



Fig. 1 METIRIO® A1 housing variant and METIRIO® A1 Encoder with linear scale (Inset)

When every nanometer matters

The METIRIO® A1 encoder enables a new level of precision in nano-scratch testing and sets new measurement standards.

Researchers of the Harbin Institute of Technology in China have developed a four-degree-of-freedom (4-DOF) inchworm piezoelectric platform and demonstrated how combining this system with sub-nanometer position feedback from the METIRIO® A1 encoder can reveal mechanical behaviors that would otherwise remain undetectable. The work, conducted by a six-member team and supported by the National Natural Science Foundation of China and State Key Laboratory of Robotics and Systems, highlights how encoder-based feedback is advancing nano-scratch research.

Advances in nanotechnology increasingly demand multi-dimensional, cross-scale, and va-

riable-depth structures for applications including nanofluidic chips, nanosensors, nanoelectronics, and biomedical devices. Among current methods, nano-scratching stands out as cost-effective and versatile: a sharp tip is guided across a sample to create nanoscale grooves or features. Its effectiveness, however, depends critically on the ability to measure and control motion with extreme precision. Even minimal drift or vibration can distort results.

Nano-scratching can serve two complementary purposes: it can be used both as a fabrication method for producing defined surface structures and as a tool for investigating the mechanical and tribological properties of materials. Under controlled loading conditions, parameters such as scratch depth, lateral force, and friction provide

valuable information about wear resistance, coating adhesion, and the behavior of interfaces between thin films and their substrates. This makes the method relevant not only for nanomanufacturing but also for the development and qualification of functional coatings, semiconductor structures, and other advanced materials.

Optical accuracy in a compact form

To overcome these challenges, the researchers built a three-dimensional piezoelectric manufacturing system (PMS) around their custom 4-DOF platform, integrating the METIRIO A1 optical encoder from SmarAct. Its grating-based displacement sensors deliver sub-nanometer resolution and closed-

loop feedback, ensuring stable cross-scale machining and precise depth control.

In practice, the METIRIO A1 enables exact scratch-path control and captures dynamic processes in real time. Its low power consumption and compatibility with ultra-high vacuum environments make it ideal for sensitive experimental setups, while a configurable software interface ensures straightforward integration into a wide range of research platforms.

The encoder operates on an incremental principle with a 20 μm pitch and reference-mark detection for quasi-absolute positioning. Its modular readhead design allows both OEM integration and flexible system-level use. In the experiments, the METIRIO A1 continuously supplied position data to the control unit, compensating for thermal and mechanical drift in real time and maintaining constant scratch speeds even as material properties varied across the sample. This enabled high-resolution correlations between force and displacement, offering deeper insights into material responses.

Performance and results

The new 4-DOF platform combines translation along three axes with full rotation about the vertical axis, while remaining compact enough to fit into a unit only slightly larger than a lunchbox. Within a working volume of approximately one cubic centimeter, it achieves motion increments of just a few tens of nanometers, while rotational adjustments can be controlled with a resolution of only a few microradians. Despite this high precision, the system reaches speeds of up to one millimeter per second in linear motion and 0.16 rad/s in rotation, while generating forces of up to 10 N and torques of 0.05 Nm, all without the

backward slip often observed in conventional piezoelectric stages.

In their experiments, the researchers used the platform to scratch stainless steel, aluminum, and copper samples. As expected, harder materials produced shallower grooves when subjected to identical voltages. Increasing the excitation frequency not only stabilized the scratching process but also significantly improved surface quality. The system was subsequently used to create intricate nanostructures, including grooves, nested rectangles, and concentric circles, with remarkably uniform depths ranging from 500 to 700 nm.

For functional surfaces, such geometric consistency can be critical, as variations in groove depth or spacing may affect properties such as friction, wettability, and fluid transport. The ability to reproducibly create complex structures with controlled depths therefore extends the platform's relevance beyond a proof of concept to the systematic development and evaluation of application-specific surface functionalities.

By combining advanced inchworm actuation with SmarAct's high-resolution encoders, the researchers have developed a robust platform for three-dimensional nanostructuring. Their work demonstrates how sub-nanometer position feedback can enable not only higher measurement accuracy but also faster development of advanced functional materials. Future research will focus on sensor integration and enhanced control strategies to further reduce errors and push the boundaries of nanoscale fabrication.

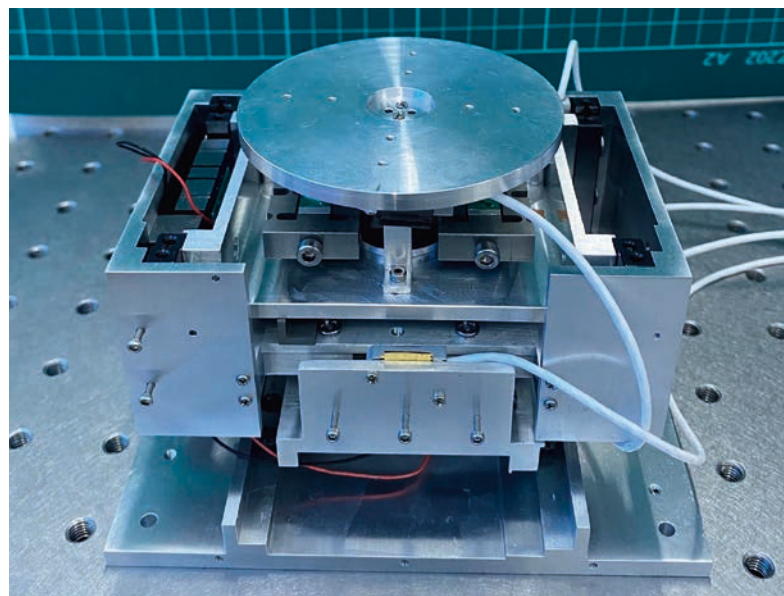
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Fig. 2 This four-degree-of-freedom piezoelectric platform is used for nano-scratch experiments. Integrated METIRIO® A1 encoders provide real-time position feedback, enabling precise control of three linear axes and rotation about the Z-axis.