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IOP

IOP Precision Technology

Pico-drift monitoring device

A monitoring device for determining pico-drift

SUBJECT:

Pico-drift monitoring device

PURPOSE:

To develop and build an instrument to determine the drift rate of materials and connection techniques in at least one dimension with an accuracy of at least 10 picometres for measurements conducted over 100 seconds, or 100 picometres for those conducted over a period of three weeks

MARKET APPLICATION:

Electron microscopy, high-end precision systems for use in astronomy, lithography equipment

POTENTIAL USE:

The measuring of drift phenomena to facilitate the study of materials or to measure connections and construction elements

RESEARCH PERIOD:

June 2007 - February 2011

TOTAL BUDGET:

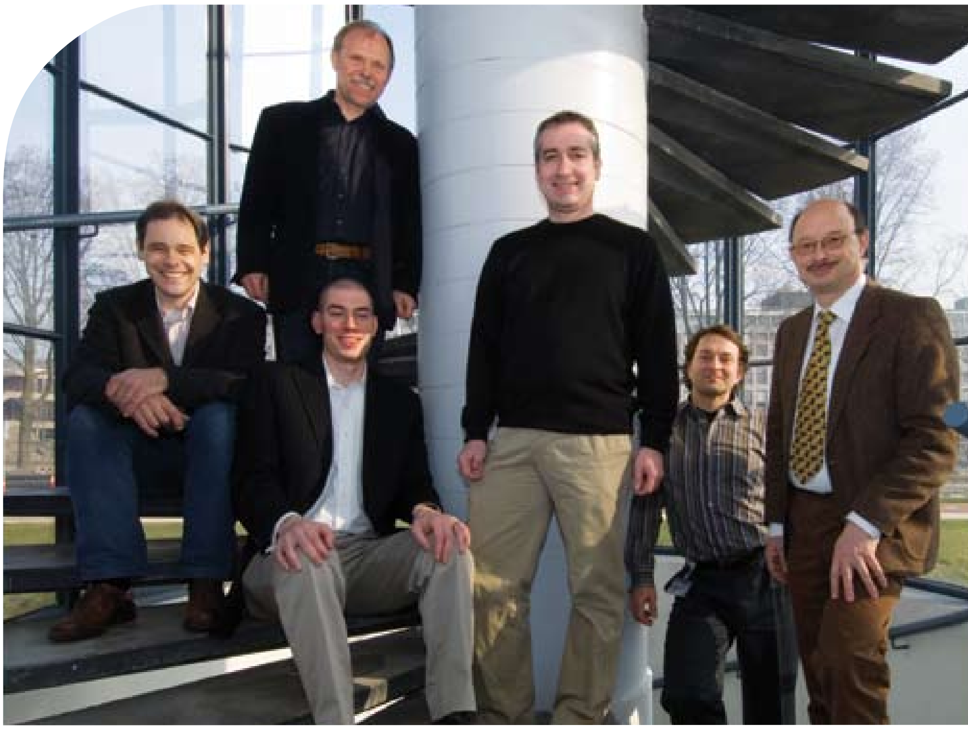
EUR 698,194, of which EUR 450,762 funded by IOP

RESEARCH INSTITUTES:

Delft University of Technology, NMi Van Swinden Laboratorium, TNO Science & Industry

PROJECT LEADER:

Dario Lo Cascio (TNO)



Project team (on the stairs from top to bottom): Jo Spronck (TUD), Paul van Kan (NMi), Jon Ellis (TUD), Rob Bergmans (NMi), Dario Lo Cascio (TNO), Rob Munnig Schmidt (TUD). Peter Giessen, Bart van Mierlo and Ad Verlaan from TNO are absent

The technology for linear measurements has evolved to such an extent that unintended displacement ('drift') at the picometre level is now a problem. Researchers at TNO, TU Delft and NMi are developing an instrument for measuring this 'pico-drift'.

Increasingly higher demands are being placed on high-end precision systems such as electron microscopes, lithography equipment and devices used in astronomy. In the coming years, accuracies even at the subnanometre level will need to be attained. "In the face of such demands, pico-drift will be playing an increasingly important role," says Dario Lo Cascio of TNO Science & Industry. "Static components such as mirrors and lenses shift unintentionally over time. That is the result of changes that take place either in the material or in the construction under the influence of fluctuations in temperature, air swirls or stress-induced deformation. To a certain extent, it is comparable to the way currents or wind can take a ship off course. In most cases, picometre drift won't lead to any major difficulties: materials drift in any machine. But at the subnanometre level, pico-drift actually does pose a problem."

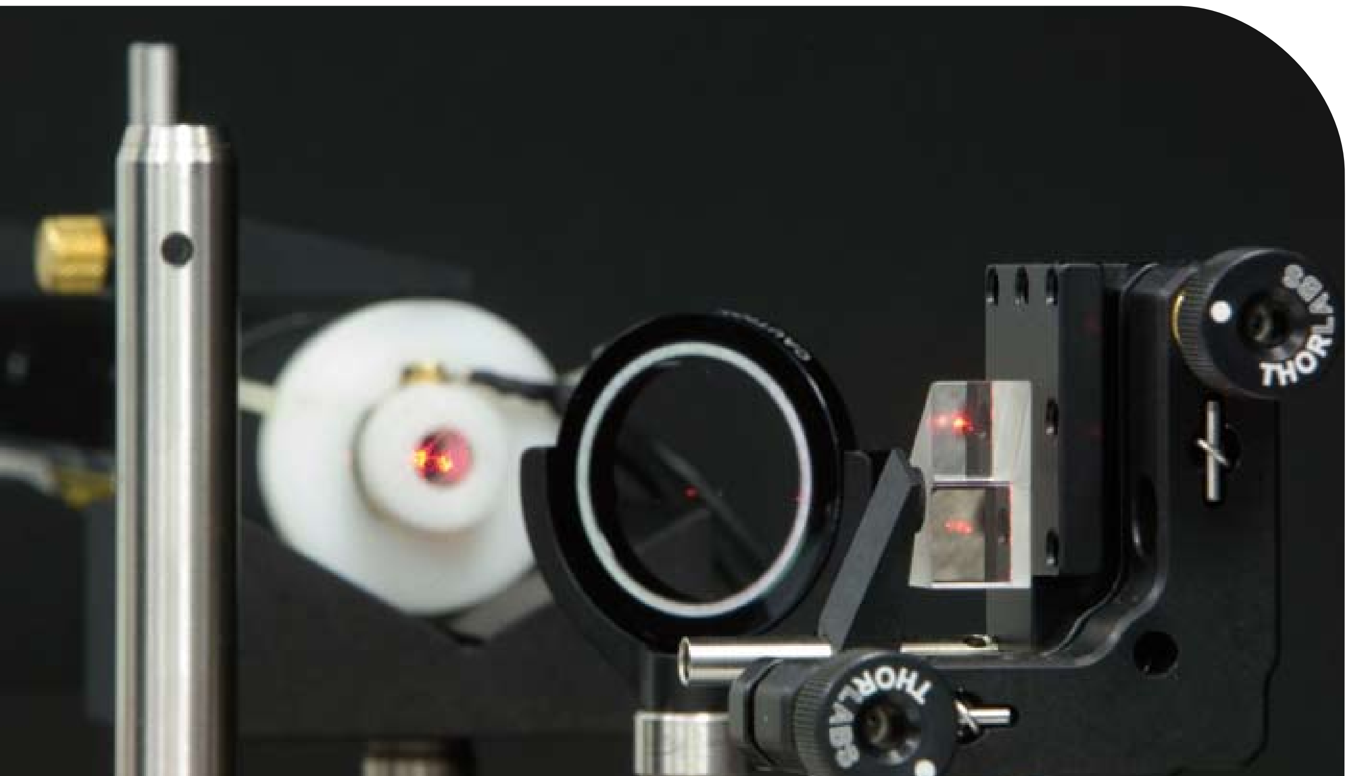
Recalibration

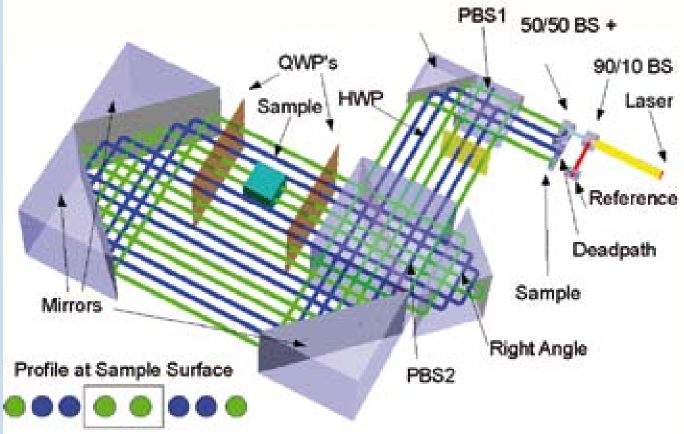
Picometre drift is clearly visible when nanostructures are observed through an electron microscope. The surface being observed will move and even slowly disappear from the field of vision. Pico-drift poses a problem primarily when measurements need to remain highly accurate over a longer period of time, Dario Lo Cascio explains. "Consider the lithography equipment used in the semiconductor industry. Although such equipment has the possibility of correcting deviations, the different subsystems still end up drifting slowly away following calibration. If that exceeds the admissible boundaries, you need to recalibrate, which means that you have to put production on hold. And that is expensive." Something comparable happens with an instrument such as the Scanning Probe Microscope, which needs to be extremely stable to satisfy the required degree of precision. Here, too, less recalibration is beneficial. The field of astronomy offers yet another example: instruments sometimes need to remain accurately positioned throughout a satellite's entire lifespan (i.e. several years) without recalibration. Components for each successive generation of astronomical instruments are subject to more and more extreme requirements. The currently available means and expertise are nevertheless hardly sufficient to allow us to determine their stability on the subnanometre level. Knowledge about the stability of materials and how construction elements will behave on the picometre level are lacking as well.

Ideal situation

To build up that knowledge, it is necessary to study drift rates. "But it is extremely difficult to measure drift at the subnanometre or picometre level, because every measuring device is itself also subject to pico-drift," Dario Lo Cascio explains. The ideal pico-drift monitoring device (an instrument for measuring picometre drift) should be able to take highly accurate measurements over a period of several years. That is not yet attainable due to the effects of noise and the drift of the electronics and lasers in the measuring device, and due to the environment and the construction elements and materials involved. So far it is only possible to measure for a few minutes with an accuracy of 200 picometres.
The IOP 'Pico-drift monitoring device' project, led by Dario Lo Cascio, aims at producing a measuring instrument that can measure over a period of three weeks with an accuracy of 100 picometres, or with an accuracy of at least 10 picometres over a maximum period of 100 seconds. "To achieve that, we are looking for solutions that result in an instrument with as

Initial setup of the pico-drift monitoring device in 2007





Schematic representation of the interferometer with a sample between the mirrors

little picometre drift as possible. First of all you need to keep the temperature as constant as possible. Then you have to decide whether you will be measuring in vacuum or in air. The advantage of vacuum is that you won't have any problems with swirling air. The drawback, however, is that the thin little layer of air and water molecules found on any surface will slowly disappear in vacuum. Also, any thermal gradients, for example those induced by the act of measuring itself, are less apt to settle, which means you may introduce new problems as well."

Enhancement

Another research question involves how to position the object to be measured on the measuring instrument without causing any vibration or drift in the process. A low-vibration environment is clearly a pre-condition. And the design of the measuring instrument obviously needs to be very stable in other ways as well. Researchers will therefore use (relatively new) materials with a very low transmission coefficient (e.g. Zerodur glass), a high inherent stability (e.g. the ceramic material carborundum) or a good thermal conduction (e.g. aluminium). Likewise, the connections between the components are subject to high demands in terms of stability. The researchers will even be developing new connecting techniques whenever necessary.

The heart of the measuring machine is naturally the measuring itself. "Of the various methods of measuring, the one that is based on the wavelength of light, known as interferometry, appears to be the most promising," Dario Lo Cascio says. While the first generation of the instrument will focus on measuring in just one dimension, a later version will be able to measure in six spatial degrees of freedom.

The IOP project is a collaborative effort between TNO, NMi and TU Delft. "Each of the three partners has different competencies and contributes in its own way. The university is more oriented towards fundamental research, NMi focuses primarily on measuring and TNO is interested in broader applications for the knowledge gained," Dario Lo Cascio explains. "Those differences in perspective enable us to see new opportunities, which actually enhance the project."

Drift in practice

The NMi Van Swinden Laboratorium plays an important role in the project. Its staff is not only experienced in methods of measurement and environmental influences, it also has laboratories with very high temperature stability and very low levels of vibration. Paul van Kan is a scientist in the Research and Development Department at NMi. He says: "We can offer the PhD student from TU Delft the ideally conditioned facilities for testing the measuring instrument and its components. Measuring at the subnanometre level is for the most part still unexplored territory, and the results are often contradictory. We hope this project will enable us to better advise our customers in the area of nanotechnology and to refine our own measuring instruments."

As a test case for the measuring instrument to be developed, Paul van Kan mentions the classic standard for length: a metal

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gauge block with a known expansion coefficient. "We measure those gauge blocks annually at a temperature of 20.000 degrees Celsius with an accuracy of 20 nanometres. But there are also gauge blocks that keep growing longer or shorter by 20 nanometres a year. A pico-drift monitoring device would allow you to study those gauge blocks for example on a weekly basis to gain insight into the material's behaviour. So far that has not been possible. In this way, the instrument could play an important role in research on the properties of new materials."

New materials

One of the companies that have great interest in the behaviour of materials at the subnanometre level is IBS Precision Engineering. This engineering firm designs and produces customer-specific high-precision measuring devices and it is a supplier of capacitive sensors and air bearings. Guido Florussen, a measurement specialist at IBS PE: "Those sensors allow you to measure with extreme accuracy, but we want to know even more precisely just how accurate they are. Another important reason for closely following this research is the advent of new materials such as composites. The thermal behaviour of these materials, certainly over a longer period of time, is still pretty much unknown. For designers it is interesting to know which materials are best to use in which circumstances. That is another thing we hope to study in the course of the project."
Guido Florussen also has reasons of his own for being a member of this IOP project's industrial users group. "This study is obviously beneficial for the company, but personally I find the physics behind it really fascinating. Besides that, I also enjoy the networking. It is a pretty small world, so it's convenient if you can find each other easily."

Various different types and sizes of capacitive sensors for measuring distance very precisely

PHOTO: IBS PRECISION ENGINEERING

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The innovation-driven research program (IOP) on precision technology stimulates research projects at universities which fulfil the long-term needs of industry. Through this approach, the Dutch government wants to make the research world more accessible to the business community and improve and intensify contacts between the two. The IOP Precision Technology has three themes: (1) systems oriented design for precision, (2) measurement and fabrication technology and (3) micro system technology for precision.

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