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Team proposes microprinting a fiber-tip polymer clamped-beam probe for high-sensitivity nanoforce measurements

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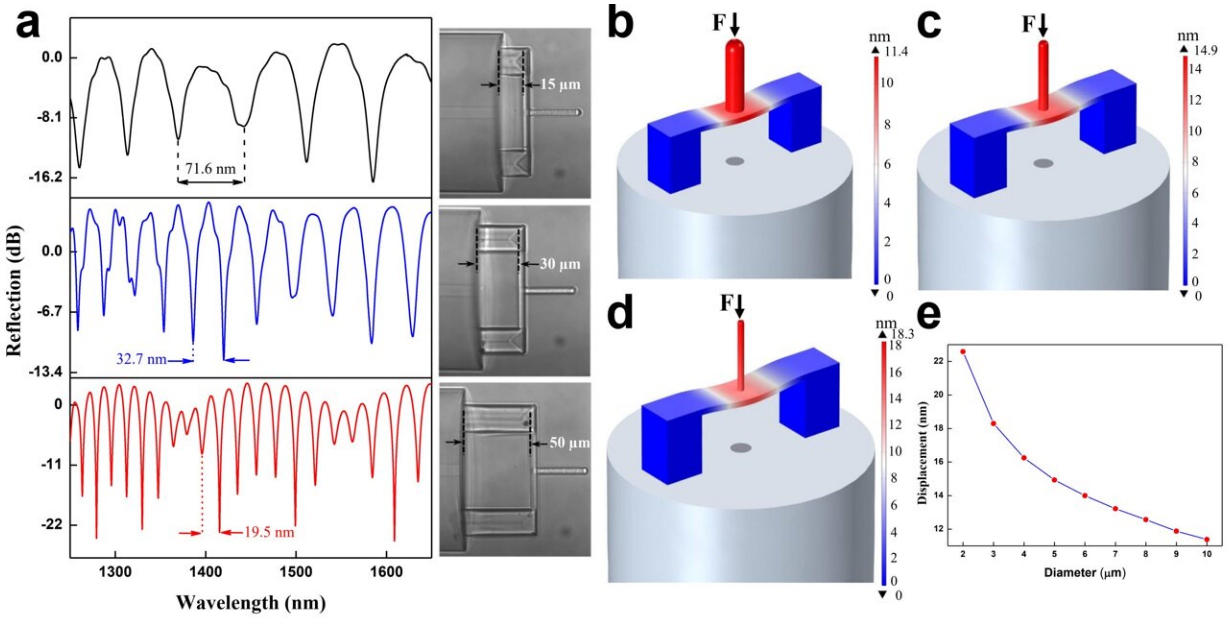
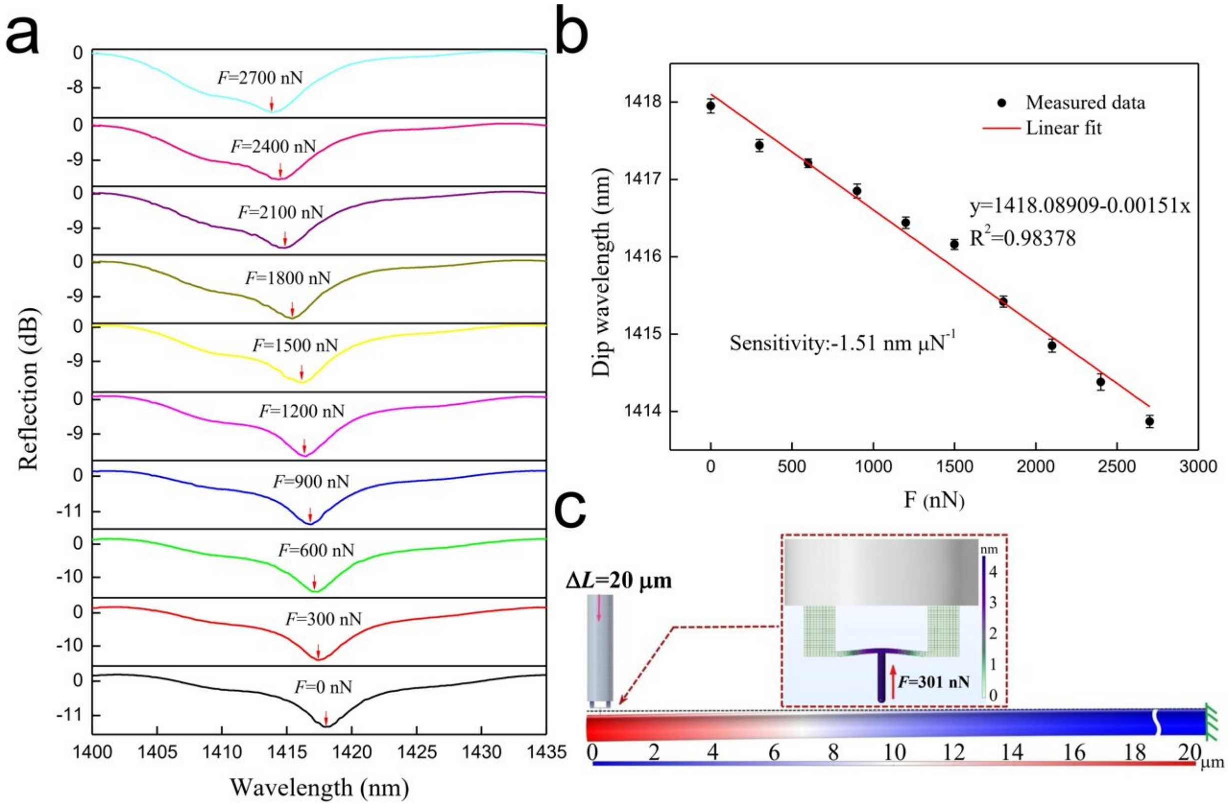


a Optical microscopy images of clamped-beam probe with different heights and their corresponding reflection spectra. b, c, and d are the bending deformation simulation results of the sensor under the same micro force (1 µN) acting on the probe with different diameters (10, 5, and 3 µm). e Relationship between the probe diameter and flexure deformation under the same micro force (1 µN). Credit: Mengqiang Zou, Changrui Liao, Shen Liu, Cong Xiong, Cong Zhao, Jinlai Zhao, Zongsong Gan, Yanping Chen, Kaiming Yang, Dan Liu, Ying Wang and Yiping Wang

The control and measurement of asserted forces on small objects are frequently seen in micromanipulation, material science, and biological and medical applications. Researchers in China have proposed for the first time the microprinting of a novel fiber-tip-polymer clamped-beam probe micro-force sensor for the examination of biological samples. This approach opens new avenues towards the realization of small-footprint AFMs, and the proposed sensor has great application prospects for examining biological samples and the mechanical properties of materials.

Due to the trend of miniaturization of devices, micromanipulation has been a hot topic in the last two decades. Unlike the macro world, a micro object can easily be damaged if the contact force is not accurately detected and controlled. For instance, in medical cardiac catheterization, if physicians don't know the exact contact force between the catheters and blood vessel walls during an interventional procedure, the delicate blood vessel networks could be damaged, causing severe consequences. However, it remains challenging to scale down the size of the nanomechanical sensor and increase force resolution because of mechanical feedback mechanisms and active components. Developing a compact all-fiber, micro-force sensor can open up countless capabilities, including real-time intracellular monitoring, minimally invasive probing, and high-resolution detection.

In a new paper published in *Light Science & Applications,* Professor Yiping Wang from Shenzhen University and his research team have proposed the microprinting of a novel fiber-tip-polymer clamped-beam probe micro-force sensor for the examination of biological samples. The proposed sensor consists of two bases, a clamped beam, and a force-sensing probe, which were developed using a femtosecond-laser-induced two-photon polymerization technique. A miniature all-fiber micro-force sensor of this type exhibited an ultrahigh force sensitivity of 1.51 nm/μN, a detection limit of 54.9 nN, and an unambiguous sensor measurement range of 2.9 mN. The Young's modulus of polydimethylsiloxane, a butterfly feeler, and human hair were successfully measured with the proposed sensor. This approach opens new avenues towards the realization of small-footprint AFMs that could be easily adapted for use in outside specialized laboratories. This device will be beneficial for high-precision biomedical and material science examination, and the proposed fabrication method provides a new route for the next generation of research on complex fiber-integrated polymer devices.

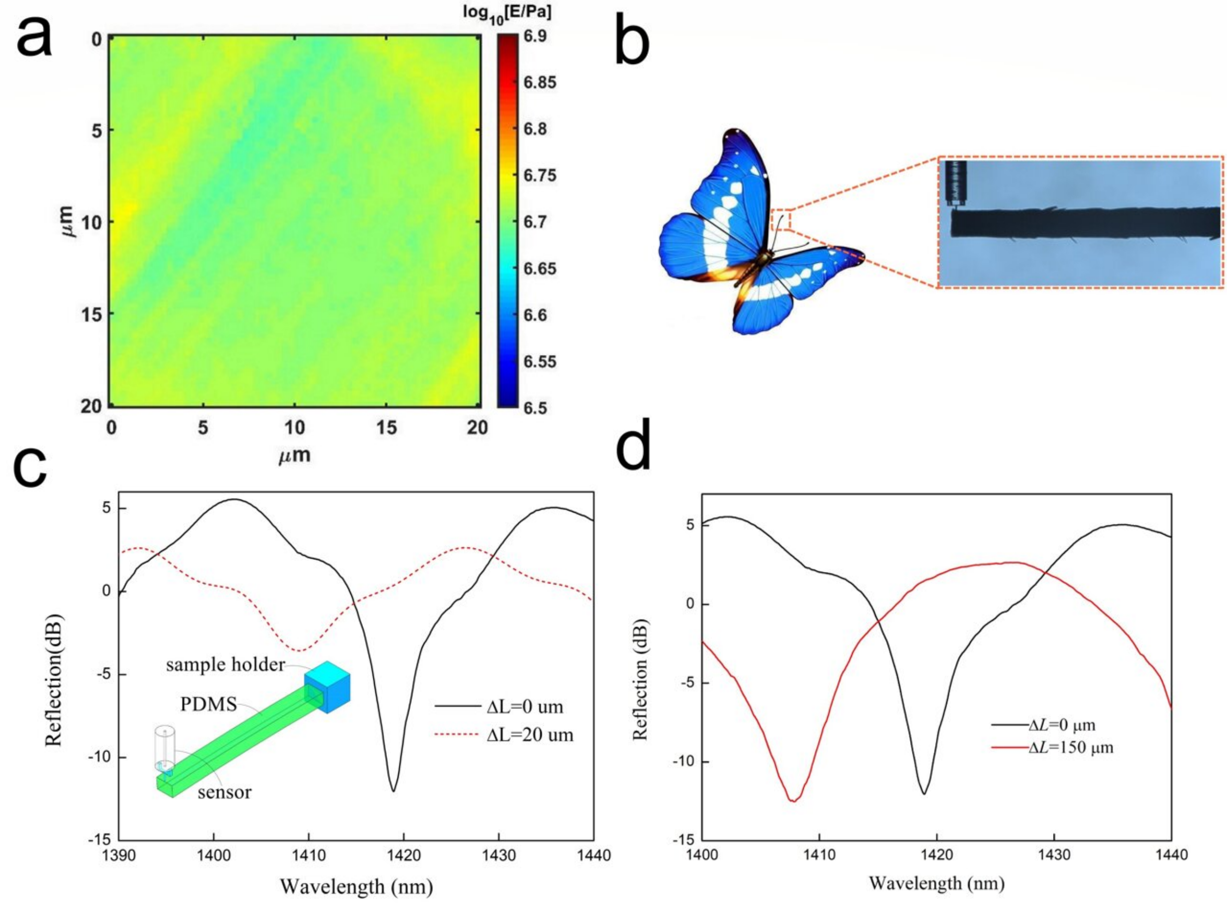


a Evolution of reflection spectra of the sensor as the force increased from 0 to 2700 nN, as indicated by the arrows. b Dip wavelength versus force. The line is the linear fitting of measured data points and the error bar is obtained by critically repeating the experiment of force measurement three times. c Simulation results of deformation distribution based on FEM. Credit: Mengqiang

Zou, Changrui Liao, Shen Liu, Cong Xiong, Cong Zhao, Jinlai Zhao, Zongsong Gan, Yanping Chen, Kaiming Yang, Dan Liu, Ying Wang and Yiping Wang

Using the structure-correlated mechanics, the team developed a compact all-fiber micro-force sensor for the examination of biological samples. In this sensor, the clamped beam, the support bases, and the force-sensing probe were printed on the optical fiber end surface using TPP 3D microprinting method. The structure of the sensor was optimized using the finite element method (FEM), and its static characteristic was analyzed. The lead-in fiber-end surface and the clamped beam define a Fabry–Perot interferometer (FPI). When an external force is exerted on the probe, the probe deflects the clamped beam, which modulates the length of the FPI. This method utilizes the low stiffness and high resilience of the structure of the clamped beam, enables it to deform enough when a small force is applied, and thus greatly improves both force resolution and detection range of the sensor.

The team then carried out microforce sensing measurements before any sensing applications. When force was gradually applied to clamped-beam probe, the reflection spectrum of the micro-force sensor was monitored in real time. Results showed a blue shift in the dip wavelength, and the force sensitivity of the sensor was calculated to be -1.51 nm/μN by using a linear fit of the dip wavelength change, which are two orders of magnitude higher than that of the previously reported fiber-optic force sensor based on a balloon-like interferometer. Thus, the relationship between the applied force and the output of the sensor was quantified. In addition, the micro-force sensor has a detection limit of 54.9 nN, and an unambiguous sensor measurement range of 2.9 mN.



a Young's modulus mechanical diagram on logarithmic scale. b CCD image of pushing against butterfly feeler of the proposed sensor. c Evolution of reflection spectrum of the sensor as PDMS deflects from 0 to 20 μm. d Evolution of reflection spectrum of the sensor with deflection of butterfly feeler from 0 to 150 μm. Credit: Mengqiang Zou, Changrui Liao, Shen Liu, Cong Xiong, Cong Zhao, Jinlai Zhao, Zongsong Gan, Yanping Chen, Kaiming Yang, Dan Liu, Ying Wang and Yiping Wang

At the last stage, after the system was fully calibrated, the proposed sensor successfully measured PDMS, a butterfly feeler and human hair. Results were verified using an AFM. It is believed that this fiber sensor has the smallest force-detection limit in direct contact mode reported to date. With its high force sensitivity, ultra-small detection limit, micrometer-scale measurement, easy packaging, all-dielectric design, biocompatibility, and all-fiber operation, the proposed sensor has great application prospects for examining biological samples and the mechanical properties of materials.

More information: Mengqiang Zou et al, Fiber-tip polymer clamped-beam probe for high-sensitivity nanoforce measurements, *Light: Science & Applications* (2021). DOI: 10.1038/s41377-021-00611-9

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