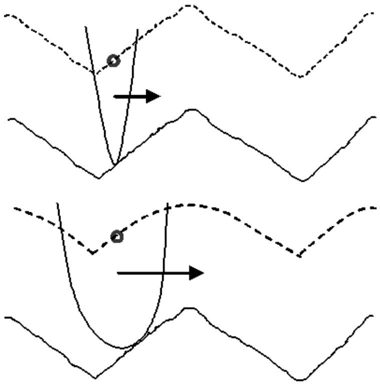

Figure 3 Sharp tip and blunt tip scanning

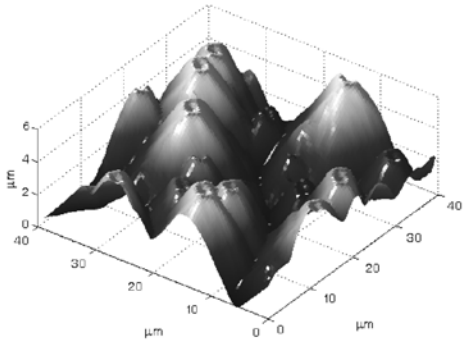

Figure 4 Solar cell topography artefact

Real topography image with artefact caused by the tip-sample mirror effect is shown in Fig. 4. Used sample is pyramidal textured silicon solar cell. There, the sharp protrusions on the sample surface act as the probe to image the scanning tip. Mirrored tip was probably heavily damaged, hence there are small pits on every of pyramids peak. Sometimes it is difficult to distinguish what is an artefact and what is a real structure. The procedures that allow verify a presence of the tip-sample mirror artefact and determine the tip shape have been found there [1, 2].

4. TOPOGRAPHY RECONSTRUCTION

Topography distortion caused by the tip imperfection can be restored providing that the shape of the tip is known. In order to find out the tip shape, measurement on calibration lattice should be made. If tip-sample mirror effect occurs there, it will be possible to determine the tip shape. The tip is mirrored perfectly if the structure, that causes mirror effect, will be spot irregularity like. Despite of measured surfaces are discreteness most often, suitable structures can be presented.

Peaks of pyramidal structure have spot irregularity like properties and so the tip-mirror effect can occur (see Fig. 4). Texturing is created by treating with an anisotropic chemical etching, which acts preferentially along the (111) crystal planes and leaves a pattern of pyramids on the surface [3], hence the top angle of structure is well known. This fact allows us to perform accurate estimation of tip shape. For this estimation, some algorithms have been recently developed. The method known as blind tip reconstruction is based on mathematically extracted geometry from a given image [5]. In this paper, we develop new method based on the modification of Villarrubia's tip characterizion [2].

First, it is necessary to estimate the tip size. That can be achieved by subtraction of a scanned pyramid and an ideal pyramid. Result of the subtraction is shown in Fig. 5. The peak of real pyramid and the peak of topography image are not situated in the same place, if the tip is not symmetric (see Fig. 6). Nevertheless, for the tip size estimation, it is not necessary to know an accurate position of the pyramids peak. For subtraction purposes, it is possible to put a peak of ideal pyramid in the same place where the peak of scanned surface is. Notice, that in areas where the tip is not mirrored, the distance between ideal pyramid and distorted pyramid is constant (see Fig. 6). The tip size can be estimated using spatial derivation of subtraction result.

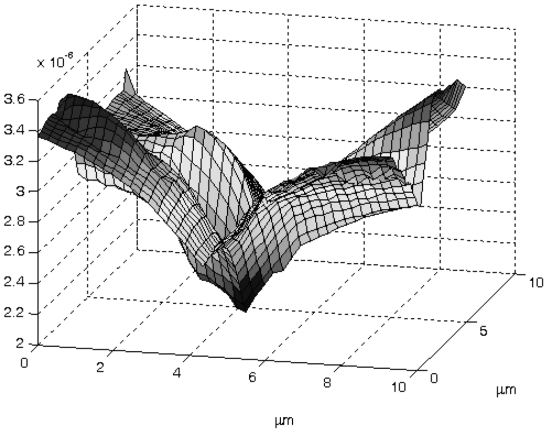

Figure 5 Real surface and ideal pyramid subtraction

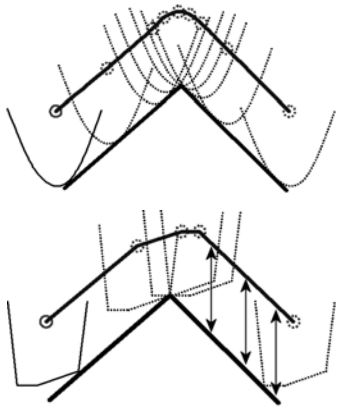

Figure 6 Artefact - symmetrical and unsymmetrical tip.

The numerical deconvolution is most effective method of image restoration [1, 3]. It is necessary to note, that the full restoration of image is only possible if the tip has touched all points of the surface during the scan, and the tip has been always touching surface only in one point [4]. If these two conditions are not satisfied, the image reconstruction will be only partial. The partial surface reconstruction is illustrated for one-dimensional case in Fig. 7. From this image, it is clear, that there are areas where the topography cannot be restored, nevertheless these areas can be marked using map of uncertainty.

As follows from Fig. 7, the topography reconstruction can be explained subsequently: the known tip (mirrored shape) that moves along a distorted topography curve creates the deconvolution image. In areas where the topographic image cannot be restored, there is the tip-print. The number of point simultaneously touching the restored surface is higher in areas of the tip-print. One point of uncertainty map can be determined as minimum count of points simultaneously touching the restored surface. Topography image, as a result of numerical deconvolution with uncertainty map colour mapping is shown in Fig. 8.

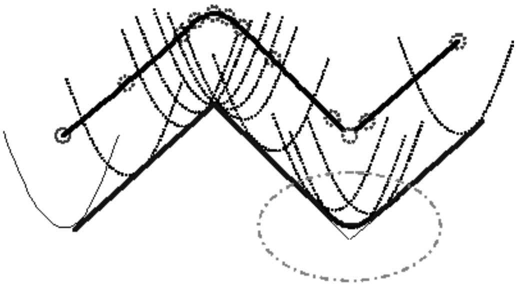

Figure 7 Surface reconstruction issue

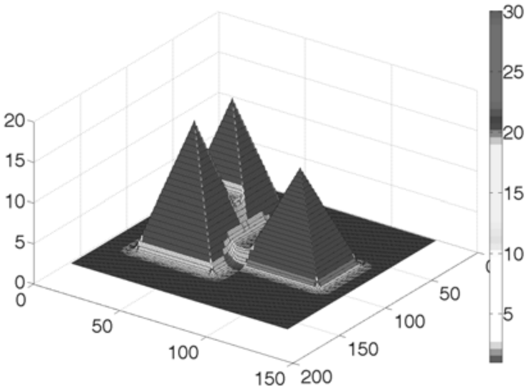

Figure 8 Restored topography with marked uncertainty regions

5. RESULTS

Matlab script was created that allows tip shape determination and deconvolution of distorted image. Moreover, it additionally allows localization of uncertainty regions (see Fig. 8). The script was tested using generated surfaces and with the real topography images, too. As seen in Fig. 9 (left), the tip is mirrored onto every peak of pyramids. After tip shape determination, the topography image was restored using deconvolution (Fig. 9 right). The tip shape determination had to be correct in as much as the peaks of all pyramids are sharp.

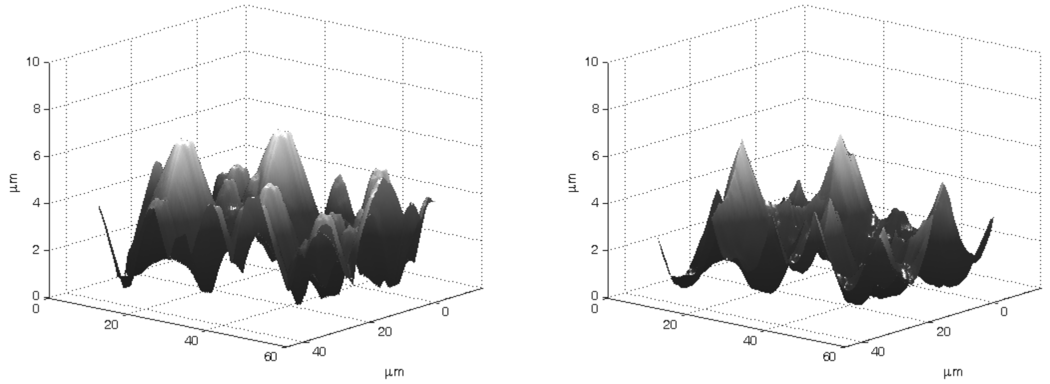

Figure 9 Distorted topography image (left), restored topography image after surface deconvolution (right)

6. CONCLUSION

Artefacts are presented in every SPM topography image due to final tip size. In most cases, a distorted image can be partially restored using numerical deconvolution. There are some methods for tip size and shape estimation: imaging the tip using scanning electron microscopy, blind tip estimation and reconstruction by known sample structure. The knowledge of sample surface morphology allows accurate tip shape determination. In many cases only the partial reconstruction of topography could be performed. The proposed method is satisfactory for purposes of silicon solar cells study, where the topography is not as important as other locally measured properties that also depend on the tip shape. This method is applicable only for samples with specific surfaces nevertheless it also affords opportunity for confrontation and estimation of various methods results.

ACKNOWLEDGEMENTS

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