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Current Advances in 3D Tip- and Laser-based Nanofabrication in Extended Working Areas

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Summary:

Nanotechnology is affecting almost all areas of life, from semiconductor industry to optics, medicine and agriculture. Classical methods for sensing, measuring and fabricating on the nanoscale are faced with new challenges: features are getting smaller and the variety of structures and materials is increasing. Thus, many new techniques are developed in this field. Research at the Technische Universität Ilmenau aims to support transferring these new technologies to industrial scale for future application. The focus is on tip- and laser-based processes together with devices for nanometer positioning.

Keywords: nanomeasuring, nanomanufacturing, scale-spanning, tip-based, laser-based

Introduction and Motivation

Classical optical lithography was and still is the main technology for fabricating structures in the nanometer range. However, with the trend to ever smaller structures, complex 3D features and large processing areas [1], the necessary effort has become huge, making this technology expensive and inflexible with respect to design changes [2]. On the other side, nanotechnology can give the answer to many questions in almost all areas of live from energy to environment and climate [3] and many more. In this fields, many new technologies for measuring, structuring and sensing in the nanometer range are developed [4]. However, these technologies are often only investigated in lab scale, leaving the question of their suitability for large scale application unanswered. To bring these new technologies to larger scale, it is necessary to provide a flexible technological framework which is capable of nanomeasuring, nanopositioning and nanofabrication in the range of several square centimeters. For that purpose, the research training group (RTG) *NanoFab* at the Technische Universität Ilmenau is aiming to combine their nanopositioning and nanomeasuring machines (NPMMs) [5] with new nanofabrication technologies to close the gap between lab scale proof-of-concepts and industrial application [6].

Methods

Basic devices for research in our RTG are the NPMMs which have been developed at the Technische Universität Ilmenau since two decades. They offer highly accurate, high dynamic, reproducible and long-term stable nanometer positioning in a large working range between 25 x 25 x 5 mm^3 [5] and 200 x 200 x 25 mm^3 [5] or a 2D area of Ø100 mm [7]. This makes them perfectly suitable for the challenges in current alternative nanofabrication technologies. Based on these NPMMs, several research topics are currently investigated in the RTG *NanoFab*, including tip-based and laser-based processes as well as solutions for curved surfaces, nanooptical systems, measuring of small forces and future nanopositioning systems [6].

Results

In the field of tip-based fabrication, current research in our RTG is on the combination of atomic force microscopy (AFM) with field-emission scanning probe lithography (FE-SPL) which can be used for resistless structuring of 2D materials by a defined electron exposure dose [8]. With this technique, sub-20 nm resolution nanolithography can be performed on different materials, including graphene, semiconductors, semimetals and topological insulators. This tool combination is also used for long-range exposure of Calixarene-coated samples. Using the NFM-100 for positioning, gap-less and stitching-less FE-SPL [9] (see Fig. 1) and nanometer-resolution AFM measurements [10] (see Fig. 2) over several millimeters can be performed. To enhance the position uncertainty and stability of the NPMMs, these machines are constantly developed further. In addition to the investigation of alternative measuring systems [12], focus is on new concepts for the control system [13] to further enhance the positioning performance. For that purpose, a control con-

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cept for a pneumatic gravity compensation was developed to reduce heat dissipation in the vertical drive axes of NPMMs (see Fig. 3).

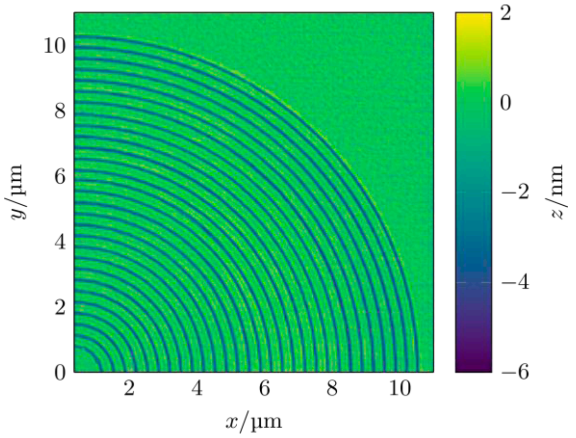

Fig. 1. Detail of a 1 mm FE-SPL line in spiral trajectory seamlessly written with the NFM-100. [11]

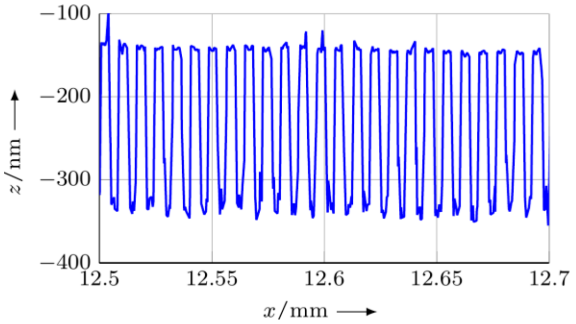

Fig. 2. Detail of a seamless 50 mm AFM scan of a periodic grating using the NFM-100. [10]

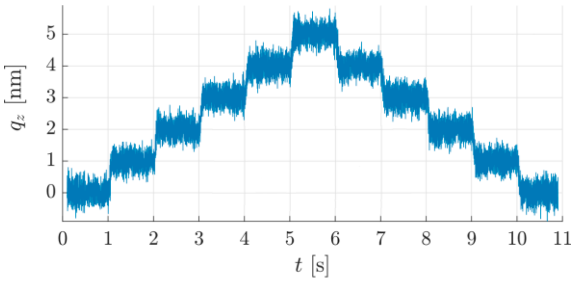

Fig. 3. Vertical positioning of a 4 kg payload with nanometer accuracy. Due to pneumatic gravity compensation, heat dissipation is only 54 nW. [13]

Besides the tools for fabrication, devices for measuring in the nanometer range are investigated, as pre- and post-inspection of the manufactured structures is an important link in the complete toolchain. Where lateral resolution is of lower priority, optical principles are preferred due to their neglectable interaction with the sample and the achievable measuring speed. For ensuring nanometer depth-accuracy, the influence of the measured surface has to be exactly modeled and compensated [14].

Conclusion

Nanopositioning and nanomeasuring in large working areas is required for bringing alternative technologies from lab scale to industrial scale. In the RTG *NanoFab*, a broad spectrum of the resulting challenges in the fields of tip- and laser-based fabrication processes, measurement technology and control theory is addressed.

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