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Three-Dimensional Laser Writing on the Nanometer Scale

Piezo Drives are Driving Technology Forward

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The best possible positioning accuracy is now mandatory in many fields of application. The examples stretch from the manufacture of semiconductors through biotechnology to optical metrology and microscopy. Nanopositioning systems with piezoelectric actuators are usually the devices of choice in such applications. They operate with repeatabilities in the nanometer range with response times below a millisecond, are vacuum-compatible and work in a wide temperature range. And so, they are opening up new fields of operation for the precision positioning systems. New laser lithography systems are a typical example.
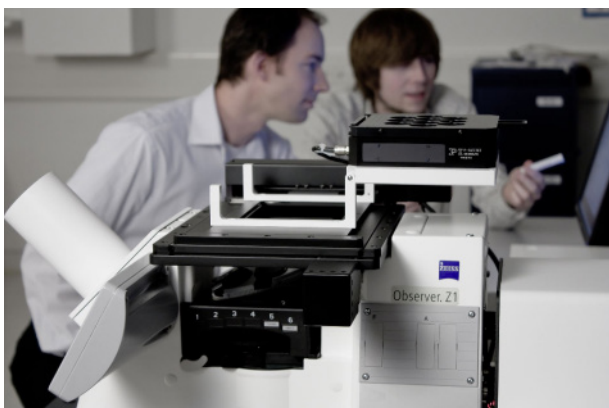

Fig. 1 Novel laser lithography system from Nanoscribe GmbH which – for the first time – allows the production of complex three-dimensional microstructures and nanostructures using photo-sensitive materials (Image: Nanoscribe GmbH)

Nanoscribe GmbH, which was founded at the end of 2007 in Eggenstein-Leopoldshafen, has launched a new laser lithography system (Fig. 1) which, for the first time, allows the production of complex three-dimensional microstructures and nanostructures using photosensitive materials. More than seven years of research flowed into the start-up company, at both the Institute for Nanotechnology at the Karlsruhe Research Center (FZK) as well as at the Institute for Applied Physics at the University of Karlsruhe (TH).

Many applications, especially those in the field of research and development, will benefit from the new lithography system, which can be used to produce reproducible structures on submicrometer scales fully automatically and with a design flexibility not previously known.
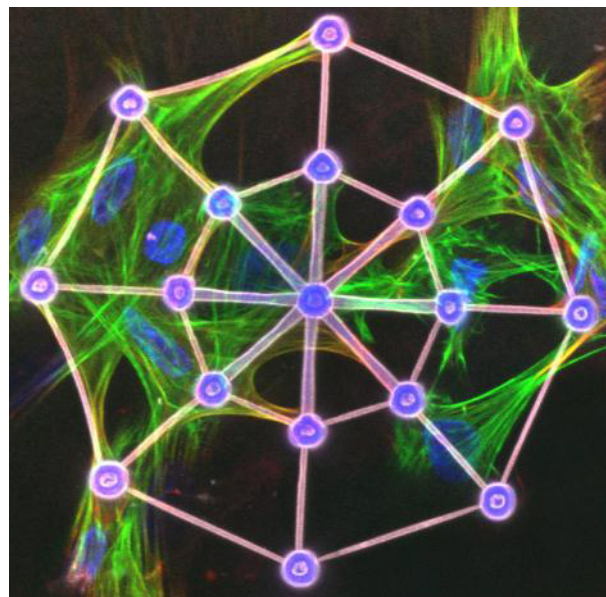

Fig. 2 A matrix for cell biology produced with 3D lithography (Image: Nanoscribe GmbH)

Typical fields of application for the new technology are, for instance, the production of three-dimensional matrices for cellular biology (Fig. 2), the manufacture of micro-optical components or photonic crystals (Fig. 3) and also as a rapid-prototyping instrument for microfluidic and nanofluidic systems and their production in small batches.

The desired structures can be designed and then imported using any CAD software which supports the DXF format, or alternatively by using the specially developed script language GWL, which is specially designed to meet the needs of 3D structuring.
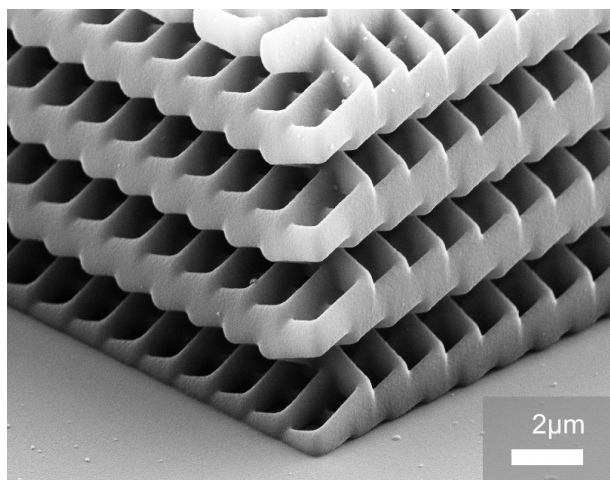
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Fig. 3 Photonic crystal (Image: Nanoscribe GmbH)

Track widths down to 150 nm are possible

The operating principle of the new lithography process, which is suitable for a large number of commercially available photoresists, is easily understood: Ultra-short laser pulses are strongly focused into the material, which is thus exposed by means of a nonlinear optical process in the focal point. Like a pen that is moved in three dimensions, the laser beam writes on the material following arbitrary paths. It is thus possible to achieve track widths from several micrometers down to 150 nm. Two-dimensional or 2½ D structurings are, of course, also possible and have a resolution which is significantly higher than that allowed by conventional systems up to now.

High precision can only be achieved with three-dimensional lithography if the corresponding accurate positioning is possible, however. "During the writing process, both the laser and the focus remain fixed, the sample is moved according to the three-dimensional writing task," explains Martin Hermatschweiler (Fig. 4), CEO of Nanoscribe GmbH.

"This enables us to achieve very high quality results. This positioning task is made all the more difficult by the fact that it is not sufficient to drive to specific positions very accurately. The path here is just as important as the destination, which means the application must also have a precise trajectory control. During the journey, we can then vary the laser intensity according to the acceleration or delay of the drive system in order to achieve the required lithography result."

Fig. 4 Martin Hermatschweiler, CEO of Nanoscribe GmbH (Image: Nanoscribe GmbH)

Positioning System with Piezo Drive and Parallel Motor Metrology for Fine Adjustments

One of the key components for the demands is thus the positioning system from Physik Instrumente (PI). PI offers the largest selection of high-speed and high-resolution piezo nanopositioning system for scientific and industrial applications in the world (Figure 5). "The piezo stage can easily be mounted on the XY scanner stage usually used with microscopes for the coarse adjustment (Figure 6). It operates with scanning ranges up to 300 × 300 × 300 µm³, and the repeatability is in the nanometer range," Hermatschweiler is happy to explain.
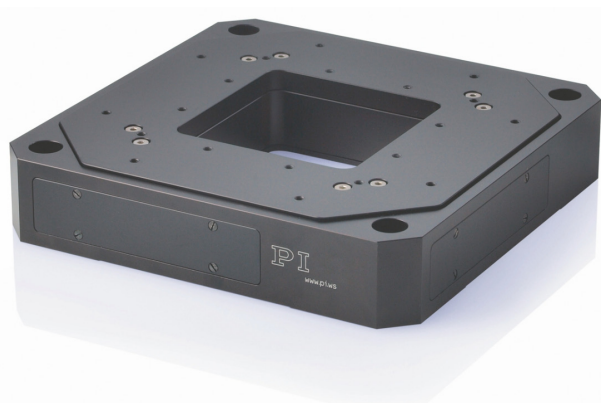
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Fig. 5 The high-speed and high-resolution piezo nanopositioning systems are suitable for a wide variety of scientific and industrial applications (Image: PI)

The high-precision capacitive sensors integrated into the positioning system ensure the accurate actual value measurement which is required to move the sample with precision below the laser is achieved. They record the motion directly and thus make it possible to have higher phase fidelity and bandwidth than indirect systems.

Fig. 6 The fine adjustment of object or sample is carried out by the piezo nanopositioning system, which not only operates with high accuracy but can also be readily integrated into the application (Image: PI / Nanoscribe GmbH)

The way it is constructed as a parallel kinematics multi-axis system also contributes to the high positioning accuracy because the driving force of the nanopositioning systems are preloaded, extremely durable high-performance piezo actuators, which are integrated into a friction-free parallel kinematics guiding system with FEM optimized flexures.

This means all piezo actuators act on a central platform. And so all axes can be made to behave with identical dynamics. This is particularly advantageous with 3D lithography because the samples can have any type of structure. One "slower" axis, which would be unproblematic for a linear scan, for example, would have detrimental effects here. Moreover, the sensorics register all closed-loop controlled degrees of freedom simultaneously. This parallel metrology makes it possible to actively prevent axis crosstalk and lateral runout. This benefits the track accuracy and reproducibility.

Fig. 7 The controller card is constructed as a PCI board and is specially matched to the control of multi-axis piezo nanopositioning systems (Image: PI)

The trajectory control required here is carried out by a digital controller constructed as a PCI board. Both the nanopositioning system and the PCI board come from the PI program and the former is specially matched to the multi-axis parallel kinematics piezo nanopositioning systems.

"It is even possible to meet the very high demands which our 3D lithography systems make on the track accuracy" adds Hermatschweiler. The highly accurate piezo nanopositioning systems have thus made a significant contribution to driving lithography technology a decisive step forward.

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WHITEPAPER – THREE-DIMENSIONAL LASER WRITING ON THE NANOMETER SCALE
Dipl.-Phys. Steffen Arnold

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Piezo Actuators – High Accuracy and Dynamics

Piezo actuators are the driving force behind the high speed parallel kinematics nanopositioning systems used in the new 3D lithography systems for the fine positioning of the objects or samples. These piezo actuators convert electrical energy directly into mechanical energy and vice versa. Travel ranges of up to one millimeter can typically be achieved with resolutions down to the nanometer range, and high dynamics with frequencies of up to several kilohertz are also achievable. The motion is based on crystalline effects and so there are no rotating parts or friction; piezo actuators are therefore maintenance-free and non-wearing, and because no lubrication is required, they are suitable for use in a vacuum. They can move large loads and have a very compact design.

Author

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About Nanoscribe

Nanoscribe GmbH, the first spin-off of Karlsruhe Institute of Technology (KIT) introduced the 3D laser lithography system PhotonicProfessional on the market in early 2008. Over the last five years, the company has established itself as market and technology leader in the area of 3D laser lithography. The multitude of systems sold to leading research institutes and universities across the world demonstrates the triumph of this innovative technology. The portfolio of the company additionally comprises in-house developed resists tailored to the different needs of customers. The portfolio is completed by consultation on reproducing these three-dimensional polymer structures in metals or semiconductors.

About the PI Group

Over the last four decades, PI (Physik Instrumente) with headquarters in Karlsruhe, Germany, has developed into the leading manufacturer of positioning systems with accuracies in the range of only a few nanometers. With four company sites in Germany and ten sales and service offices abroad, the privately managed company operates globally.

More than 700 highly qualified employees all over the world enable the PI Group to fulfill almost any requirement from the area of innovative precision positioning technology. All key technologies are developed in-house. This allows the company to control every step of the process, from design right down to shipment: precision mechanics and electronics as well as position sensors.

The required piezoceramic elements are manufactured by our subsidiary PI Ceramic in Lederhose, Germany, one of the global leaders for piezo actuator and sensor products. The PI miCos GmbH in Eschbach near Freiburg, Germany, is a specialist for positioning systems for ultrahigh vacuum applications and parallel-kinematic positioning systems with six degrees of freedom and custom-made designs.

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