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PrimeView
Thermal scanning probe lithography

Thermal scanning probe lithography (tSPL) is a nanofabrication method for the chemical and physical nanopatterning of materials with a lateral resolution of 10 nm and a depth resolution of 1 nm. tSPL involves scanning a heated nanoprobe over the sample surface to locally activate chemical and physical transformations.

Experimentation

A basic tSPL set-up includes a heatable probe and a system to scan the probe on the sample surface. This set-up can be adapted depending on the application. For example, a controlled atmosphere may be needed for biology. During patterning, the probe is scanned in contact with the surface to produce highly localized reactions. Parameters influencing patterning can be divided into two categories: those relating to the sample (thermal conductivity and thickness) and those relating to the patterning process (heater temperature, patterning speed and probe load). The heater temperature is the main parameter controlling the reactions and can be varied point-by-point while scanning. Sample preparation varies depending on the application. For example, in biological applications, polymer resists can be spin-coated onto substrates then subjected to chemical deprotection with nanoscale precision, enabling functionalization of the polymer resist with different biomolecules.

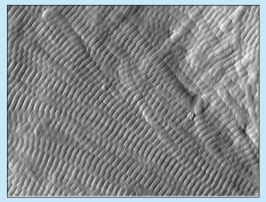
Results

In biomedicine, topography can be visualized through traditional scanning probe microscopy imaging. If visualizing a programmed gradient of reactive groups on the polymer surface, chemistry-sensitive techniques must be used, for example friction force microscopy and/or fluorescence microscopy. In nanomagnetism, characterization techniques are divided into static techniques suited for visualizing the magnetic domain structure and dynamic techniques able to study magnetization dynamics.To assess the output of the tSPL process for nanoelectronic applications, independent measurements must be performed post-patterning. These measurements include X-ray photoelectron spectroscopy, Kelvin probe force microscopy, friction force microscopy, Raman spectroscopy and tests of the material response in the finished device, such as testing of field-effect transistors.

Applications

The unique features of tSPL make it suited to perform tasks not achievable by standard lithographic techniques.

Biomedical


Bone tissue image

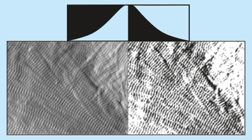
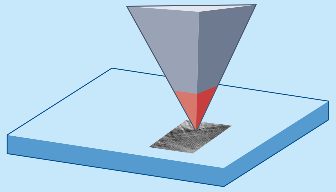
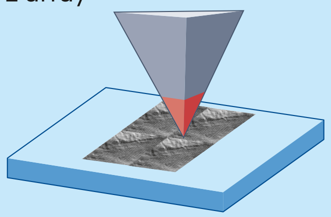


Image processing

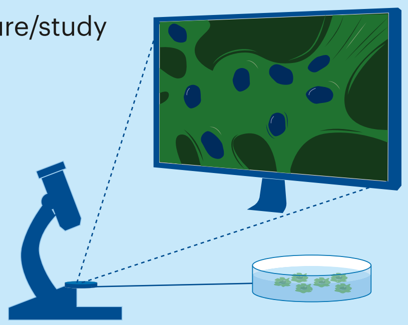
Large-scale tSPL



Large-scale tSPL array

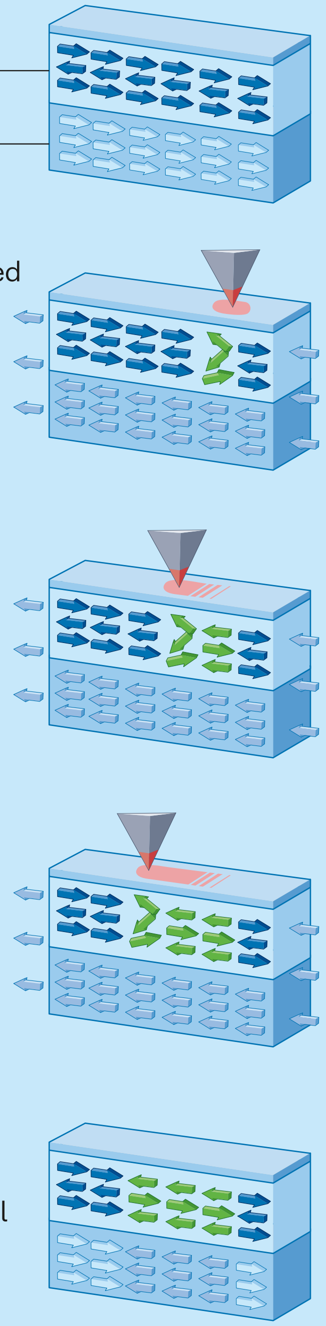


Cell culture/study



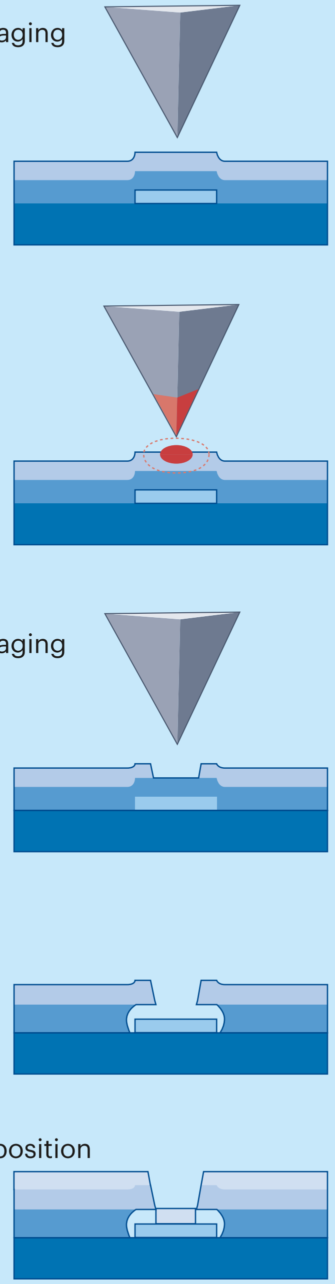
Bone tissue replicas fabricated using bio-tSPL create new possibilities for reproducing the chemical and physical complexity of biological tissues in vitro.

Nanomagnetism



By controlling the probe temperature, pattern geometry and magnetic field point-by-point, it is possible to write complex spin textures in a variety of magnetic systems.

Nanoelectronics



Polymer stacks can facilitate pattern transfer to substrates of interests. For example, patterning high-performing electrodes on 2D semiconductors.

Credit: Microscopy image (by J. M. Wallace), Springer Nature Limited

Reproducibility and data deposition

A number of factors can influence reproducibility. tSPL probes generally undergo changes during scans performed at high temperature and over time when in contact with the surface. In particular, the probe size can be affected by probe blunting and probe contamination. Unexpected outcomes can arise from these changes in the probe properties. The consistency of the probe can be rapidly checked in situ during experiments through calibrations. To date, no specific data repositories, data formats or standards exist for tSPL.

Limitations and optimizations

Resolution is limited by the size and quality of the thermal contact, which in turn depends on the tip geometry, load and the time the probe is in contact with the surface during patterning. Scan speed, positional accuracy and the thermal time constant of the probe vary between set-ups and can limit the patterning speed. In 3D nanopatterning, the lateral resolution and maximum depth are limited by the tip shape and height. Unexpected outcomes can arise from non-optimized protocols for sample preparation, changes in the probe properties and hardware instabilities such as vibrations or drifts during patterning.

Outlook

Using tSPL for producing highly localized tunable physical and chemical transformations is a powerful strategy that is only now being explored. Developing enhanced thermal probes and adapting the technique to specific applications represent important ongoing efforts that will advance the universality of the technique in the desired field. tSPL has the potential to accelerate scientific and technological advances in the fields of nanomedicine, nanoelectronics and nanomagnetism.

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