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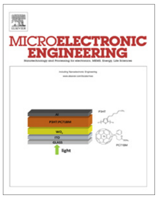

A dedicated calibration standard for nanoscale areal surface texture measurements

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ABSTRACT

Assessing product quality already during manufacturing is vital in order to optimize production processes, increase product quality, reduce waste and preserve resources. Product quality can be assessed by measuring specific product characteristics that are correlated to the quality, i.e. critical to quality parameters. Currently, product features and characteristics are entering the nanoscale domain and require increasingly accurate measurement instrumentation to inspect and validate product quality. Accurate calibration of instrumentation at the nanometer length scale has therefore become increasingly important to substantiate the validity of measurements on manufactured products. Although calibration standards are available for some application dedicated calibration standards for specific application are usually not available and have to be designed, manufactured and calibrated. In order to enable accurate calibration the nanoscale, we have designed and realized a calibration standard to calibrate instrumentation for the areal surface texture parameter *Sq*. The realized standard has been optimized for scanning probe applications. A method for the calibration of the standard itself is demonstrated resulting in sub nanometer measurement uncertainty of the standard.

1. Introduction

Within the European 7th framework program the aim4np (automated in-line metrology for nanoscale production [1]) project team is developing a metrology platform that will be dynamically positioned over the product in order to measure critical to quality (CTQ) surface properties already in the production environment. This will enable quality assessment at the early stages of manufacturing and provide the possibility to adjust production parameters when CTQ parameter values are about to run out of tolerance. The platform will carry a white light interferometer based on coherence scanning interferometry for optical inspection and an atomic force microscope (AFM) for more detailed inspection on the nanometer scale. In order to ensure the reliability of measurement results obtained by the metrology instruments, these instruments have to be calibrated and measurement uncertainties have to be established. The calibration of these instruments will be performed by transfer standards since this approach provides a practical, cost effective solution that is still sufficiently accurate. The functionality of the surfaces for the products that will be produced in this project, i.e. organic solar cells and precision molded parts, is determined by measuring the areal surface texture parameter *Sq* for values over a range up to 20 nm. The requirement for the measurement uncertainty in the *Sq* value is 0.6 nm. The measurement uncertainties in this paper are stated for 95% coverage probability. This paper will describe the development and implementation of a dedicated calibration standard for the parameter *Sq*. From the available budget of 0.6 nm for the uncertainty in the measured values of *Sq* we have we have set a maximum value for the uncertainty of the calibration standard itself of 0.3 nm.

Procedures for the measurement of surface texture parameters are extensively described in literature [e.g. 2–4]. These papers and publications provide definitions, guidelines and methods to extract surface texture information from a 3D data set in a consistent way in order to provide comparability between measurement results obtained by different instruments and techniques. The development of a coherent set of calibration documents is facilitated by the results from working group ISO TC213-WG16 “Areal and profile surface texture” that has identified a set of common metrological characteristics for all instruments that measure areal surface topography. Methods for the measurements of the metrological characteristics measurement noise, residual flatness, the amplification coefficient, the linearity, squareness and lateral resolution have been reported in recent years [5–7]. The subtraction method [5] is applied in this paper to eliminate background texture.

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In order to calculate surface texture parameters from a raw data set, application of S, L and F filters is usually required to remove small-scale (e.g. to remove noise) and large-scale features or form [2,3]. The resulting scale-limited surfaces are then processed to extract the required texture parameter. In this paper the measured surface texture data is not filtered using an S, L, F or combined filter since the shape of the designed profile of the standard must be preserved as good as possible. Removing information by filtering modifies the derived relation between the processed data and the calculated reference value of the surface texture parameter.

Standards for the calibration of surface texture have been developed in the form of physical standards previously [8–10] where the authors describe the design, fabrication and characterization of irregularly shaped standards. The properties of these standards are, however, not suitable to be used in the current project because of relatively large *Sq* values (50 nm–1 μm) while we require *Sq* values smaller than 20 nm.

2. Areal surface texture parameter *Sq*

Although areal surface texture parameters have some resemblance to the classical roughness as measured by profile parameters, they provide a more suitable way to correlate the surface condition to the actual functionality [4]. Whereas a single profile only samples the surface in one direction, areal surface texture truly captures the spatial characteristics of the surface. With the development of scanning probe measurement techniques and the advances in optical probing, the demand for standardized areal surface texture parameters has increased. The efforts to standardize these parameters have resulted in a publication of an ISO document with the formal definitions for a wide range of areal surface texture parameters [2]. According to this document, the areal surface texture parameter *Sq* is defined as follows:

$$Sq = \sqrt{\frac{1}{A}\iint_A z^2(x,y)dxdy} \tag{1}$$

where z denotes the height values as a function of the lateral coordinates x and y that define the measurement area A. Therefore *Sq* represents the root-mean-square of all z values of the 3D coordinates in the measurement field. Since the z value of each 3D coordinate is relative to some arbitrary offset, this offset has to be compensated first. The definition of *Sq* does not contain a recipe for offset compensation but common sense dictates that the z-values in Eq. (1) should be calculated relative to the most suitable reference surface.

For a surface that is nominally flat, the reference surface would be the plane resulting from a least squares fit of the dataset, see Fig. 1. When the measured points are part of a non-planar surface, the reference surface is based on a fit to the nominal shape of the surface as defined by the design of the surface.

3. *Sq* calibration standard design

The design process is governed by a set of boundary conditions regarding the calibration of the standard itself, the applicability for the metrology instruments that have to use the standard and its manufacturability. Depending on the linearity of the instrument to be calibrated, it has to be considered that a set of several standards with different *Sq* values has to be used. Since we require a limited but specific range of *Sq* values it would also be highly advantageous to be able to calculate the *Sq* value for the structure to be designed instead of just fabricating a standard that later turns out to have an improper *Sq* value.

Additionally, the use of the standard to calibrate metrology instrumentation in a production line should generate as little overhead as possible. Therefore, the design should avoid the need for alignment of the standard, a search for a specific region or adjustment of the instrument to a specific measurement range; the standard should provide the same value whatever the orientation, offset, and magnification. Finally, the implementation of the standard should be feasible with existing manufacturing processes without adding substantial effort and cost compared to the effort and cost of producing the product.

The design process that we followed is based on the details in the definition of the *Sq* parameter. We first rewrite the definition to include the raw data z_{raw} and the reference plane z_{ref}:

$$Sq = \sqrt{\frac{1}{A}\iint_A (z_{\text{raw}}(x,y) - z_{\text{ref}}(x,y))^2 dxdy} \tag{2}$$

The reference plane z_{ref} is calculated from the actual raw measurement values by a least squares fit to the data set. As a consequence, the reference plane and therefore the value of *Sq* will generally depend on the size, position and orientation of the area that is measured. One way of making the reference plane and therefore the value of *Sq* independent of the size, position and orientation of the area is to restrict the allowed values of z_{raw}. When we allow only two values for $z_{\text{raw(max)}}$ and $z_{\text{raw(min)}}$ that cover equal areas the value of the reference plane reduces to:

$$z_{\text{ref}} = 0.5 \cdot (z_{\text{raw(max)}} + z_{\text{raw(min)}}) \tag{3}$$

When we only have equal amounts of the values $z_{\text{raw(max)}}$ and $z_{\text{raw(min)}}$ we can split the integral in Eq. (2) into two parts, each representing half the surface area A. Since the upper level value $z_{\text{raw(max)}}$ and lower level value $z_{\text{raw(min)}}$ are located symmetrically with respect to z_{ref} by definition, the two integrals in the first line of Eq. (4) are the same because the values are squared. This yields the second line of Eq. (4) and represents the square root of the

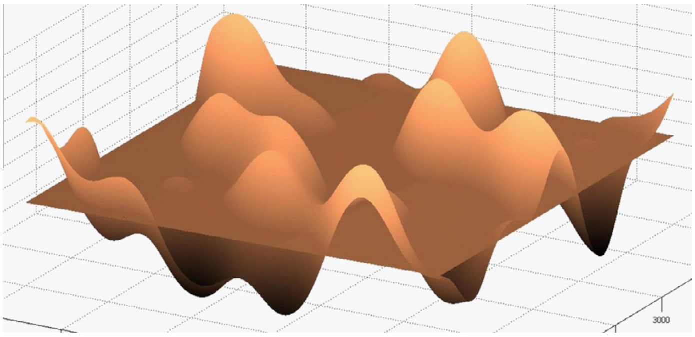

Fig. 1. Schematic representation of a 3D measurement field of a surface area and the plane that represents the best fit.