

WORLD'S MOST VERSATILE

MICRO-MECHANICAL TESTING MACHINE



FT-MTA03
MICROMECHANICAL TESTING
AND ASSEMBLY SYSTEM



FT-MTA03 MICROMECHANICAL TESTING

AND ASSEMBLY SYSTEM



FEMTOTOOLS



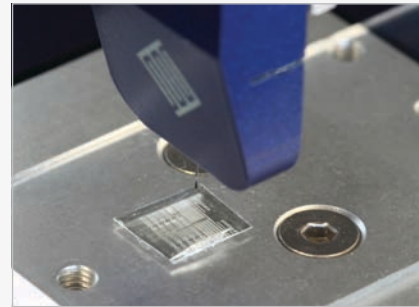
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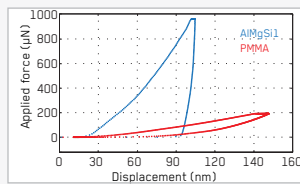
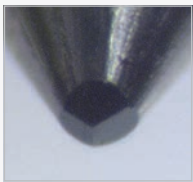
FT-MTA03 MICROMECHANICAL TESTING

AND ASSEMBLY SYSTEM

The FT-MTA03 Micromechanical Testing and Assembly System is a highly versatile testing instrument for the accurate quantification of mechanical properties and dimensions/geometry in the micro- and nanoscale. The FT-MTA03 combines the capabilities of a nanoindenter, a micro-tensile tester, a stylus profilometer and a versatile microstructure analyzer. It enables force measurements within ± 200 mN with a resolution of 0.5 nN (covering 9 orders of magnitude) and displacements from 0.1 nm to 29 mm (covering 8 orders of magnitude) along three axes. Furthermore, the FT-MTA03 can be reconfigured to meet a large range of applications and requirements, offering a complete solution for the comprehensive analysis of microstructures.



NANOINDENTER



Nanoindentation

Soft material characterization

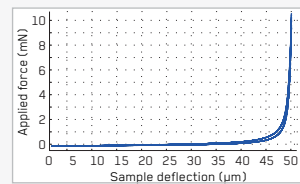
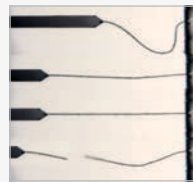
Indentation creep testing

Thin film mechanical characterization

Microcapsule / particle compression testing

Failure / fracture testing of materials

MICRO-TENSILE TESTER



Tensile testing of fibers (electrospun, silk, textile)

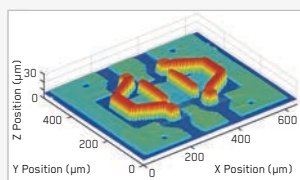
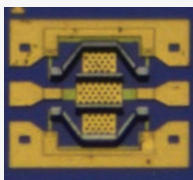
Creep and stress relaxation testing

In-liquid tensile testing of fibers

Fracture testing of micro-composites

Tensile testing of biological fibers

STYLUS PROFILOMETER



2D and 3D mapping of topographies

Dimensions of high aspect ratio structures

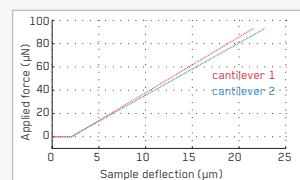
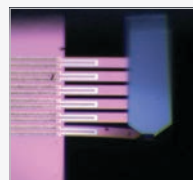
Topography of soft or suspended samples

Determine the geometry of micro structures

Thin film step height measurements

Edge depth measurement

MICROSTRUCTURE ANALYZER



Highly adaptable force-deflection testing machine

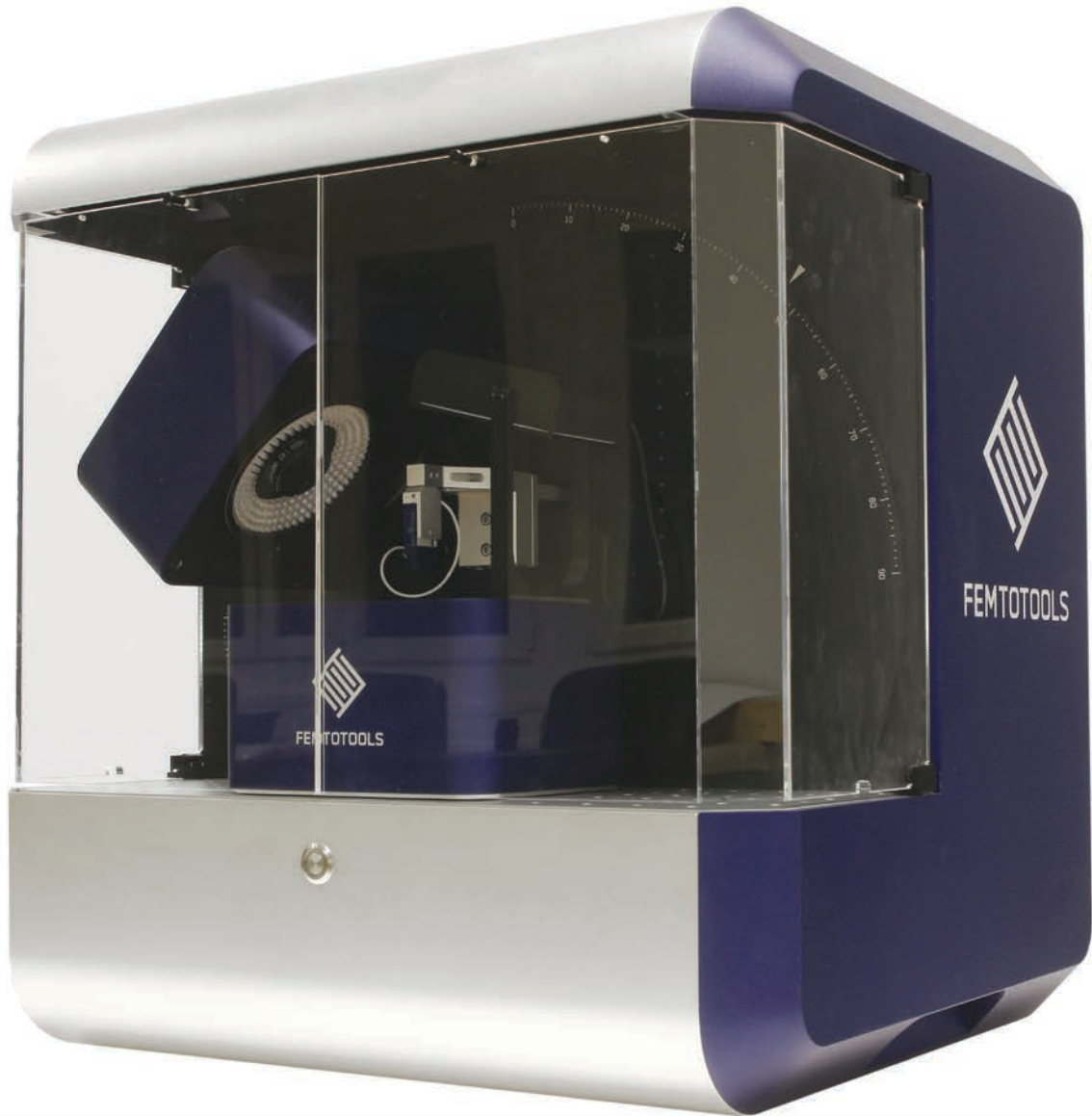
Microforce analyzer from 0.5 nN to 200 mN

In- and out-of-plane micromechanical testing

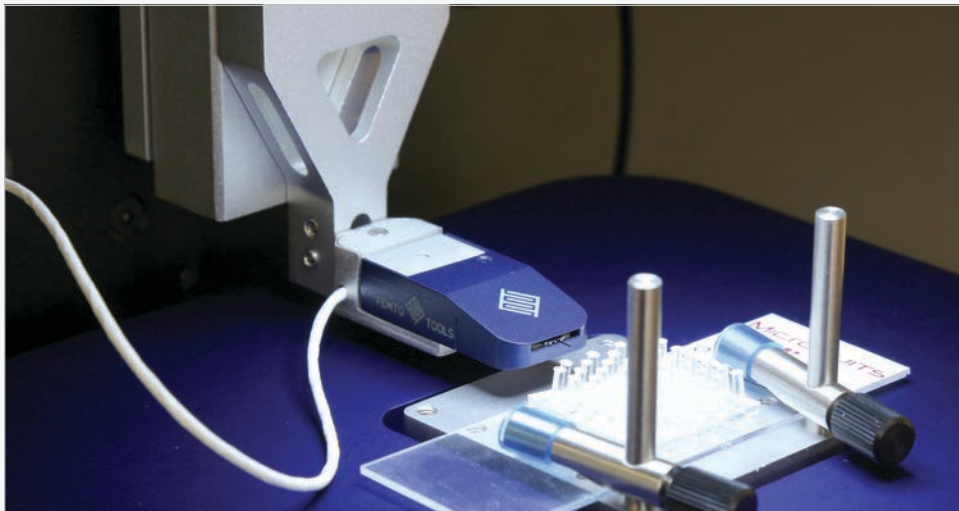
Mechanical MEMS testing (stiffness, reliability, ...)

Microactuators characterization (actuation force)

Adhesion force measurement (dry adhesives, ...)



VERTICAL AND HORIZONTAL TESTING

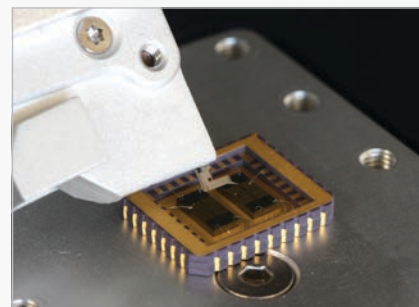
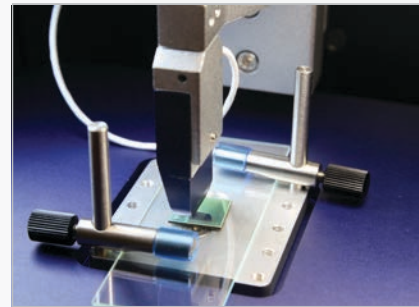


MICROMECHANICAL

TESTING MODULE

The FT-MTA03 Micromechanical Testing System consists of two main parts: a micromechanical testing module and a tilttable microscope module.

The micromechanical testing module includes a 2-axis sample positioning stage, a 3-axis piezoscanner, a MEMS-based FT-S Microforce Sensing Probe and a 3-axis nanopositioning platform (stick-slip actuation). All of these positioners are motorized and can be controlled with the FemtoTools mechanical testing and handling software suite. This combination of actuators and sensors enables the user-friendly micromechanical and topographical metrology as well as the sample-to-microscope and sample-to-force sensing probe alignment. For large range measurements, the piezoelectric stick-slip actuator can perform mechanical tests along three axes over a range of up to 29 mm with a position resolution of 1 nm. For short range measurements, the 3-axis piezoscanner is used to measure over a range of up to 50 μm with a position resolution of 0.1 nm along three axes. Furthermore, the piezoscanner is especially well suited for fast, continuous measurements.



FEATURES

Enables a large range of mechanical testing principles such as nanoindentation, compression/tensile, bending, creep, fatigue and fracture tests

High aspect ratio topography mapping (sub-nanonewton contact force resolution)

Quantitative nanomechanical testing and simultaneous visualization of the measurement

Force measurement within ± 200 mN and resolution of 0.5 nN (9 orders of magnitude)

Displacement sensing range from 0.1 nm to 29 mm (8 orders of magnitude)

Automated mapping of the mechanical properties and topographies in 3D

Adjustable sensing direction (vertical, horizontal, angles)

The compact, MEMS-based force sensing probe enables minimal signal drift and high signal-to-noise ratio

Various force sensing probe tip options, such as high-aspect-ratio tungsten probes, spherical tips, diamond Berkovich tips and conical tips

User-friendly software and intuitive GUI provide easy access to accurate data

Customizable measurement procedures and principles

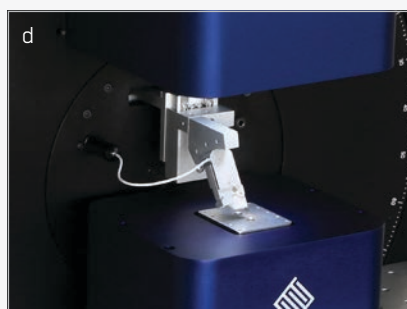
Hardware-level sensor protection mode to prevent overloading of the sensing probes

Compatible with the FemtoTools FT-S Microforce Sensing Probes for mechanical testing and the FT-G Microgripper for microrobotic handling of microstructures



- 1 **3-axis nanopositioning stage** for large-range mechanical tests with displacement up to 29 mm as well as the accurate alignment of the force sensing probe tip relative to the sample. Featuring optical position feedback on all three axes, this stage can be used for automated measurements and the mapping of mechanical and topographical properties.
- 2 **3-axis piezoscanner** for high resolution, continuous mechanical testing over a range of 50 μm with a resolution of 0.1 nm. Furthermore, by operating it in a tapping mode, the mechanical properties and the topography of the sample can be mapped within an area of 50 μm x 50 μm .
- 3 **2-axis microscope positioning stage** for the alignment of the field-of-view of the tiltable microscope relative to the measurement location of the FT-S Microforce Sensing Probe.
- 4 The **FT-S Microforce Sensing Probes** and **FT-G Microgrippers** are based on the unique FemtoTools microforce sensing technology and microgripper technology, which combine outstanding flexibility and accuracy. This enables the measurements of force within +/- 200 mN with a resolution of 0.5 nN and the handling of structures with a width of up to 100 μm .

FOUR SYSTEM CONFIGURATIONS

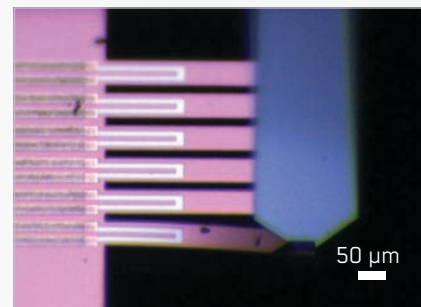
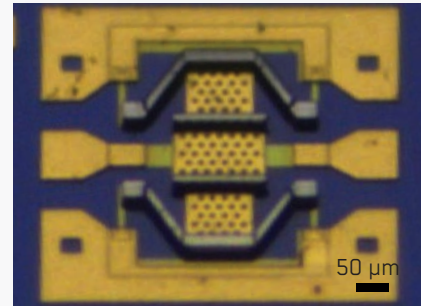


There are 4 main configurations of the micromechanical testing module of the FT-MTA03. **Figure a** shows out-of-plane (vertical) mechanical measurements such as nanoindentation and topography mapping. **Figure b** depicts the configuration for measurements under an angle relative to the sample plane. In **figure c** the configuration for in-plane (horizontal) measurement is shown, often used for tensile testing of microfibers. In **figure d**, an alternative configuration for measurements in the sample plane (horizontal), using the FT-S Lateral Microforce Sensing Probe, is shown. This enables mechanical testing in narrow gaps, often used for the in-plane testing of microsystems.

MICROSCOPE

MODULE

Micromechanical testing or microrobotic handling of small samples requires a high-resolution microscope with a large working distance that allows the force sensing probes or microgrippers to access the sample with simultaneous visualization. For this purpose, the microscope module of the FT-MTA03 Micromechanical Testing and Assembly System can be tilted over a range of 180° around the sample. This enables an accurate sensor/gripper-to-sample alignment while avoiding that the sensor or microgripper obstructs the view of the sample. This high performance digital microscope has an extremely high working distance of 95 mm and a large depth of field that can be adjusted by an iris. The microscope is equipped with a 3 megapixel CMOS USB camera. The microscope also features a 7:1 motorized optical zoom and motorized focus, to observe samples within a field of view ranging from 9.5 mm x 7.1 mm down to 1.4 mm x 1.0 mm. Depending on the sample reflectivity and the observation angle, three different adjustable LED illumination principles can be selected: Coaxial through-the-lens illumination, ring-light and diffuse backlight. Some testing applications require additional equipment such as electrical probes. Therefore, the FT-MTA03 features a breadboard with M6 screw holes for the attachment of auxiliary equipment.



FEATURES

Tiltable microscope (180° rotation range around the sample)

Adjustable field of view: 9.5 x 7.1 mm to 1.4 x 1.0 mm

Large working distance (95 mm)

Motorized 7:1 zoom and focus

Manual iris to adjust the depth of field

3 megapixel CMOS digital camera with USB interface

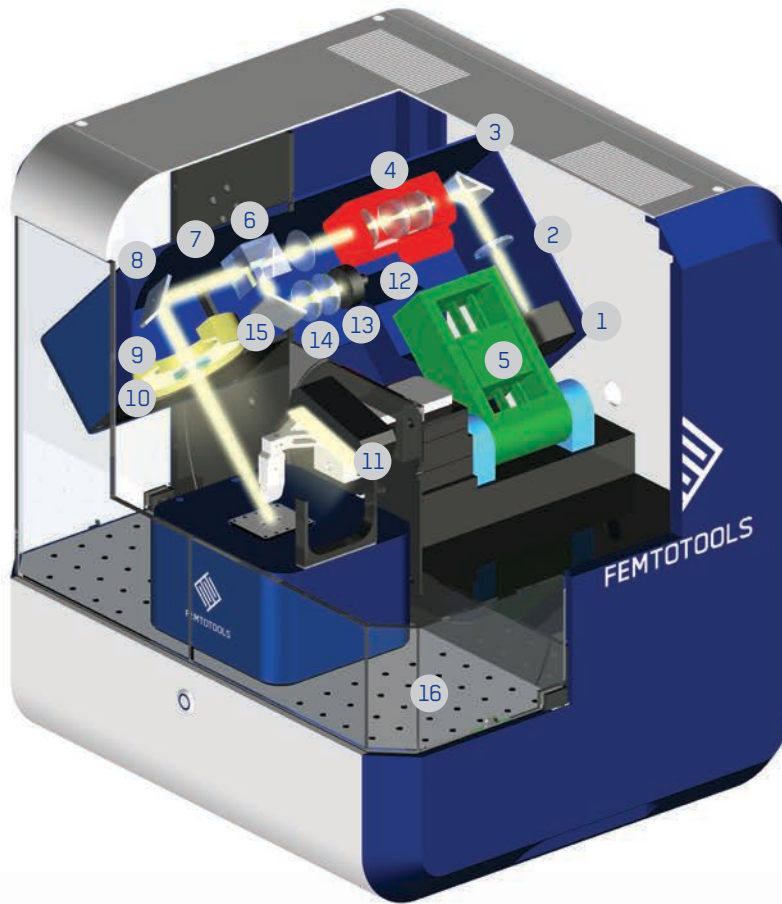
Ring-light LED illumination

Coaxial, through-the-lens LED illumination

Diffuse backlight LED illumination

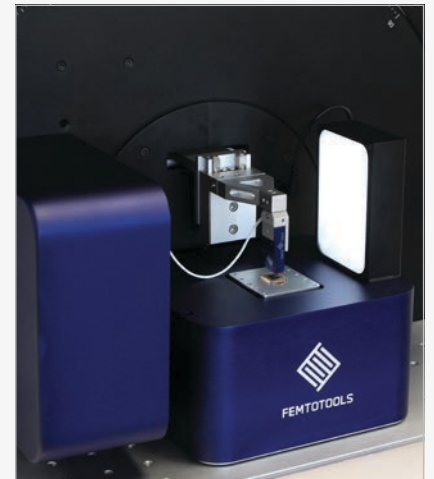
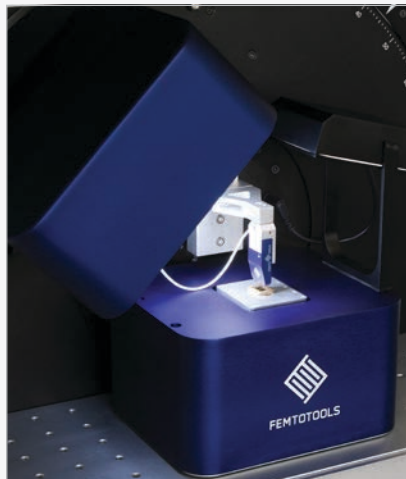
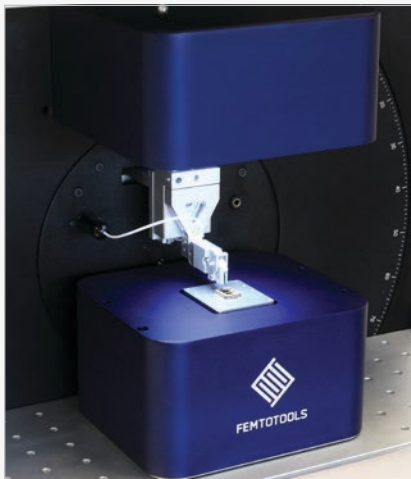
2-axis motorized sample stage

MICROSCOPE MODULE



- | | | |
|---|---|--|
| 1 CMOS Camera, 3 megapixel (2048 x 1536 pixels) | 7 Prisms - couples the light into the optical path for the coaxial illumination | 12 LED light source (6'000 K) |
| 2 Projection lens | 8 Mirror | 13 Diffusor |
| 3 Mirror | 9 LED ring-light illumination | 14 Aspheric condenser lens |
| 4 Motorized 7:1 optical zoom | 10 Objective lens | 15 Mirror |
| 5 Motorized focus drive | 11 Backlight - homogeneous illumination for the side-view microscope | 16 M6 breadboard for auxiliary equipment |
| 6 Adjustable iris (adjusts depth of field) | | |

SELECTED SYSTEM CONFIGURATIONS

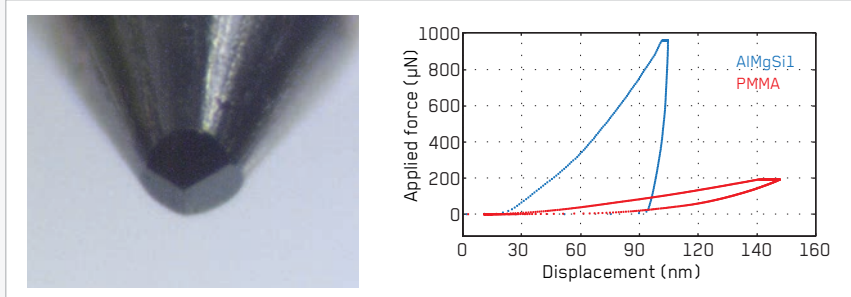


APPLICATION EXAMPLES

NANOINDENTER

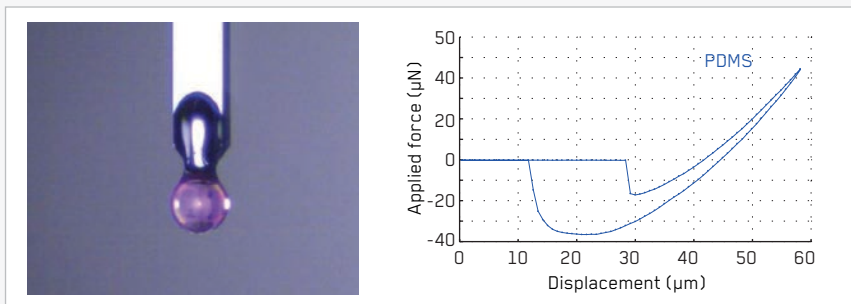
NANOINDENTATION

For the localized material testing of small volumes, the FT-MTA03 offers both position-controlled and force-controlled nanoindentation. The tiltable microscope enables the real-time visual observation of the sample during the load application.



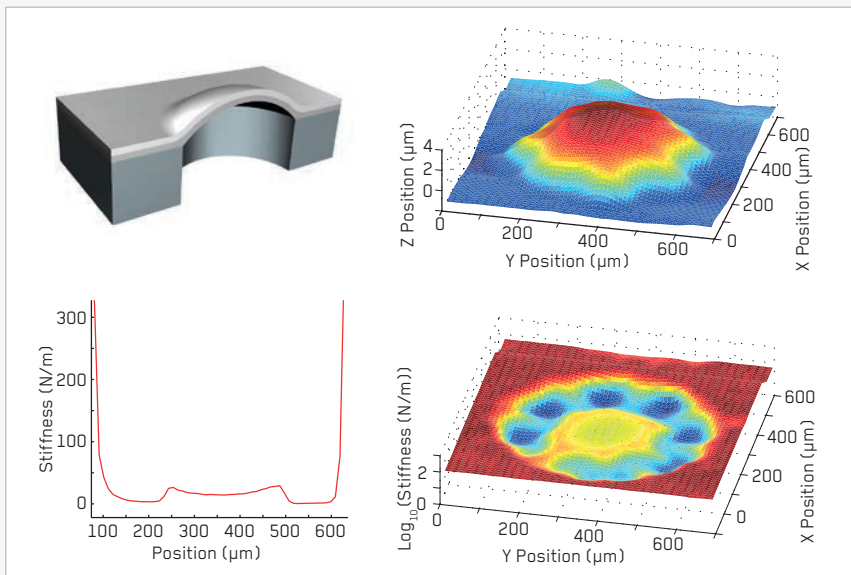
NANOINDENTATION INTO SOFT MATERIALS

The large displacement range in combination with the low-force sensing capabilities makes the FT-MTA03 an ideal tool for soft material characterization. Here, a spherical tip is used to indent the PDMS sample. Besides the standard material parameters, the raw force-displacement-time data is provided for different material models.



MECHANICAL PROPERTY MAPPING OF A SUSPENDED DIAMOND MEMBRANE

This work reports the testing of a nanocrystalline diamond and aluminum nitride membrane for the use in tunable micro-optics. Both the topography and the stiffness of the membrane are measured. The upper right graph illustrates the topography of the micromembrane, while the lower right graph shows its stiffness distribution. The lower left graph is a cross-section of the stiffness map going through the central section of the membrane.



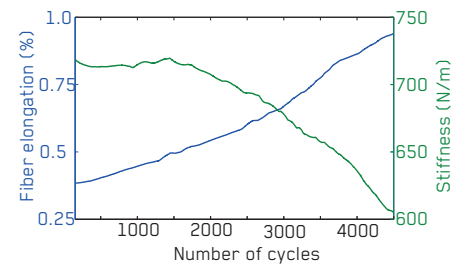
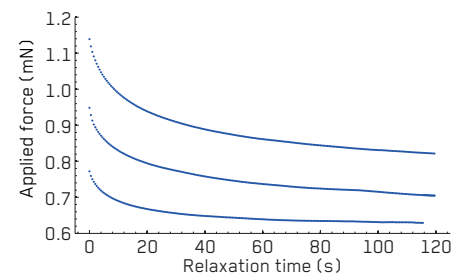
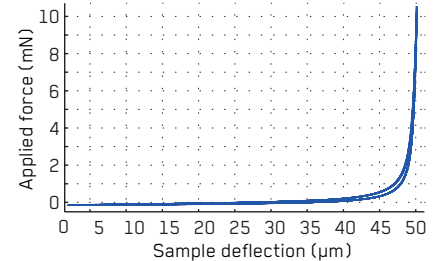
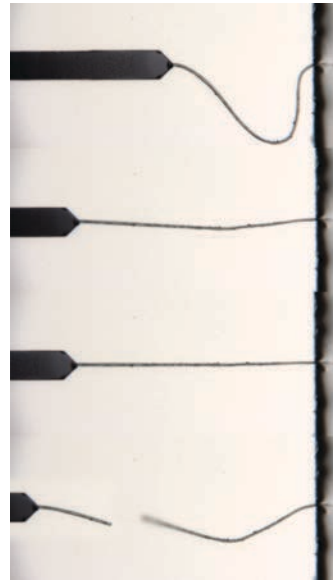
MICRO-TENSILE TESTER

MICROSCALE TENSILE TESTING OF SILICA FIBERS

Silica microfibers created by roller electrospinning are mechanically characterized by performing tensile tests. Both the sample preparation process and the tensile testing are performed using the FT-MTA03 Micromechanical Testing and Assembly System.

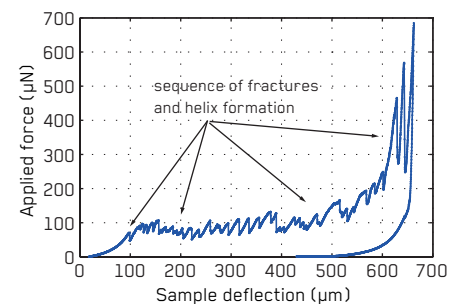
First, an individual fiber is collected using a FT-G103 Force Sensing Microgripper and attached on one side onto a glass slide using UV curable glue. Subsequently, the opposite side of the fiber is glued to the probe tip of a FT-S20'000 Microforce Sensing Probe.

The upper microscope image shows the fiber in a relaxed state. The fiber is stretched until it is straight and then stretched even further. The stiffness, the elongation, the maximum yield strength and the maximum elongation are measured. Additionally, the relaxation behavior is analyzed by stretching the fiber and measuring the force while keeping the position constant. Cyclic testing is performed to measure the change of stiffness and fiber elongation after a large number of loading and unloading cycles.



MICROSCALE TESTING OF ROOT HAIRS

The quantitative knowledge of the mechanical properties of plants cells is crucial for an accurate understanding of plant growth. In this application tensile testing and fracture testing of a single root hair is demonstrated. For this purpose the tungsten tip of the FT-S Microforce Sensing Probe is glued to the end of the root hair. For tensile testing, the root hair is stretched while the applied force and the deformation is recorded. From the resulting force-versus-deformation plot it can be observed that after an initial loading, the root hair starts to fracture, as indicated by a force drop. However, the root hair does not fail completely but rather only fractures partially and starts to form a helical shape. As the force is increased, the root hair continues to form more fractures while completely transforming into a helix.

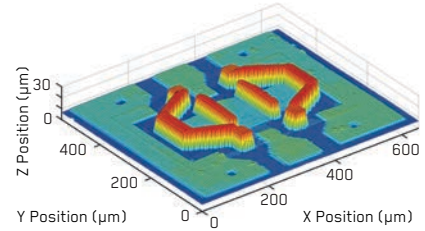
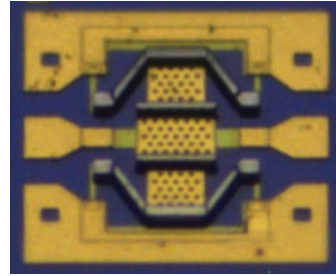


APPLICATION EXAMPLES

STYLUS PROFILOMETER

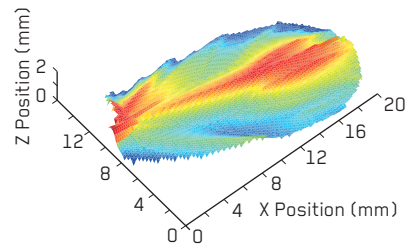
DIMENSIONAL METROLOGY OF MICROSTRUCTURES

Innovations in microtechnology enable the fabrication of ever smaller, high aspect ratio structures. This miniaturization causes an increase in dimensional and mechanical imperfections. The FT-MTA03 can measure the dimensions and the mechanical properties of microstructures for the optimization of fabrication processes. (Device courtesy: Prof. Ionescu, Nanolab, EPFL)



DIMENSIONAL METROLOGY OF SOFT SUSPENDED SAMPLES

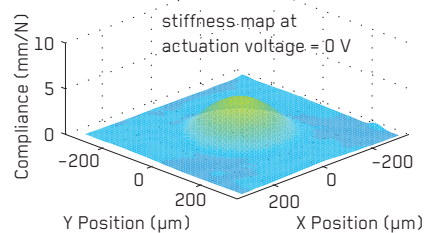
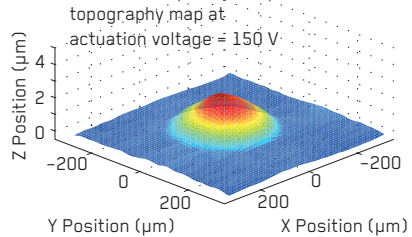
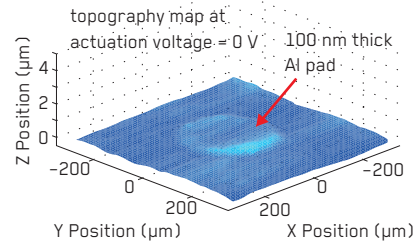
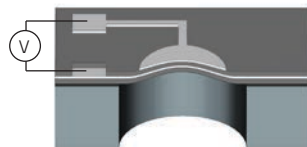
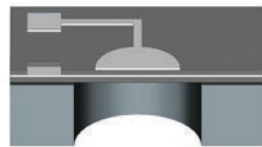
Insect wings are ultra-lightweight mechanical structures, strengthened by a number of longitudinal veins, which have cross-connections that form closed "cells" in the membrane. To analyze the aerodynamics of a butterfly wing, an accurate knowledge of the shape and the mechanics of the wing is required. The figure shows the topography map of a butterfly wing.



TOPOGRAPHY AND COMPLIANCE MAPPING OF A PIEZOELECTRIC MICRO-MEMBRANE

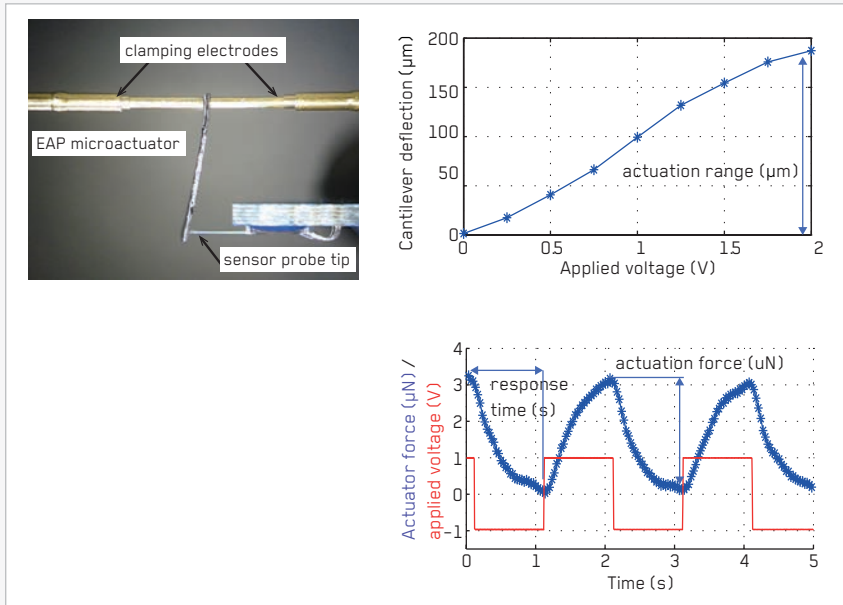
A MEMS piezoelectric micro-membrane is tested by characterizing its compliance as well as its topography while it is actuated. Force-displacement data is automatically acquired in a $600\ \mu\text{m} \times 600\ \mu\text{m}$ area.

The top image illustrates the topography of the membrane at an actuation voltage of 0 V. Then, a voltage potential of 150 V is applied to the membrane by two electric probes that are mounted on the breadboard of the FT-MTA03. The middle image illustrates the actuated membrane topography at 150 V. The lower image illustrates the compliance (inverse of stiffness) of the membrane and the middle image illustrates the



MICROSTRUCTURE ANALYZER

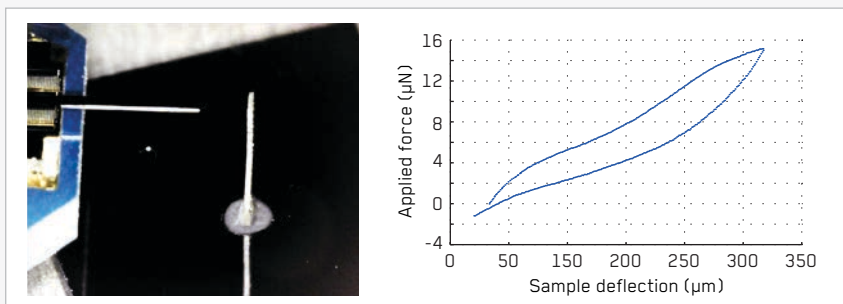
ELECTROACTIVE POLYMER ACTUATOR TESTING



Conjugated or conducting polymers are receiving significant attention as smart materials for novel microfabricated devices such as actuators and sensors. The deflection range, the actuation force and the time-response of the beam-shaped electroactive polymer (EAP) actuator are tested in this application.

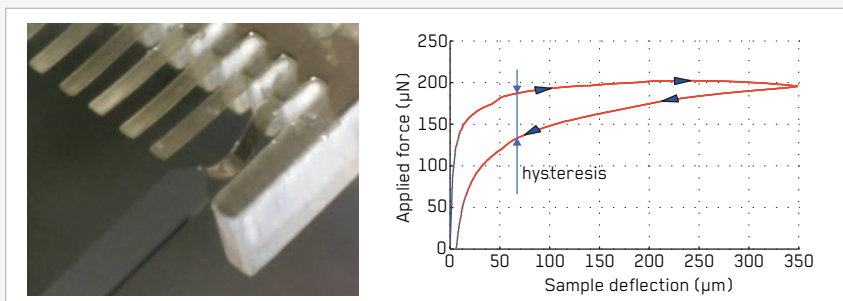
The beam-shaped microactuators are clamped between two electrodes, enabling the application of the actuation signal to drive the microactuator. The top graph illustrates the maximum deflection of the EAP actuator beam tip versus the actuation voltage. The lower graph shows the driving force generated by the EAP actuator as well as the square-wave driving signal plotted versus time.

PT-SILICONE COMPOSITE MICROELECTRODE TESTING



For the manufacturing of implantable neural electrodes, a highly compliant platinum microsphere filled PDMS composite material has been developed. Bending tests are performed on the 300 μm diameter electrode to measure the elastic and plastic deformation at different strain levels.

MICROSCALE TESTING OF THE MATERIAL PROPERTIES OF POLYMERS



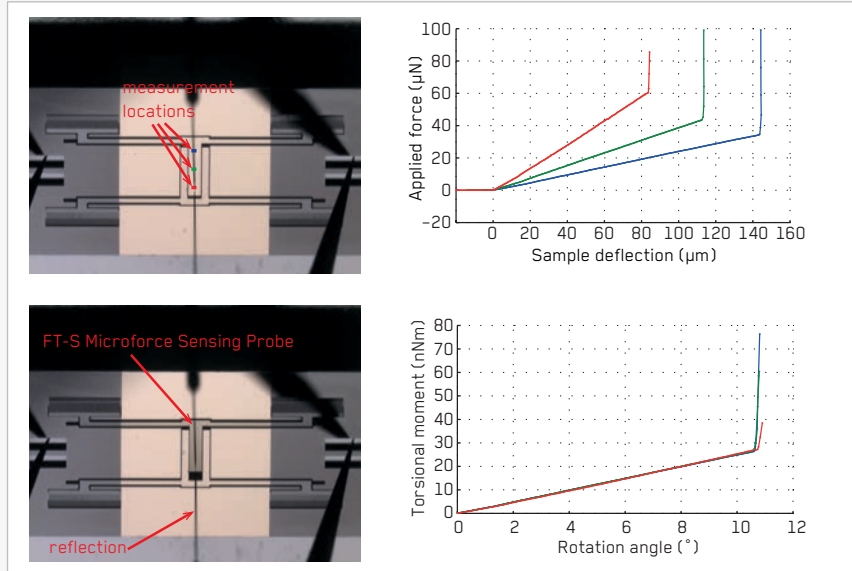
Polymer materials (e.g. PMMA, PDMS, SU-8) are commonly used for MEMS sensors and actuators. However, the incorporation of polymers for mechanical purposes in MEMS devices raises new issues and challenges. In this application PMMA cantilevers are loaded to measure device properties such as buckling forces, elastic/plastic deformations and hysteresis.

APPLICATION EXAMPLES

MICROSYSTEM TESTING

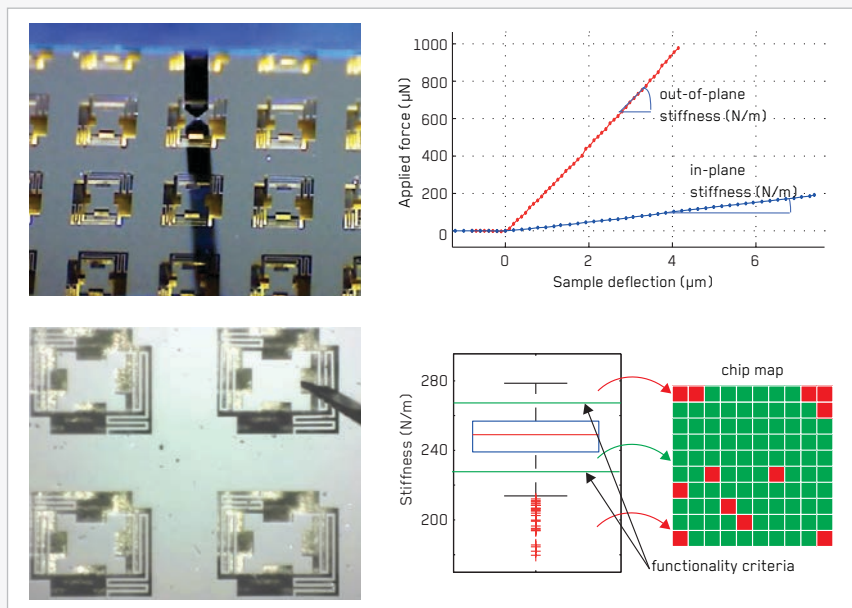
DEFLECTION RANGE AND STIFFNESS MEASUREMENTS ON A MEMS MIRROR

This application illustrates the mechanical testing of a micromirror designed for large rotation angles. The reflective mirror plate is suspended by an elastic torsional beam, allowing the plate to rotate. The FT-MTA03 is used to perform compression tests at different locations on the plate. From the measured force-deflection data, both the maximum deflection range and the torsional stiffness of the mirror plate is extracted.



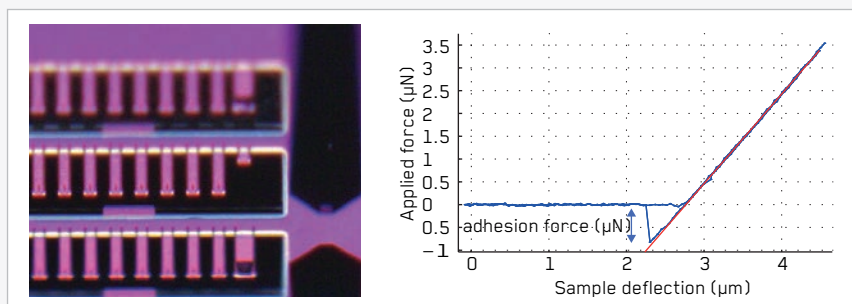
TESTING OF MICROFABRICATION YIELD

During the micro-manufacturing process development, a large number of process parameters influence the mechanical properties of the MEMS structures. In this application both the in-plane stiffness and out-of-plane stiffness of an array of MEMS flexures are tested using the FT-MTA03. By defining an upper and a lower limit for the target stiffness, a chip map is created to identify the working flexures (green) and flexures that are outside the desired specifications (red). Flexures that have not been successfully released from the wafer (very high stiffness) or flexures with cracks (low stiffness) are identified. The yield rate can easily be computed by the ratio of green to the total number of devices.



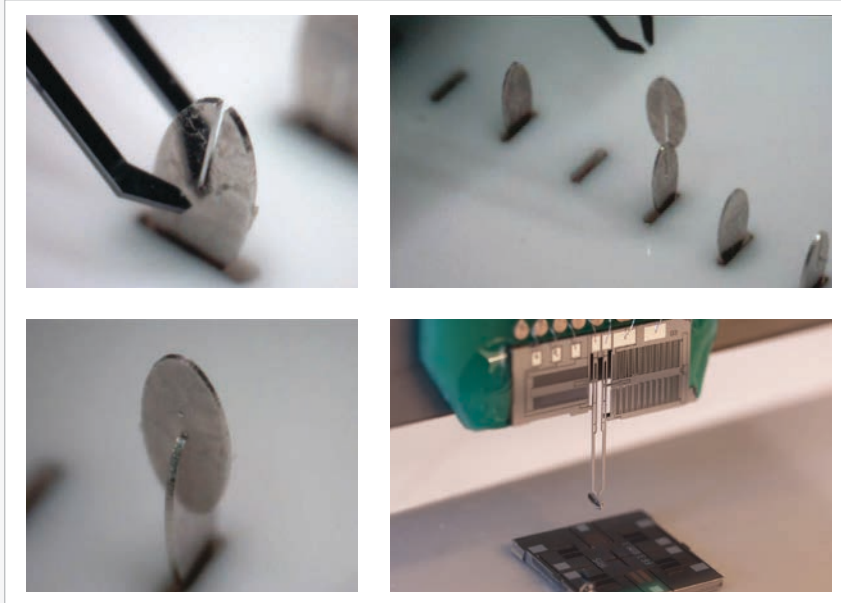
MICROCANTILEVER ADHESION FORCE TESTING

An array of microcantilevers for biological screening applications has been fabricated featuring variable surface coatings at the microcantilever tip. The FT-MTA03 system is used to measure both the elasticity of the microcantilever and the adhesion force at the tip. The adhesion force corresponds to the minimum force during the unloading of the microcantilever.



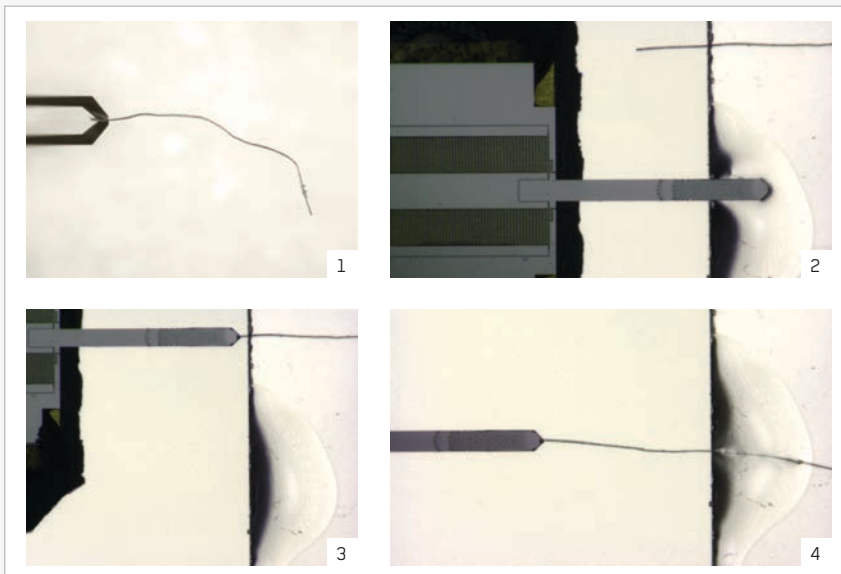
MICROHANDLING

3D MICROPART ASSEMBLY



Standard microfabrication processes are limited to a planar fabrication and do not allow the creation of complex three-dimensional structures. Additionally, only certain combinations of different materials are possible, limiting the functionality of such microfabricated devices and systems. For the development of true three-dimensional hybrid micro-electromechanical systems microassembly is required. For a biomedical application, the FT-G Microgripper was used to assemble soft-magnetic electroplated nickel pieces into a three dimensional structure. Subsequently, the assembled parts are combined with a silicon-based microsensor.

SAMPLE PREPARATION



The analysis of microscopic samples often requires challenging sample preparation steps due to the small sample size of the objects under investigation. The FT-MTA03 can be equipped with the FemtoTools force sensing microgrippers. This enables the force-controlled handling of delicate microscopic objects without causing any damage to their structure.

The image sequence illustrates the sample preparation of a microfiber for micromechanical testing. First, a single fiber is placed on a glass slide such that the end is overhanging. Then, the tip of the FT-S Microforce Sensing Probe is dipped into UV curable glue. After bringing the glue-covered sensing tip into contact with the overhanging part of the fiber, the glue is cured with a UV light. In the last step, the fiber is lifted from the glass slide and its free end is steered into the remaining glue droplet before curing the glue. As a result, the fiber is fixed on both sides and can be mechanically tested by e.g. tensile, creep, stress-relaxation or fatigue testing.

ACCESSORIES

FT-S MICROFORCE SENSING PROBES

The FemtoTools FT-S Microforce Sensing Probes are microforce sensors capable of measuring forces from 200 millinewtons down to sub-nanonewtons along the sensor's probe axis. Both compression and tension forces can be measured. The FT-S Microforce Sensing Probes are available with various tip material and geometry. The individual calibration in combination with an outstanding long-term stability guarantees significantly higher measurement accuracy than any other force sensing system in this force range. A calibration data sheet is delivered for each individual sensor.



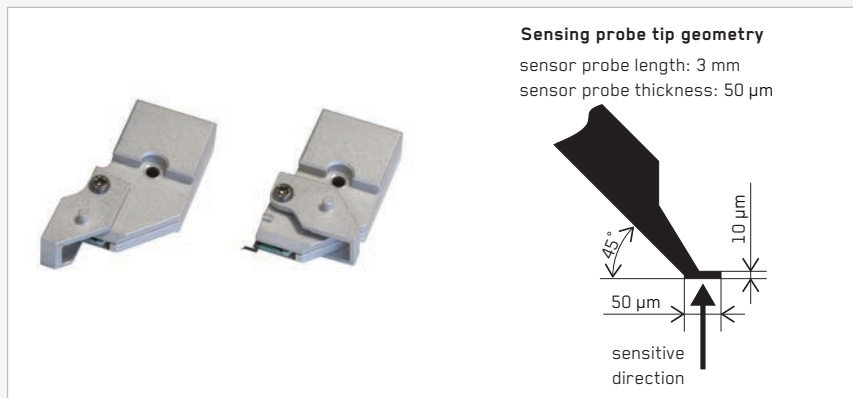
Model	Range	Resolution
FT-S200	+/- 200 µN	0.5 nN
FT-S2'000	+/- 2'000 µN	5 nN
FT-S20'000	+/- 20'000 µN	50 nN
FT-S200'000	+/- 200'000 µN	500 nN

Tip options

Material	Geometry
Silicon (standard)	Flatpunch with an area of 50 µm x 50 µm
Tungsten	Conical with tip radius <5 µm, <2 µm or <0.1 µm
Ruby / glass	Spherical with a radius of 125 µm or 25 µm
Diamond	Berkovich, conical or custom geometry

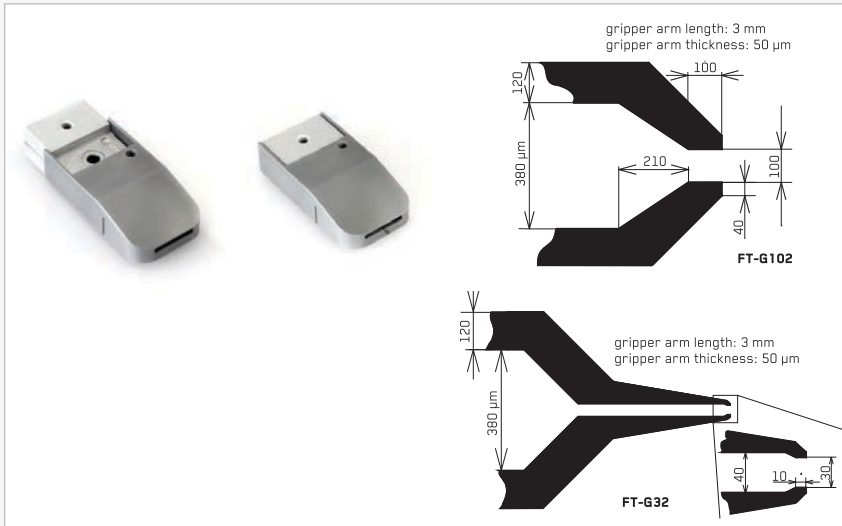
FT-S-LAT LATERAL MICROFORCE SENSING PROBE

The FemtoTools FT-S2000-LAT Lateral Microforce Sensing Probe is a microforce sensor capable of measuring forces from 2 millinewton (10^{-3} N) down to 10 nanonewtons (10^{-9} N) perpendicular to the sensor's axis. Both compression and tension forces can be measured. This off-axis measuring capability allows for the vertical micromechanical testing while observing both the sensing-probe tip and the sample under a top-view microscope.



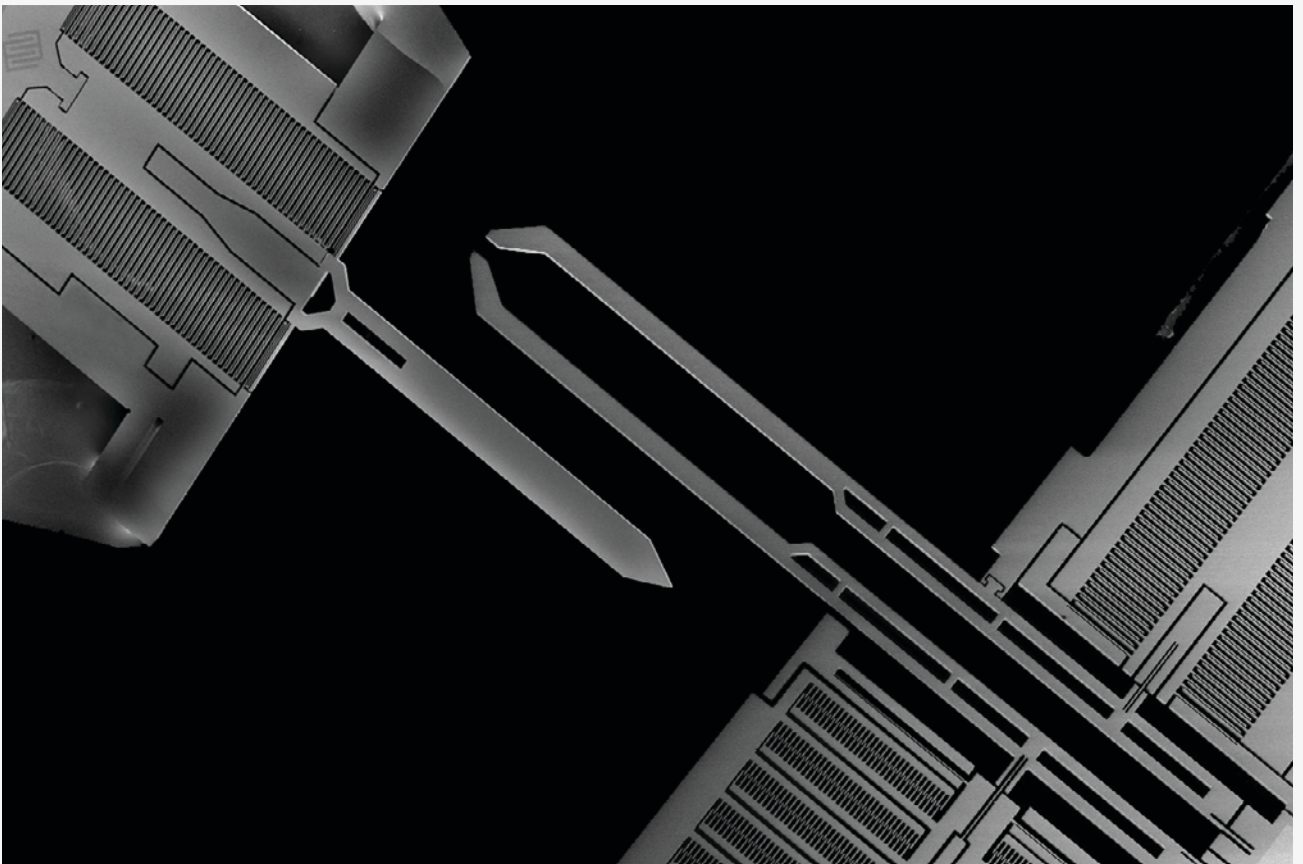
Model	Range	Resolution
FT-S2'000-LAT	+/- 2'000 µN	10 nN

FT-G FORCE SENSING MICROGRIPPER



The FT-G Microgripper series is designed to handle microscale objects. The initial openings of the gripper arms are 30 µm for the FT-G33 and 100 µm for the FT-G 103 and can be fully closed. The opening can be controlled with nanometer precision. Both the FT-G33 and the FT-G103 Force Sensing Microgripper feature an integrated force sensor to measure the gripping force. The force feedback greatly enhances the ability to handle fragile, microscopic samples, as often required for sample preparation.

Model	Opening	Force Sensor
FT-G33	0 - 30 µm	yes
FT-G103	0 - 100 µm	yes



TECHNICAL

SPECIFICATIONS

MECHANICAL TESTING MODULE

FT-S Microforce Sensing Probe

Maximum force range* ¹	± 200 mN
Smallest force resolution* ²	0.5 nN* ³ (at 10 Hz)
Measurement frequency	up to 96 kHz
Probe tip options	
- Tungsten probe	tip radius < 5 µm, < 2 µm or < 0.1 µm
- Diamond probe tip	Berkovich Conical (2 µm tip radius)
- Glass sphere	Radius = 25 +/- 1 µm
- Ruby sphere	Radius = 125 +/- 1.3 µm

*¹ Using a FT-S200'000 Microforce Sensing Probe

*² The resolution is defined as 1 sigma of the measured noise

*³ Using a FT-S200 Microforce Sensing Probe

FT-G Microgripper

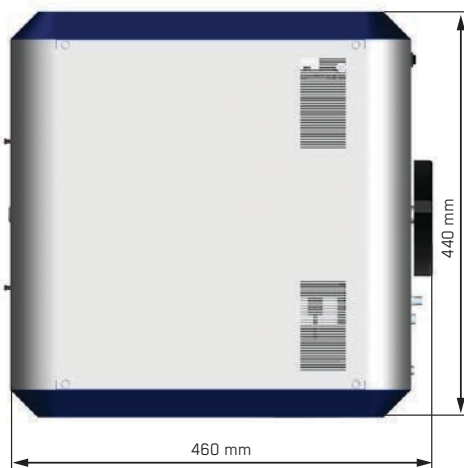
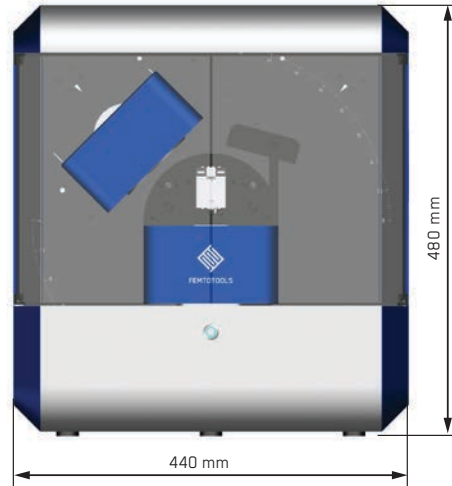
Gripper opening	0 - 100 µm
Gripping force feedback	yes

3-axis nanopositioning stage (coarse)

Number of axes	3
Actuation principle	Piezoelectric stick slip
Actuation range	29 mm x 29 mm x 80 mm
Min. motion increment	20 nm
Encoder resolution* ²	1 nm (at 10Hz)
Maximum velocity	10 mm/s
Measurement frequency	up to 50 Hz

3-axis piezoscanner (fine)

Number of axes	3
Actuation principle	Piezoelectric scanning
Actuation range	50 µm x 50 µm x 50 µm
Min. motion increment	0.1 nm
Encoder resolution* ²	0.1 nm (at 10 Hz)
Measurement frequency	up to 96 kHz



MICROSCOPE MODULE

Microscope

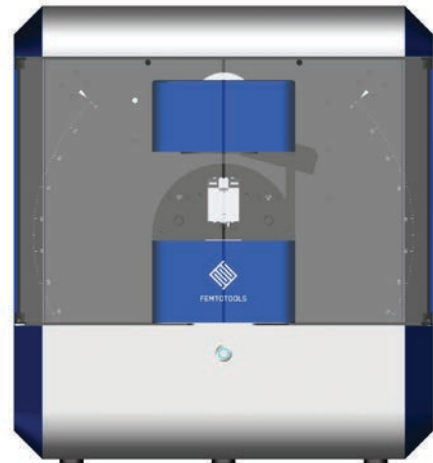
Optical zoom range	1:7 motorized
Field of view, zoomed out	9.5 mm x 7.1 mm
Field of view, zoomed in	1.4 mm x 1.0 mm
Working distance	95 mm
Iris	adjustable
Camera	5 megapixel CMOS sensor
Focus block range (coarse)	25 mm motorized
Microscope tilting angle	-90° - 0° (vertical) - +90°

Microscope Positioning Stage

Number of axes	2
Actuation principle	stepper motor
Actuation range	10 mm x 40 mm
Sample mounting	2 clamps

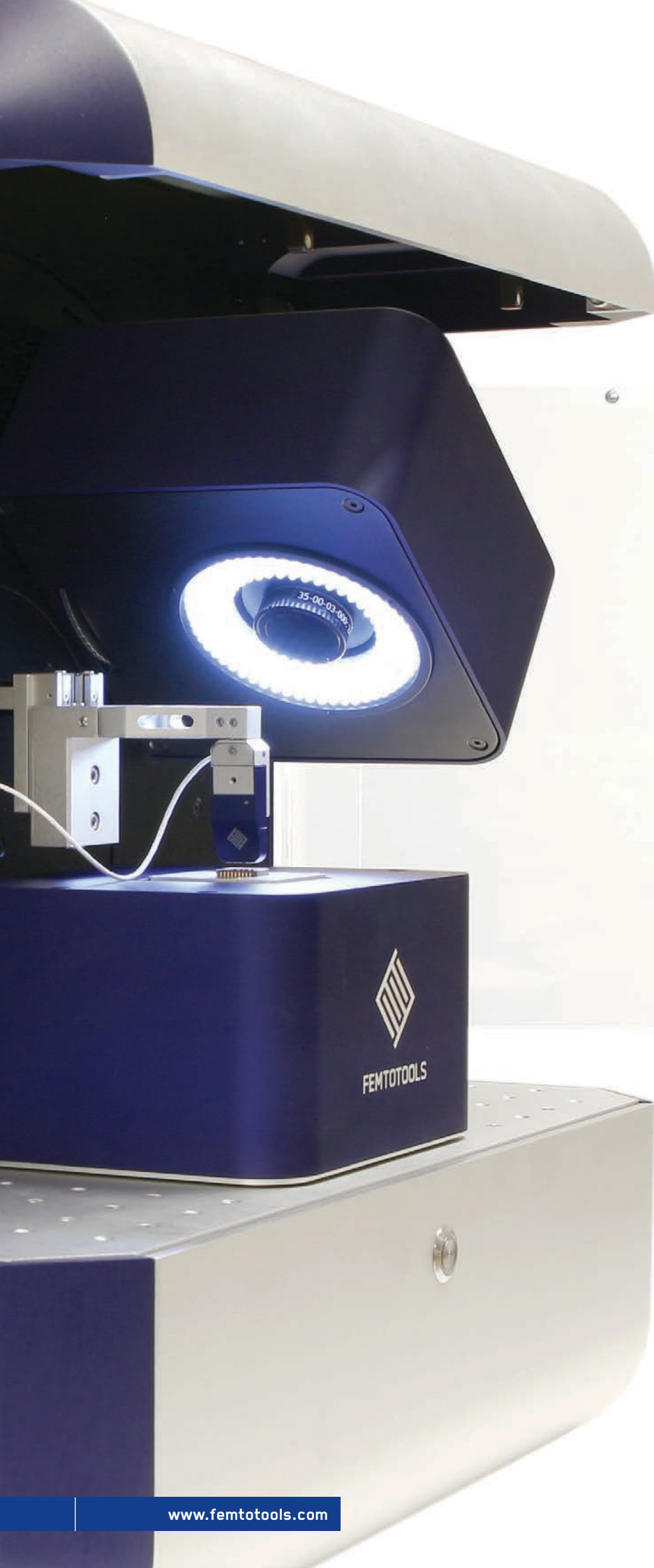
Lighting

Coaxial through-lens	LED, adjustable
Ring light	LED, adjustable
Backlight (low angle)	LED, adjustable
Backlight (high angle)	LED, adjustable



GENERAL SYSTEM SPECIFICATIONS

Interface	USB 3
Power supply	12 V power supply with Europlug (110 V/230 V)



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