Lateral Force Contrast on Dots produced by Dip-Pen Nanolithography (DPN)

Introduction

Several different lithography techniques exist that allow modification of material surfaces during or after their microfabrication. One of the most versatile of these techniques probably is the so-called "Dip-Pen Nanolithography" (PDN). DPN is the nanoscale equivalent to writing with a fountain pen, in which the tip of an atomic force microscope (AFM) cantilever acts as the pen (Figure 1). The "ink", which can consist of a wide variety of nanoscale materials, is transferred from the tip to the sample surface through a water meniscus that automatically forms between tip and surface at ambient humidity.

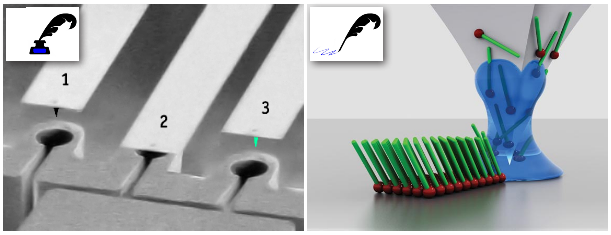

Figure 1: Principle of Dip-Pen Nanolithography (DPN). (Left) Loading: A cantilever [1] is dipped into a nano-well of "ink" [2] and is retracted [3]. (Right) Writing: The loaded cantilever is brought into contact with the writing surface, and "ink" is being deposited through a self-forming water meniscus. Images courtesy of Nanoink Inc.

The strength of DPN lies in its high patterning resolution (15 nm) and accuracy (5 nm). This way, it is possible to deposit new substances (e.g. Thiols or other chemicals) onto a surface in a highly controlled manner and on a tiny scale, resulting in exciting new applications. The technique was first reported under the name Dip-Pen Lithography (DPL) by Manfred Jaschke and Hans-Juergen Butt in 1995, but was not detailed or pursued further. In 1999, it was discovered independently by the research group led by Professor Chad Mirkin at Northwestern University, who was awarded the patents for the process. Currently, the exclusive license for the DPN technology resides with Nanoink Inc, which is the sole provider for DPN equipment. The characteristics of materials deposited by DPN are usually studied by Lateral Force Microscopy (LFM), as it is one of the few techniques capable of detecting material differences at such high resolutions. The Nanosurf easyScan 2 FlexAFM offers LFM in combination with easy handling, making it Nanoink's instrument of choice for DPN analysis.

Lateral Force Microscopy

Lateral Force Microscopy allows areas with different frictional attributes to be distinguished. Differences in frictional attributes can arise through differences in viscosity, elasticity, adhesion, capillary forces, surface

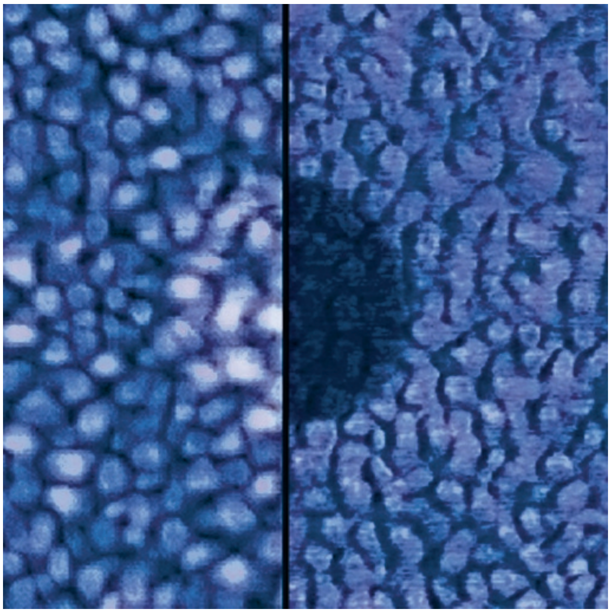

Figure 2: AFM recordings on Alkanethiol molecules deposited on gold using Dip-Pen Nanolithography (DPN), NanoInk's patented process for deposition of nanoscale materials onto a substrate. (Left) Topography data. (Right) Lateral force data. The combined scan area of the two image halves corresponds to 1.0 µm × 1.0 µm.

chemistry, or electrostatic interactions of the materials involved. When a cantilever is scanned statically and perpendicularly to its longitudinal axis, a torsional bending of the cantilever occurs. The angle of torsion is proportional to the lateral force acting on the tip. When moving over a flat surface with regions showing different frictional attributes, the angle of torsion will be different for each region. These regions with different friction attributes can therefore be mapped, and their properties analyzed (Figure 2).

As the cantilever load normal to the surface has a lateral component at inclined surface features, surface topography has an influence on the lateral force measurement. Fortunately, it is possible to distinguish between lateral deflection due to topographic features of the surface and due to frictional forces by simply comparing the forward and backward scan of the AFM images. The lateral deflection due to frictional forces changes sign while the one produced by topography does not (compare Figure 3, left and right).

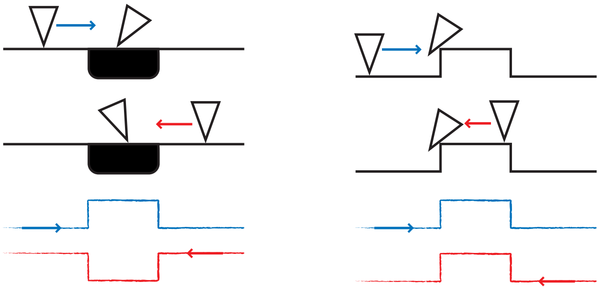

Figure 3: Differences between lateral forces caused by friction and the ones caused by topographic features of the scanned surface. (Left) Mirroring of lateral deflection due to frictional forces. (Right) No mirroring with topographically induced lateral deflection. All forward scan traces are in blue, backward scan traces in red.

Depending on the elasticity of the sample, the sample surface can be deformed during measurements in lateral force mode, especially when it has steep inclines or high topographic features. This deformation may lead to artifacts in the measurement or even to damage of the sample due to the excessive lateral forces that arise from these features. To avoid these deleterious effects, make sure the effective stiffness of the surface is higher than the cantilever's torsional stiffness.

LFM has been successfully used to investigate surface contaminations, chemical specifications, and frictional characteristics of materials such as semiconductors, polymers, thin films, and data storage devices.

Instruments used

All measurements were performed with a Nanosurf easyScan 2 FlexAFM Large Scan (100 µm scan range) scan head operated in Lateral Force mode in air.

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Nanosurf is a leading provider of easy-to-use atomic force and scanning tunneling microscopes. Nanosurf products and services are trusted by professionals worldwide to help them measure, analyze, and present 3D surface information.

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