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Three-directional Drift Correction Method Based on Iterative Closest Point (ICP) Algorithm

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Summary:

A new method for evaluating and correcting full three-dimensional drift in AFM measurements has been proposed. The method applies two measurement sets: (A) Multiple measurements with reduced resolution and thus reduced measurement time and drift; and (B) One detailed measurement with higher spatial resolution at costs of longer measurement time and larger drift. The data sets are aligned using the iterative closest point (ICP) algorithm to quantitatively evaluate the drift in full 3D. The obtained drifts are then applied to correct the measured data sets to significantly reduce drifts.

Keywords: drift correction, AFM, data fusion, iterative closest point (ICP) algorithm, nanometrology

Background and motivation

Accurate and traceable three dimensional (3D) measurements of complex nanostructures are a crucial and challenging task for e.g. the state-of-the-art nanoelectronic industry. Atomic force microscopy is a widely applied technique for 3D metrology of complex nanostructures with high spatial resolution. To obtain true 3D measurements of complex nanostructures, two kinds of AFM techniques such as flared AFM tip and tilting AFM technique have been widely used.

At the Physikalisch-Technische Bundesanstalt (PTB), a 3D-AFM based on the flared AFM tip has been successfully developed and applied for calibration services [1]. It has the benefit of full 3D measurements of nanostructures with a single AFM measurement. However, due to the complex tip shape of the flared AFM tip, it is difficult to measure dense nanopatterns. To solve this problem, currently a new 3D-AFM based on the tilting tip technique is being built up. Using this technique, a nanostructure is measured by an AFM tip tilting in different angles, where the obtained AFM images will be then fused to derive the real 3D topography of the nanostructure. Owing to the sharp AFM tip applicable in the tilting AFM, it has the advantage of measuring high dense patterns. To accurately realize data fusion in the tilting-AFM, the drift compensation is becoming a critical issue [2].

Concept

Drift in AFM is a time dependent shift in the relative position of the AFM tip and the sample. When occurring during measurements drift causes distortions in the recorded data and thus significantly impacts the measurement accuracy.

Better temperature stabilization via active or passive temperature control is a widely applied measure for reducing drift. In high-precision nanometrology, however, even such measure is insufficient. Thus, drift correction becomes essential.

The basic concept of the drift correction is based on the fact that the drift is time dependent. A reduced measurement time usually suffers less from drift. Reduction of measurement time either requires an increase in measurement speed, or a reduction of measured data. As higher measurement speed degrades measurement performance due to e.g. tip wear and/or measurement noise, the reduction of recorded data in a single measurement is a better approach to follow. Therefore, our drift correction method applies two measurement sets which are taken at the same area of the sample: (A) Multiple consecutive measurements with reduced resolution and thus reduced measurement time and drift; (B) One detailed measurement with higher spatial resolution at costs of longer measurement time and larger drift. By correlating the two data sets, the drift correction can be performed without degrading the measurement quality, as detailed below.

Each of the measurements in A provides a set of data points, containing information of the sample topography, slightly distorted by drift. A simple method to correct the 3D drift, is to merely correct the measurement sets A. By aligning the point sets with each other using the Iterative Closest Point (ICP) algorithm, the positional offsets between measurements in A can be evaluated, which reveals the 3D drift of each measurement. By fitting the curve of the evaluated 3D drift v.s. time to a polynomial function for each axis, respectively, the 3D drift functions of the tool can be approximated. The drift function can then be applied to correct the drift of individual measurement points based on their acquisition time. After the correction, the multiple point sets in A can be merged and aligned to a single point set with dramatically reduced drift. However, because of slightly different residual drift in the merged data set and small inaccuracies during the alignment process, a remaining problem is that the merged set of surface points shows an increased noise level.

To overcome this problem, the drift correction method can be extended. In this case, the measurement set B is measured additionally. Then, the merged data set A, which has corrected drift as mentioned above, is applied as a reference data set to correct the data set B. In such a way, the resulting data set has both advantages of the merged data set A (i.e. reduced drift) and B (i.e. high measurement resolution and low noise level).

In the detailed correction algorithm, the data set B is divided into several segments, usually with a certain overlap. Then they are individually aligned to the reference data set A using ICP algorithm, and the offsets of the segments are determined. Such offsets reveal the 3D drift of the data set B using A as the reference. Finally, the drift of each point in data set B can be corrected.

Results

Both simulations and experiments have been carried out, showing good performance of the proposed method. In the simulation, AFM measurement data sets A (with a point density of 30 nm) and B (with a point density of 10 nm) are simulated with several given drift curves. The corrected 3D drifts are compared to the given data to evaluate the performance of the method. The result indicates that the drift can be reduced from more than tens of nanometers to a few nm or even below.

The applicability of the correction method has been demonstrated with real experimental data shown in Fig. 1. Fig 1(a) and (b) show a data set B before and after applying the drift correction, respectively. It can be clearly seen that the distortion of the line structure due to the drift is significantly improved.

Conclusion & Outlook

Drift is a general problem in high precision measurements and metrology applications. The method proposed in this paper shows a promising performance for correcting drift distortions in AFM measurements. The idea is applicable for other measurement applications as well.

The performance of the proposed drift correction method depends on several factors, for instance, the measurement time of the data sets in A, as well as the accuracy of the ICP algorithm. Quantitative investigation of these issues will be performed in the near future.

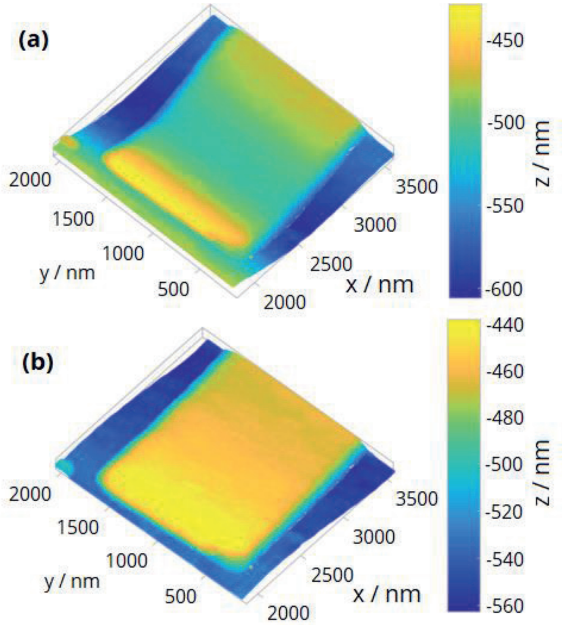

Fig. 1. Measured data set B shown as (a) before, and (b) after the application of the proposed drift correction method, respectively.

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