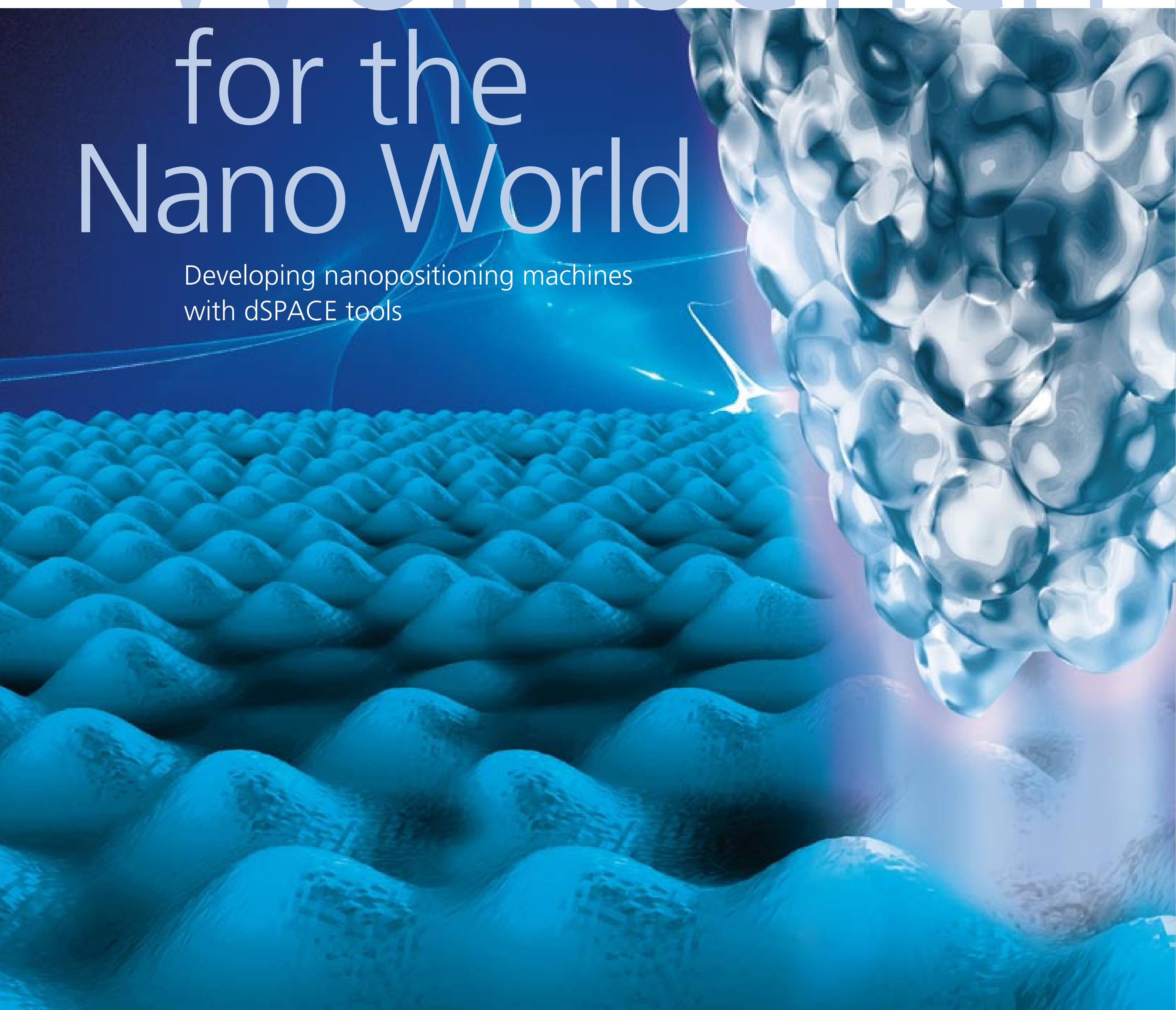
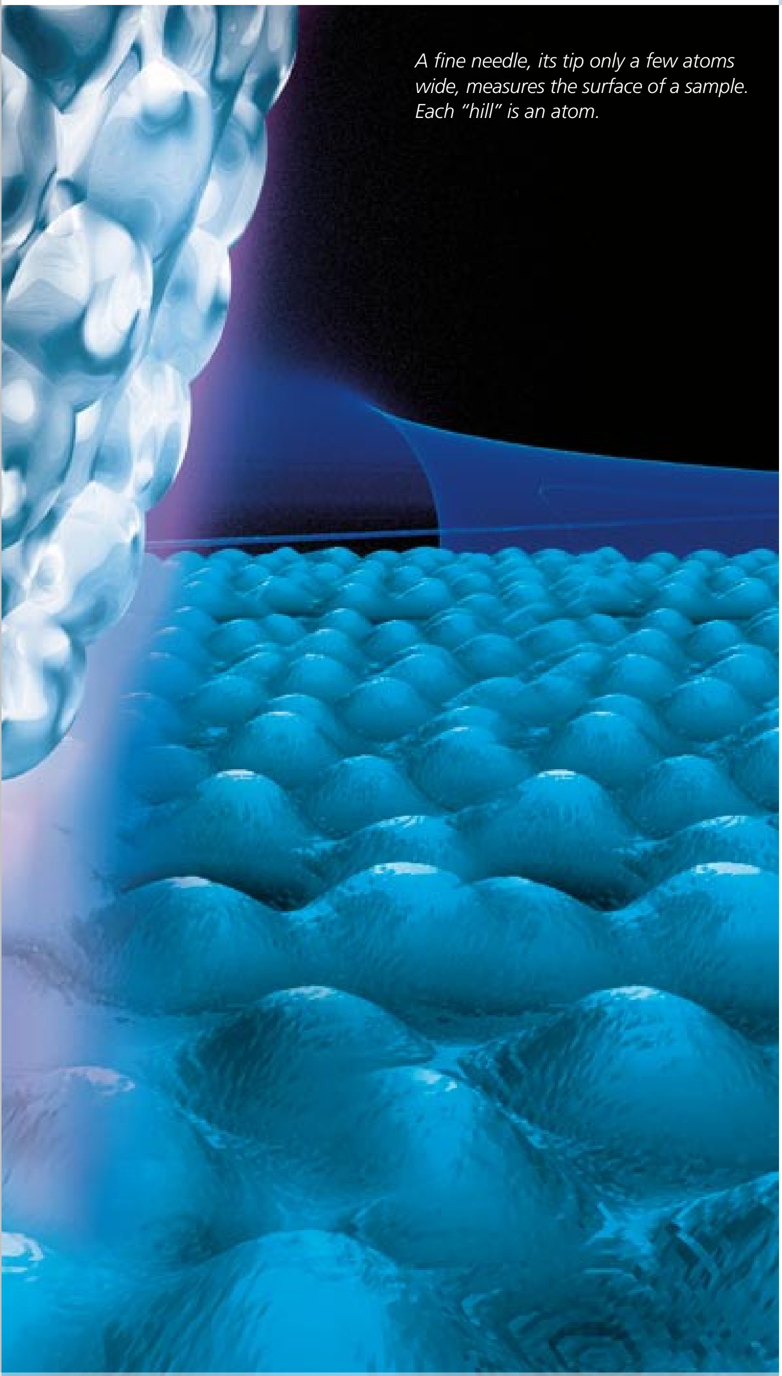
Workbench for the Nano World

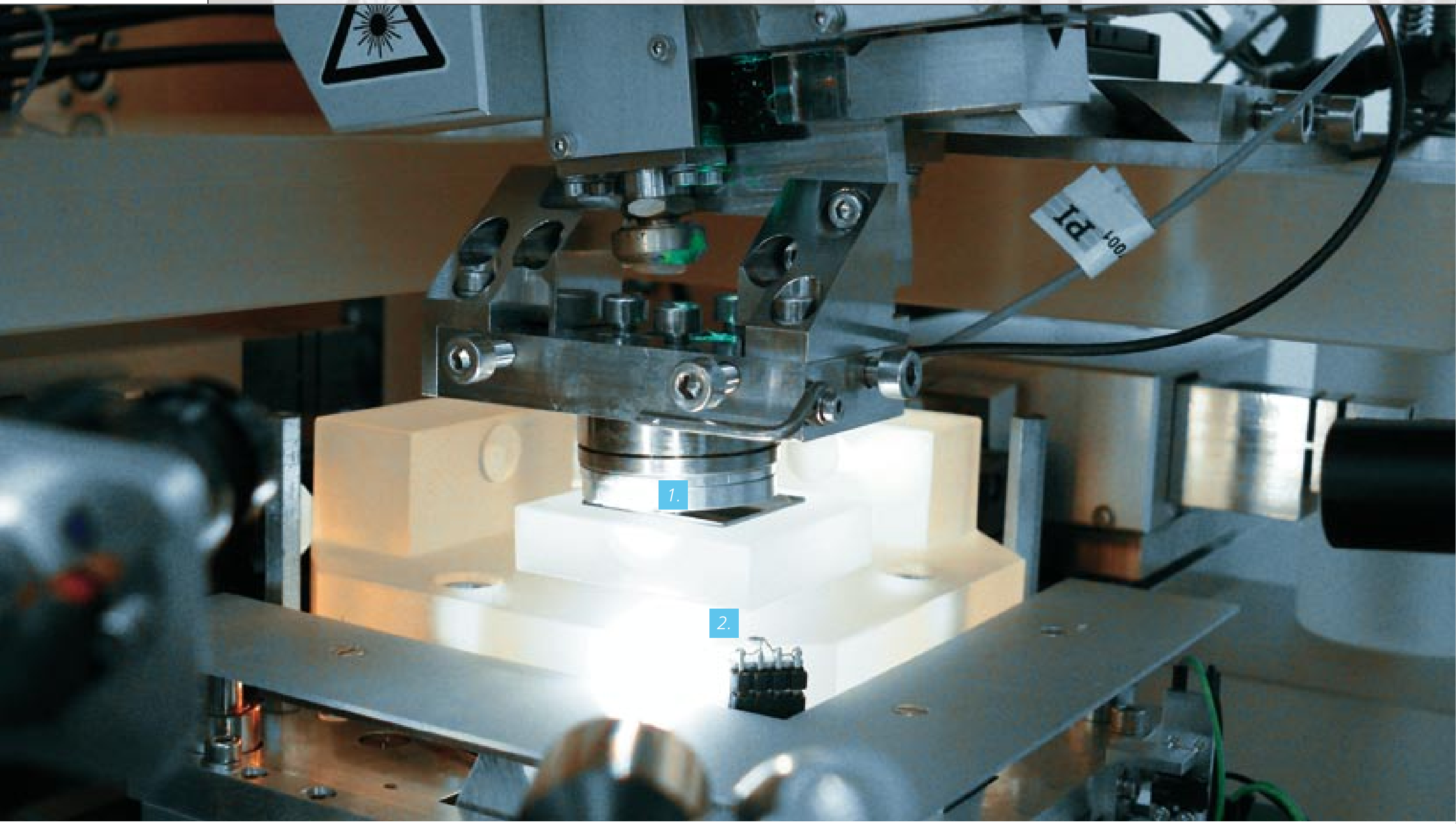
Developing nanopositioning machines with dSPACE tools





A fine needle, its tip only a few atoms wide, measures the surface of a sample. Each "hill" is an atom.

Just as Moore's Law predicts, the semiconductor industry is doubling the number of transistors per unit of area almost every two years. Processing such tiny structures requires precise positioning machines that move the processing tools to defined positions quickly and reproducibly. A team at the Technische Universität Ilmenau in Germany has designed a very versatile positioning machine for work in the nanometer range. The machine is controlled with the aid of dSPACE hardware and software.



The heart of the positioning machine is a movable positioning table with a probe fixed above it. This can be used for a wide range of different tasks in semiconductor technology, biotechnology, genetic engineering, micromechanics, etc.

1. probe
2. positioning table

From Semiconductors to Genetic Engineering

The typical uses of positioning machines include tasks in the semiconductor industry, such as inspecting wafers and photomasks or testing ICs. But they are also indispensable in other fields such as biotechnology, genetic engineering, micromechanics, and measuring and processing precision optical instruments. "In just a few years, positioning ranges of 450x450 mm will be required, along with positioning reproducibility in the subnanometer range and positioning speeds of 20-50 mm per second," says Prof. Eberhard Manske from Technische Universität Ilmenau. "In terms of human dimensions, this would mean you could locate and precisely reposition a tiny grain of sand in an area covering the whole of Russia and extending upward to the top of the stratosphere, 50 km from the Earth's surface."

> "The dSPACE hardware and software helped us achieve the high sampling rate needed for fast, nanometer-precise positioning."
>
> *Arvid Amthor, TU Ilmenau*

Atoms Become Visible

The positioning machine designed by Prof. Manske's team essentially consists of a movable positioning table that can be moved in all three spatial dimensions by means of linear motors. Its position and tilt are monitored by means of several optical distance gauges (laser interferometers). Above it is a rigidly mounted probe that scans the object mounted on the positioning table. The probe head can be fitted with various tools and sensors, such as an atomic force microscope, a kind of microscope with a fine needle whose tip consists of only a few atoms. The needle moves closely across the surface of the sample row by row in a grid. The forces that affect the needle depend on the surface structure of the sample, providing a method of measuring the sample's vertical profile that even shows individual atoms.

Handling Masses of Data

The positioning processes are controlled by a dSPACE system consisting of a DS1006 Processor Board and various I/O boards. One of the system's tasks is to read the position signals measured by the laser interferometers and compute the corresponding currents for controlling the linear motors. "For nanometer-precise positioning, the motor current has to be supplied with sufficient accuracy. We achieve this by means of

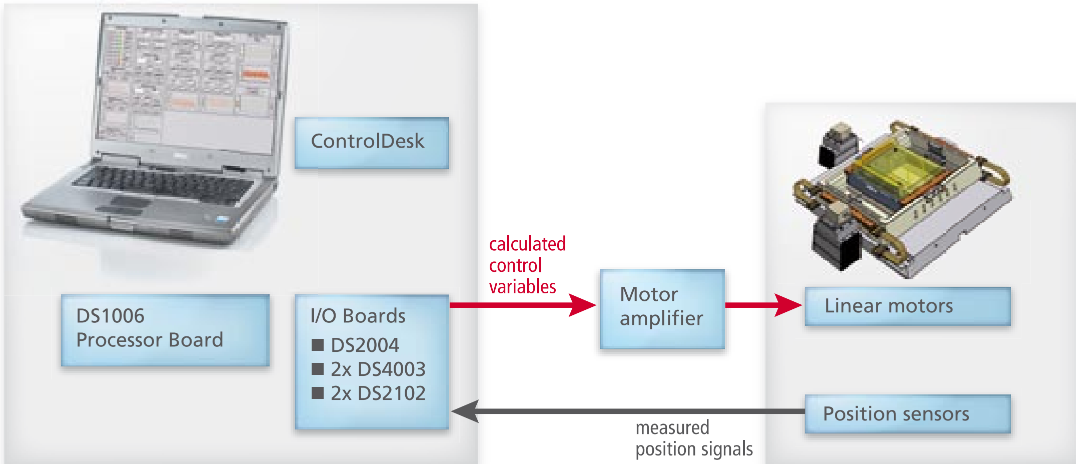


Diagram of the control. For fast, nanometer-precise positioning, the dSPACE system has to work at a high sampling rate of 10 kHz.

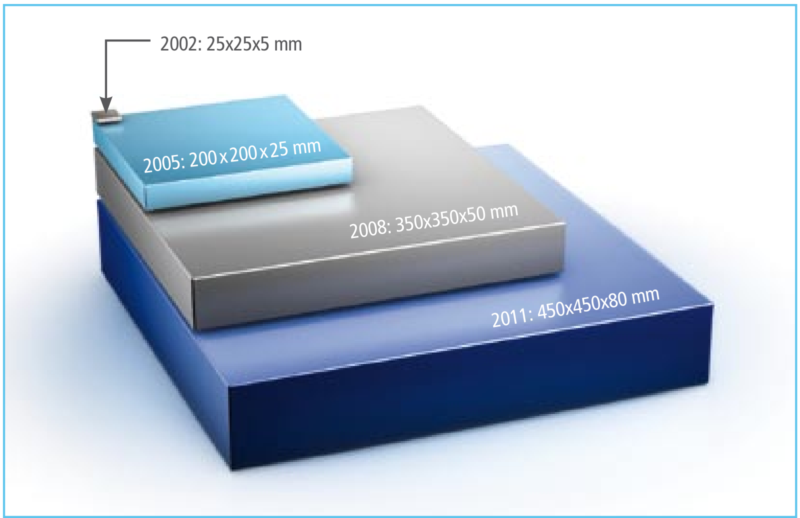
16-bit D/A conversion using dSPACE's D/A boards," explains Arvid Amthor, one of Prof. Manske's team. "The high sampling rate of 10 kHz is another major challenge. We move the positioning table at speeds of up to 30 mm/s, and 1 mm is 1,000,000 nm. This produces masses of data within a very short time, and that data has to be processed fast." All sequences are monitored by ControlDesk, the experiment software. The high positioning precision and speed require a complex, model-based, computation-intensive algorithm that is based on a dynamic sequence control. There are various disruptive effects to take into account, the main one being the nonlinear effect of friction, which dominates in the nanometer range and necessitates a lot of modeling work.

The Positioning Range Must Get Even Bigger

With a so-far unmatched positioning precision of 1 nm in a 200x200x25 mm large positioning range, the Technische Universität Ilmenau is currently the world's unchallenged leader in the nanopositioning field. In coming years, the main endeavor will be to enlarge the positioning range even further, with at least the same positioning precision and speed. "The machines will not be of any practical use unless positioning is fast enough," comments Prof. Manske.

As the first step toward this goal, the team plans to increase the positioning range to a volume of 350x350x50 mm. This requires further optimizations in measuring technology and data processing, as well as even more efficient modeling for correcting system and ambient disturbances. ■

This article was written in cooperation with Prof. Eberhard Manske and Arvid Amthor, Technische Universität Ilmenau, Germany.



The positioning range of nanopositioning machines has multiplied since 2002. Even so, future tasks will require an even greater range, which can only be achieved by using complex, model-based control algorithms.