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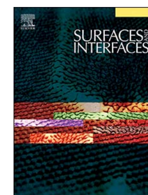

Selecting suitable image dimensions for scanning probe microscopy

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ABSTRACT

The use of scanning probe microscopy to acquire topographical information from surfaces with nanoscale features is now a common occurrence in scientific and engineering research. Image sizes can be orders of magnitude greater than the height of the features being analysed, and there is often a trade-off between image quality and acquisition time. This work investigates a commonly encountered problem in nanometrology - how to choose a scan size which is representative of the entire sample. The topographies of a variety of samples are investigated, including metals, polymers, and thin films.

1. Introduction

Surface metrology can be defined as the measurement of the deviations of a workpiece from its intended shape [1]. This include features such as deviations from roundness, straightness, flatness, cylindricity, and other descriptors of specimen shape. Surface topography measurement also detects the marks left on a specimen in trying to achieve the shape, such as those created by machining or polishing. Surface metrology is also highly relevant to nanotechnology and micro/nanofabrication, for example assessing the structure of thin films manufactured using vapour deposition [2-4], or using focused ion beam to etch surfaces [5–6]. Researchers in these fields represent a range of scientific and engineering disciplines, and hence may be unfamiliar with the complexities of measuring surface topography. It would be helpful if a simple set of rules or guidance could be established regarding topography measurement

The development of the scanning probe microscope, particularly the scanning tunnelling microscope (STM) [7] and the atomic force microscope (AFM) [8], revolutionised the ability to acquire three-dimensional topographical information. These techniques are now well-established as 'go-to' analytical tools when dealing with nanomaterials and nano-engineered surfaces. The versatility of AFM for imaging both conductive and insulating materials means it is particularly popular. Researchers have sought to capture the effect of scanning parameters such as scan speed [9], cantilever dynamics [10], tip size [11], and the choice of medium in which scanning is performed, e.g. liquid environment [12–13]. For example, Westra and Thomson investigated how the finite size of the AFM tip influenced surface profiles [14]. Vertical measures were found to be relatively insensitive to increasing tip size. In contrast, lateral measures became increasingly distorted as tip size increased.

The 1-dimensional average roughness, R_a, of a surface is defined as ``arithmetic mean deviation from the centre line through the profile" and is expressed mathematically by Eq. (1), in which n is the number of pixels in the image, and y_i is the deviation from the centre line for each pixel.

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i| \tag{1}$$

The aim of this work was to address the question “does there exist an optimal range of image sizes for the measurement of nanoscale surface roughness?” Characterisation of the surface topography of a selection of polished, machined, deposited and cast surfaces was performed using atomic force microscopy. Image sizes in the range 0.1–100 μm were employed, and the average roughness was calculated for each image.

2. Experimental

2.1. Sample preparation

Samples were immobilised onto steel specimen disks (Agar Scientific, UK) using cyanoacrylate adhesive (Loctite, UK) prior to measurement. If required, samples were trimmed to dimensions of 30 mm × 30 mm or smaller. The samples prepared were

(i) Al_2O_3 disc (Agar Scientific, UK)
(ii) polished steel disc (Agar Scientific, UK)

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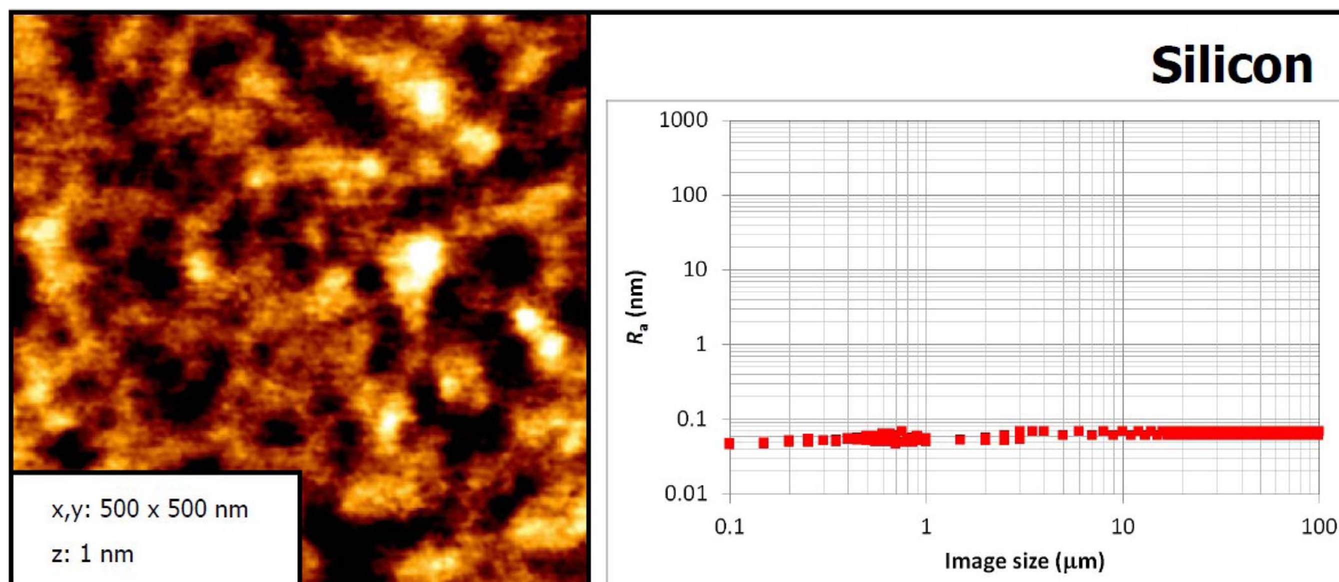

Fig. 1. AFM image (x,y = 500 nm; z = 1 nm) and R_a as a function of image size for Si(100).

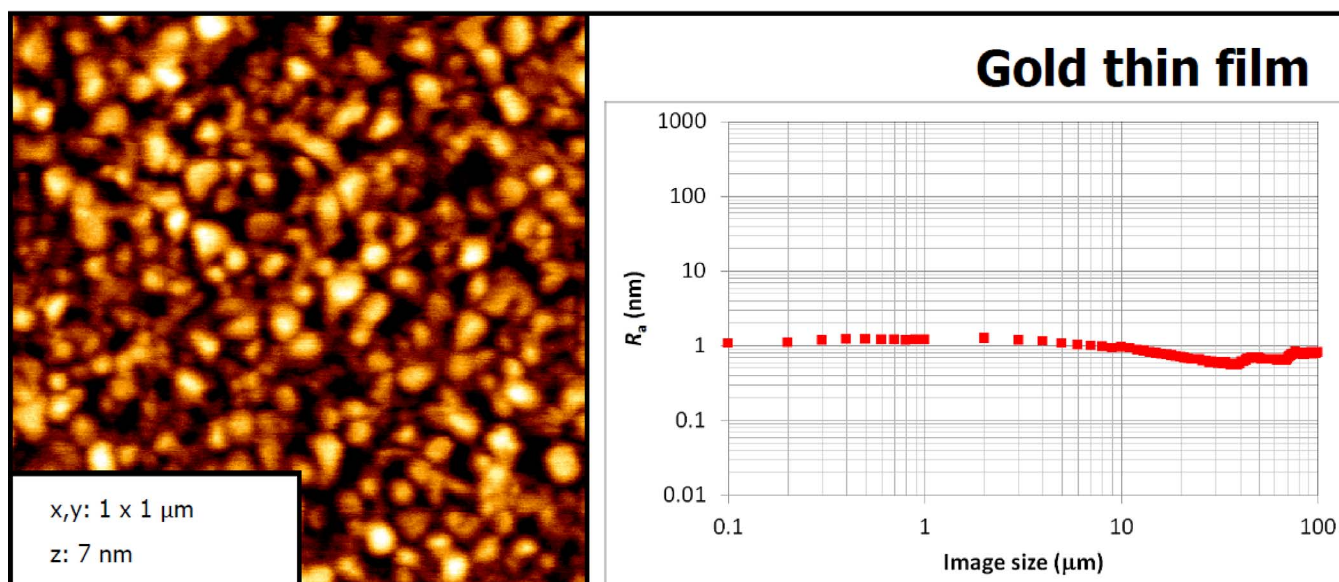

Fig. 2. AFM image (x,y = 1 µm; z = 7 nm) and R_a as a function of image size for 30 nm Au film.

(iii) poly(methyl methacrylate) tile (in-house supply)
(iv) poly(styrene) Petri dish (BD Falcon, UK)
(v) poly(tetrafluoroethylene) sheet (Altec, UK)
(vi) CaF_2 window (Crystran, UK)
(vii) Si(100) wafer (IDB Technologies, UK)
(viii) 30 nm Au film thermally evaporated onto Si wafer (Georg Albert PVD, Germany)
(ix) 100 nm CF_xO_y film deposited onto Si wafer using plasma polymerisation, see Cheneler et al. [15] for further details.

2.2. Characterisation using AFM

Surface topographies were measured within square scan windows, with equal x- and y-dimensions. The length of the x-dimension is hereafter referred to as the Image Size, s. The Image Size was varied in the range 0.1 µm–100 µm. A line pixel density, p, of 512 pixels was employed throughout; this means that images were composed of a square array of pixels measuring 512 × 512.

Images were acquired using a NanoWizard II AFM (JPK Instruments, UK) operating in Contact Mode at a temperature of 18 °C and a relative humidity of < 40%. Rectangular pyramidal-tipped Si cantilevers (CSC17/noAl, MikroMasch, Estonia) with a nominal tip diameter of < 10 nm were employed. Samples analysed using the AFM were held in place using a custom-built magnetic sample stage. 1-dimensional image analysis was performed using JPK Data Processing software (JPK Instruments, UK), while 2-dimensional image analysis was performed using Scanning Probe Image Processor software (Image Metrology, Denmark). Plane correction was performed using linewise levelling.

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