Science   SEPTEMBER 5, 2019 1:40 PM AEST   Share Twitter Facebook

NTU scientists develop optical ruler that can measure down to nanoscale

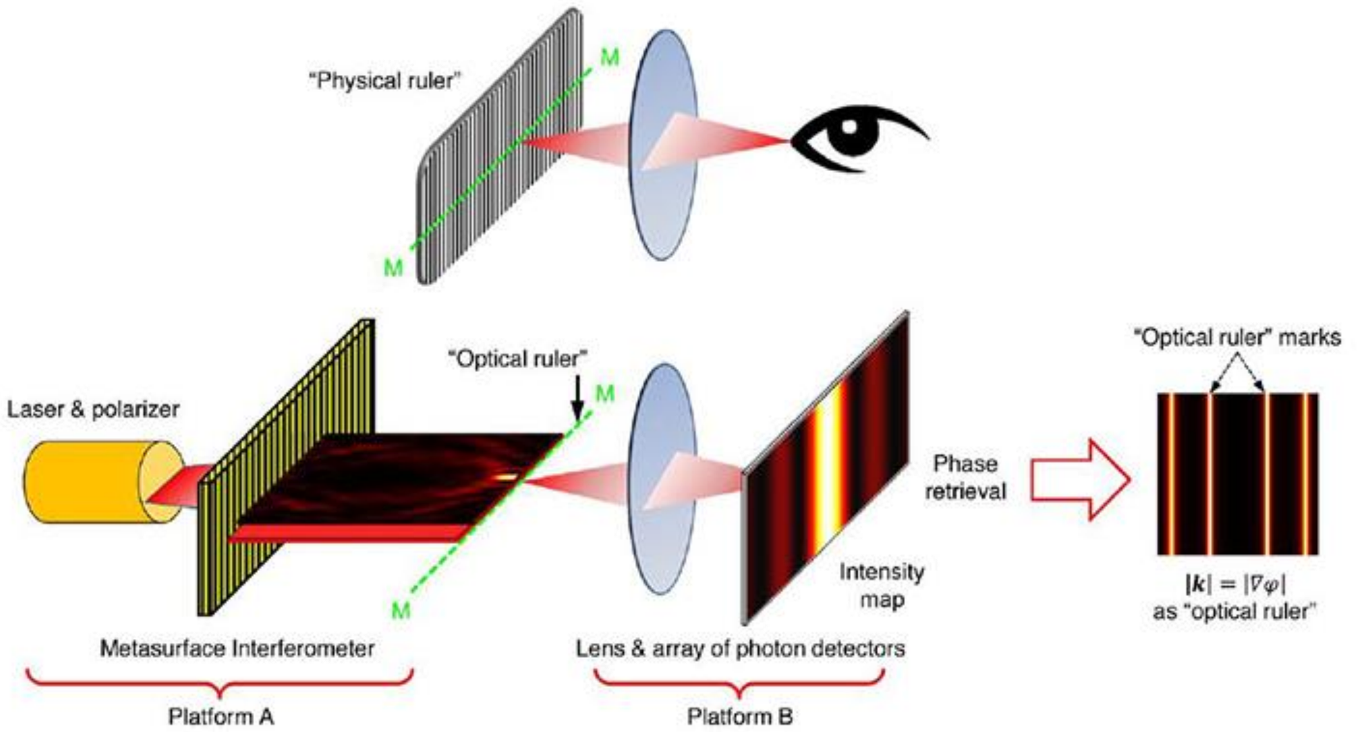

Fig. 1. Principle of the optical ruler displacement metrology. Conventional displacement metrology is based on the observation of a physical ruler moving along the MM line. The optical ruler metrology relies on observing the deeply subwavelength zones of a complex optical field with strong phase gradient $\boldsymbol{k} = \nabla\varphi$ along the MM line, which are used as marks of the optical ruler.

Scientists at Nanyang Technological University, Singapore (NTU Singapore) have developed a new way to measure distances at the nanoscale – one nanometre being one billionth of a metre – using light.

Devices that use light to see objects, such as microscopes, have a fundamental limitation based on the laws of physics, which is their resolving power.
The smallest distance that optical devices can reliably image is equal to half the wavelength of the light used, known as the "diffraction limit".

The diffraction limit is therefore above 400 nanometres, about half the wavelength of near infrared light. This is some 250 times smaller than the width of a human hair (100 microns).
But since scientists are interested in observing extremely small objects like viruses and nanoparticles that range in size from 10 to 100 nanometres, an optical resolution of 400 nanometres is insufficient.
Currently, nanometre-scale measurements are made using indirect or non-optical methods, such as scanning electron microscopy, which are not always feasible, can be time-consuming and require costly equipment to operate.

However, a discovery published in the journal Science by Professor Nikolay Zheludev and Dr Guanghui Yuan at NTU's School of Physical & Mathematical Sciences describes a new optical method that can measure displacements of a nanometre – the smallest distance ever directly measured, using near infrared light.

Their theoretical calculations indicate that devices based on this method could ultimately measure distances down to 1/4000 the wavelength of light, to roughly the size of a single atom.
Their achievement was accomplished using a 100-nanometre thick gold film with over 10,000 tiny slits cut into it to diffract laser light and to exploit an optical phenomenon known as 'superoscillation'.

The concept of superoscillation first arose in the 1980s from the quantum physics research of Yakir Aharonov, an Israeli physicist, and was subsequently extended to optics and other fields by the British physicist Michael Berry. Superoscillation occurs when a 'sub-wavelength' in a light wave oscillates faster than the light wave itself.

How it works
"Our device is conceptually very simple," says Dr. Yuan, a postdoctoral fellow at the Centre for Disruptive Photonic Technologies (CDPT), a centre under The Photonics Institute at NTU Singapore. "What makes it work is the precise pattern in which the slits are arranged. There are two types of slits within the pattern, oriented at right angles to each other. When polarised laser light strikes the gold film, it creates an interference pattern containing extremely tiny features, much smaller than the wavelength of light."

After this polarised light scatters from Zheludev and Yuan's device, it produces two cross-polarised beams: one a superoscillatory "interference pattern" containing fast phase variation and the other a reference wave to detect the phase of the superoscillatory field.

From the phase, it is possible to calculate the superoscillation's gradient, or 'local wavevector', which has an extremely narrow width (400 times narrower than the diffraction limit) and thus can be used as a high-resolution optical ruler.

A hurdle that the NTU scientists had to overcome was that these tiniest superoscillations do not appear in the amplitude of the light wave, but in its phase. To map out the phase of the light field, the scientists had to devise a special technique that could compare the intensities produced by different polarisation states of laser light.

"This phase-sensitive technique is a major improvement over previous attempts to use superoscillation for optical measurement," said Professor Zheludev, Co-Director of NTU's The Photonics Institute.

"Earlier methods, developed by us as well as others, used a class of superoscillations that correspond to localized 'hot spots' in intensity. The advantage of hot spots is that they are easy to detect. Yet if the goal is to measure the shortest distances possible, phase superoscillations are much more suitable, due to their smaller size."

Future applications

Professor Zheludev, who also serves as co-director of the Optoelectronics Research Centre at Southampton University in the UK, said their discovery would be likely to find application in industry:

"This method of optical measurement will be very useful in future, such as in the manufacturing and quality control of electronics, where extremely precise optical measurements are required, and to monitor the integrity of nano-devices themselves."

Moving forward, the team aims to develop a compact version of their apparatus using optical fibres and to commercialise the technology as a new type of ultra-precise optical ruler, which would be beneficial to advanced manufacturing processes, like semi-conductor fabrication and optoelectronics devices, which are the backbone of the telecommunications industry.

Tags:Berry, British, Discovery, Human, industry, Israel, Nanyang Technological University, Professor, research, resolution, school, science, Scientists, Singapore, UK, university