photonics tech briefs:

Laurin Publications
EUROPHOTONICS
european coverage of optics, lasers, imaging, fibre optics, electro-optics and photonic component manufacturing

Nanopositioning Stage Pulls Piconewtons in Molecular Stretching Application

by Stefan Vorndran, PI (Physik Instrumente) L.P. Auburn, MA

A multiaxis closed-loop piezo stage can generate forces of piconewtons at subnanometre displacement resolution.

Nanopositioniersystem erzeugt Kräfte im Pikonewtonbereich zur Streckung von Molekülen
Ein mehrachsiges Nanopositioniersystem ermöglicht Kraft- und Positionsregelung im Pikonewton bzw. Sub-Nanometerbereich.

Une table de nanopositionnement exerce une traction de piconewtons pour des applications d'étirement moléculaire
Une table piézoélectrique asservie à axes multiples peut générer des forces de l'ordre du piconewton pour obtenir une résolution de déplacement subnanométrique.

Uno stadio di nanoposizionamento genera piconewtons in applicazioni di deformazione molecolare
Uno stadio piezoelettrico multiasse, controllato ad anello chiuso, può generare forze di piconewtons con risoluzione in spostamento inferiori al nanometro.

Nanopositioning, the art of controlling motion on the nanometre scale and below, has been a key enabling technology in many high-tech fields. The need for miniaturization in industries such as semiconductors, telecommunications and data storage has driven the development of faster and higher-resolution motion systems over the past decades. More recently, nanopositioning devices also have been employed in biotechnology applications, and the latest developments in this technology are fostering progress in molecular biology.

Research at the Fernandez Lab at Columbia University in New York focuses on the mechanical properties of single molecules, such as proteins or saccharides, using atomic force microscopy. These properties are extremely relevant to the understanding of biological processes. Scientists can deduce the structural features of the molecules based on the observed mechanical stability and the conformational changes that occur upon the application of force.

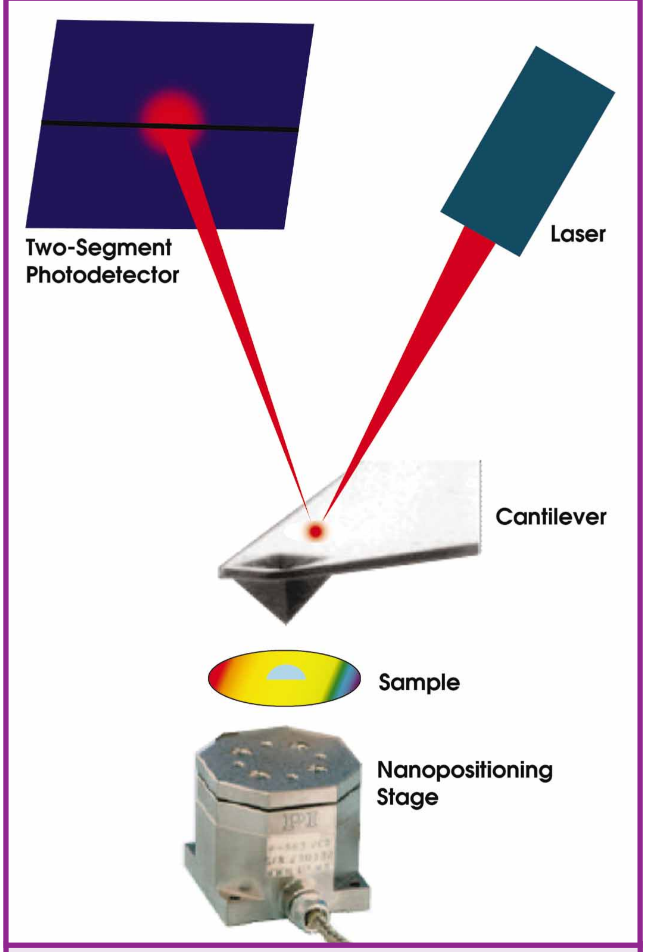

Figure 1. The basic setup of the molecule stretching application involves the PicoCube stage moving the sample and measuring the position via an integrated subnanometre-precision capacitive sensor. The cantilever, laser and photodetector provide force feedback. Courtesy of Fernandez Lab.

The basic principle of the technique involves the stretching of a molecule between a gold surface and the tip of a microscopic cantilever (Figures 1 and 2). The forces involved are incredibly small, on the order of piconewtons; 10 pN are equivalent to the force exerted by one-billionth of a gram.

The stretching experiment is run in either force- or velocity-control mode. Both require proportional integral derivative feedback. The measured force-exten-

Figure 2. The apparatus stretches the molecule between a gold surface and the tip of a microscopic cantilever. Courtesy of Fernandez Lab.

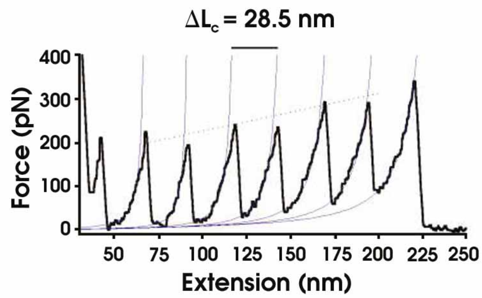

Figure 3. The force vs. extension graph of a titin molecule shows that the protein is composed of structurally rigid and nonrigid elements. Courtesy of Fernandez Lab.

Figure 4. The PicoCube is available in two- or three-axis versions. The DIP switch is shown for size comparison.

sion relationship helps to explain the structural features of the molecules (Figure 3). The length of the molecule as a function of the force is obtained from the displacement of the substrate.

Because the forces are so minute and the distances involved only a few nanometres, all the equipment used in the experiment must be of the highest precision and sensitivity. Two crucial elements in the setup are the nanopositioning stage and its position measurement system. A main requirement of the stage is that all of the parts in the motion system (actuator, sensor, guidance) be friction-free. This rules out classical positioning stages that have ball or roller bearings.

The nanopositioning system used in the Fernandez research is a PicoCube multiaxis closed-loop piezo stage from Physik Instrumente (PI) GmbH & Co. KG. It is equipped with a noncontact, direct metrology, capacitive measurement system (Figures 4 and 5).

Capacitive sensors have emerged as the default choice for nanopositioning applications with travel ranges of less than 1 mm. They are compact, high-bandwidth, absolute measuring devices (no homing procedure) that provide very good linearity and long-term stability with subnanometre resolution. These features make them ideal sensors for precisely determining the length of the molecules.

Both the actuator and the sensor have a very high bandwidth of several kilohertz and can be used for fast scanning operations. The high mechanical resonance frequency of the stage is the result of a very stiff mechanical design, important for structural stability at the nanometre level.

The PicoCube system boasts a number of novel features, such as low-inertia bipolar piezo drives and parallel metrology sensors. The bipolar drives allow for a larger travel range than similarly sized piezo drives and, thus, a more compact and stiffer package. As a further benefit, the piezo drive voltage at the centre of travel is zero, which means that the potential for failure also is zero. The use of parallel capacitive sensors to measure the single moving platform means that the orthogonal axes automatically compensate for each other's crosstalk (active trajectory control).

PI's nanopositioning stages provide travel ranges from 5 µm to 1 mm and motion from one to six degrees of freedom. They can be controlled by a variety of analog or digital controllers. Analog types are convenient in applications with analog control signals. Digital ones, on the other hand, offer a number of advanced features such as dynamic linearization, virtually eliminating tracking errors in high-speed scanning applications. They also allow the use of autocalibrating mechanics and the changing of servo and systems parameters on the fly. □

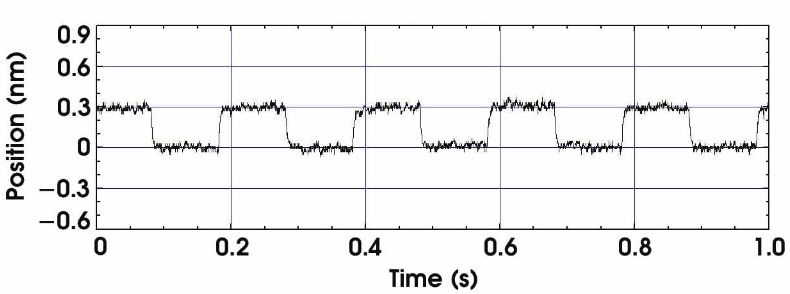

Figure 5. The 300-pm steps with the PicoCube show how fast and repeatably the system responds to positioning commands. The theoretical resolution (limited by electrical noise) is approximately 50 pm.

Contact: Stefan Vorndran, PI (Physik Instrumente) L.P., Auburn, MA, USA; www.pi.ws; e-mail: stefanv@pi-usa.us.