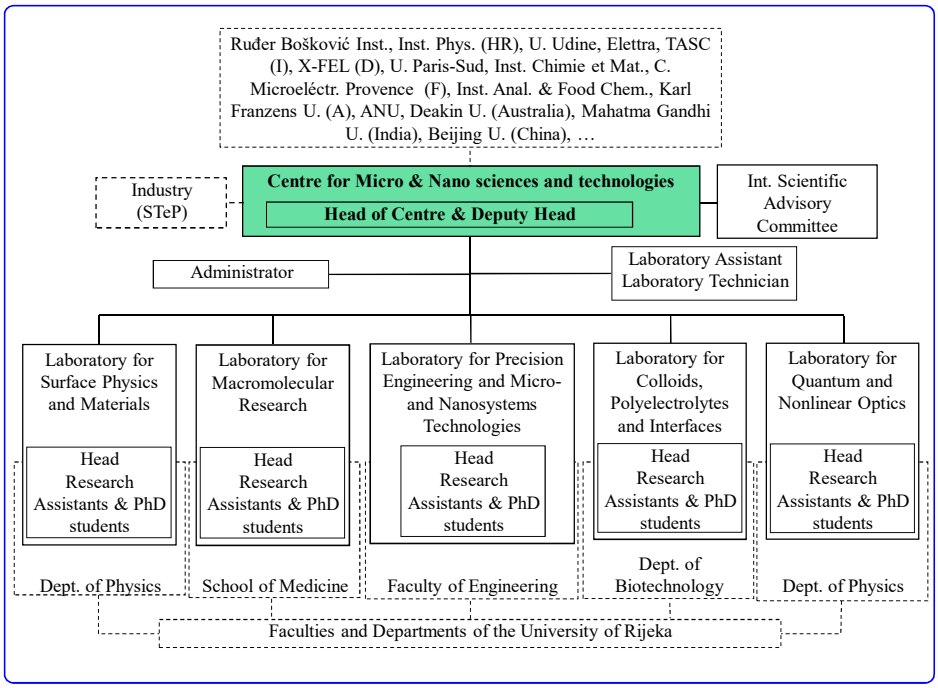
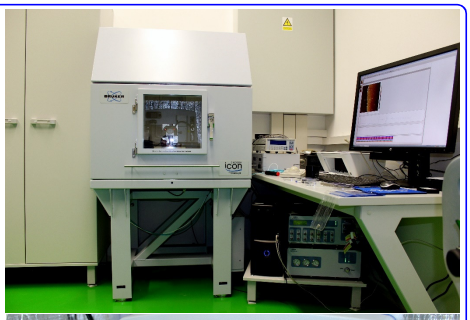
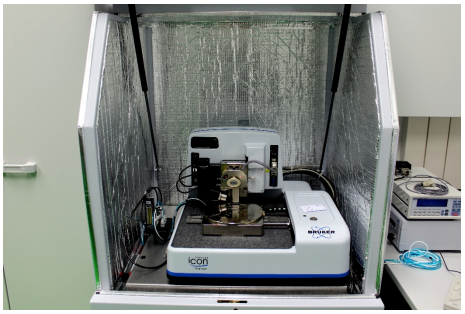


CENTRE FOR MICRO- AND NANOSCIENCES AND TECHNOLOGIES (CMNST)

Equipment installed at the Laboratory for Precision Engineering and Micro- and Nanosystems' Technologies (LPEMNT) on the campus of the University of Rijeka, Croatia (Trsat)

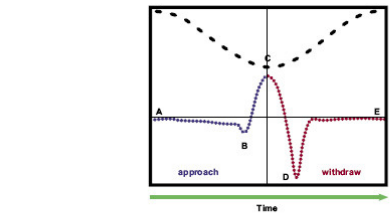
Bruker Dimension Icon Scanning Probe Microscope (SPM):

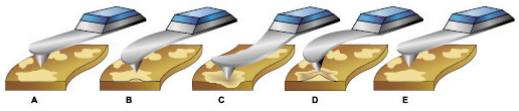




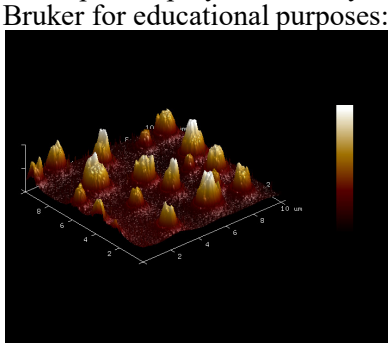
AFM and STM modules in one device.
Supports contact and tapping mode (closed loop control keeps the force (deflection of the beam which holds the tip) constant, which limits the contact forces to < 200 pN, i.e. a value far lower than the tapping forces of other devices – PeakForce tapping).
Enables measurements of elasticity modulus, adhesion, lateral force (LFM), spectroscopy and force modulation, electrochemical analysis, electric field and magnetic forces, surface potential, piezoelectric force; enables also nanolitography, …
Option to measure in liquid for biotechnical applications and measurements with heating/cooling of the samples, …
Imaging of measured data on 5'120 x 5'120 pixels.
Samples fixed to the support via a vacuum chuck can be up to few millimetres in size, with bidirectional positioning repeatability of 3 μm on a scanning area of up to 90 x 90 μm.
Includes heat (creep < 200 pm/min) and vibration isolation (1" Si damping cushion + compressed air → < 30 pm RMS), microscope and CCD camera, control SW, …

PeakForce Tapping™ is an AC imaging technique, i.e., the cantilever is oscillated but well below resonance. This results in a continuous series of force-distance curves. In addition to direct force control by keeping the peak force constant, a multitude of material properties can be extracted and quantified from the force-distance curve at each pixel within an image, such as modulus, adhesion force, and deformation depth.





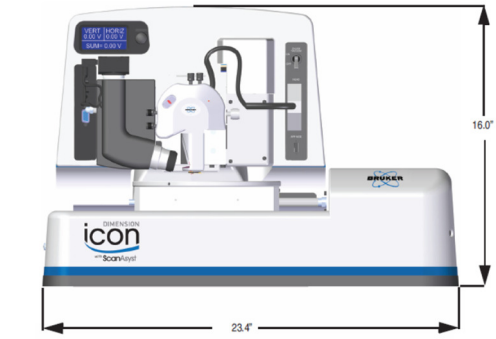
Measurement results on two-component polymer used by Bruker for educational purposes:



Technical characteristics:

Specifications	
X-Y scan range	90µm x 90µm typical, 85µm minimum
Z range	10µm typical in imaging and force curve modes, 9.5µm minimum
Vertical noise floor	<30pm RMS in appropriate environment typical imaging bandwidth (up to 625Hz)
X-Y position noise (closed-loop)	≤0.15nm RMS typical imaging bandwidth (up to 625Hz)
X-Y position noise (open-loop)	≤0.10nm RMS typical imaging bandwidth (up to 625Hz)
Z sensor noise level (closed-loop)	35pm RMS typical imaging bandwidth (up to 625Hz); 50pm RMS, force curve bandwidth (0.1Hz to 5kHz)
Integral nonlinearity (X-Y-Z)	<0.5% typical
Sample size/holder	210mm vacuum chuck for samples, ≤210mm diameter, ≤15mm thick
Motorized position stage (X-Y axis)	180mm x 150mm inspectable area; 2µm repeatability, unidirectional; 3µm repeatability, bidirectional
Microscope optics	5-megapixel digital camera; 180µm to 1465µm viewing area; Digital zoom and motorized focus
Controller	NanoScope V
Workstation	Integrates all controllers and provides ergonomic design with immediate physical and visual access
Vibration isolation	Integrated, pneumatic
Acoustic isolation	Operational in environments with up to 85dBC continuous acoustic noise
AFM modes	Standard: ScanAsyst, PeakForce Tapping, TappingMode (air), Contact Mode, Lateral Force Microscopy, PhaseImaging, Lift Mode, MFM, Force Spectroscopy, Force Volume, EFM, Surface Potential, Piezoresponse Microscopy, Force Spectroscopy; Optional: PeakForce QNM, HarmoniX, Nanoindentation, Nanomanipulation, Nanolithograpy, Force Modulation (air/fluid), TappingMode (fluid), Torsional Resonance Mode, Dark Lift, STM, SCM, C-AFM, SSRM, PeakForce TUNA,TUNA, TR-TUNA, VITA
Certification	CE

[www.bruker.com]



ca.125 kg

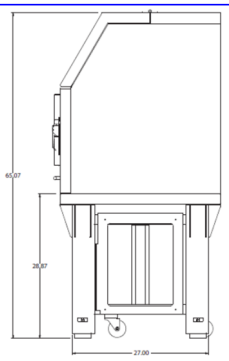
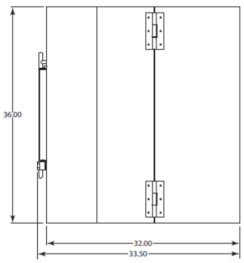


Figure 3.2e AVH-1000 Top View



Keysight G200 Nanoindenter (former Agilent, earlier HP):

[www.keysignt.com]

The device is thermally as well as dynamically (and acoustically) isolated.
Electromagnetic actuation (voice coil principle), i.e. load generation: max 0.5 N with a 50 nN resolution; additional built-in high-load system with 0.1 mN … 10 N load range. Loading system stiffness (guided by leaf springs): $5 \cdot 10^6$ N/m.
Capacitive displacement measurement: resolution < 0.01 nm for > 500 µm displacement range. Obtainable straightness in a 100 µm range is within 10 nm.
4 samples in a 100 x 100 mm sample holder with a scanning resolution of 0.1 µm and 1 µm accuracy; automatically controlled (closed loop based on incremental encoders). Measurement of elasticity modulus and hardness according to ISO 14577.
Enables LFM with a ≤ 2 µN resolution and max lateral force ≥ 250 mN. Low-force measurements enable obtaining surface topology after indentation.
Berkovich, cube corner, conical, spherical and Vickers tips. System for sample visualization (10x and 40x zoom), microscope with CCD camera and data analysis SW.

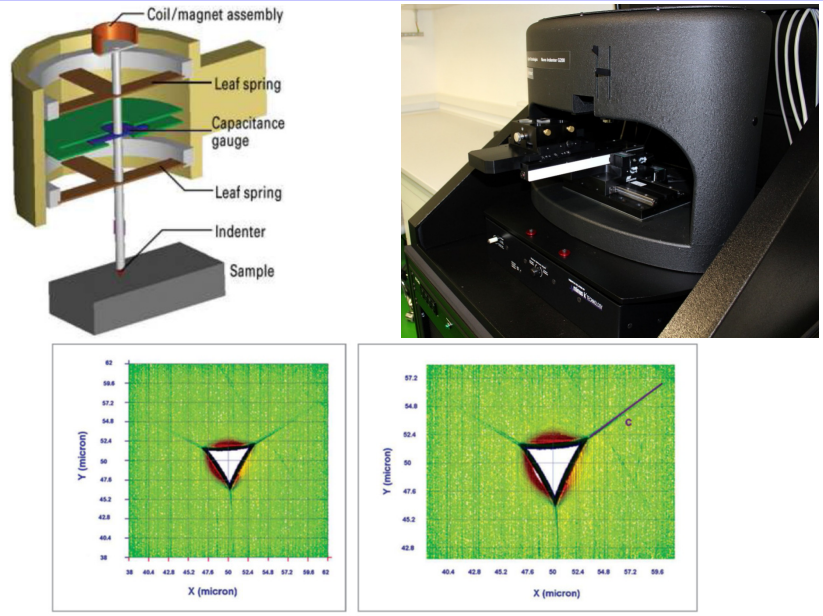
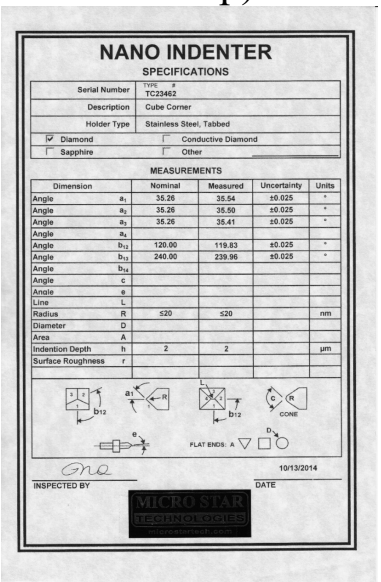


Figure 4. Fracture toughness by Nanoindentation. Left image: A 24 x 24µm scan of a 1200nm deep indent in silica. Crack features accentuated. Right image: An enlarged image of the indent taken straight from the Nano-Suite 6.2 review page.

Technical characteristics:

Keysight Nano Indenter G200 specifications	
Standard XP Indentation Head	
Displacement resolution	< 0.01 nm
Total indenter travel	1.5 mm
Maximum indentation depth	> 500 µm
Load application	Coil/magnet assembly
Displacement measurement	Capacitance gauge
Loading capability	
Maximum load (standard)	500 mN
Maximum load with DCM II option	30 mN
Maximum load with High Load option	10 N
Load resolution	50 nN
Contact force	< 1.0 µN
Load frame stiffness	~5 x 106 N/m
Indentation placement	
Useable surface area	100 mm x 100 mm
Position control	Automated remote with mouse
Positioning accuracy	1 µm
Microscope	
Video screen	25x (x objective mag.)
Objective	10x and 40x
DCM II Indentation Head Option	
Displacement resolution	0.0002 nm (0.2 picometers)
Range of indenter travel	70 µm
Loading column mass	< 150 mg
Load application	Coil/magnet assembly
Displacement measurement	Capacitance gauge
Typical leaf spring stiffness	~100 N/m
Typical damping coefficient	0.02 Ns/m
Typical resonant frequency	120 Hz
Lateral stiffness	80,000 N/m
Loading capability	
Maximum load	30 mN (13 gm)
Load resolution	3 nN (0.3 µgm)
Express Test Option	
Time per indentation	Standard < 5.0 sec
LFM Option	
Maximum lateral force	> 250 mN
Lateral resolution	< 2 µN
Maximum scratch distance	> 100mm
Scratch speed	100 nm/s up to 2 mm/s
High Load Option	
Maximum force	10 N
Load resolution	≤ 1 mN
Maximum indentation depth	≥ 500 µm
Displacement resolution	0.01 nm
Frame stiffness	≥ 5 x 106 N/m
NanoVision Option	
X-Y scan range	100 µm x 100 µm
Z scan range	Indentation head dependent
Positioning accuracy	≤ 20 nm
Resonant frequency	> 120 Hz

Calibration and conformity certificate for each tip (example for cube-corner tip):



NANO INDENTER

SPECIFICATIONS

Serial Number	TYPE # TC23462
Description	Cube Corner
Holder Type	Stainless Steel, Tabbed

☑ Diamond ☐ Conductive Diamond

☐ Sapphire ☐ Other

MEASUREMENTS

Dimension		Nominal	Measured	Uncertainty	Units
Angle	a_1	35.26	35.54	±0.025	°
Angle	a_2	35.26	35.50	±0.025	°
Angle	a_3	35.26	35.41	±0.025	°
Angle	a_4				
Angle	b_{12}	120.00	119.83	±0.025	°
Angle	b_{13}	240.00	239.96	±0.025	°
Angle	b_{14}				
Angle	c				
Angle	e				
Line	L				
Radius	R	≤20	≤20		nm
Diameter	D				
Area	A				
Indention Depth	h	2	2		µm
Surface Roughness	r				

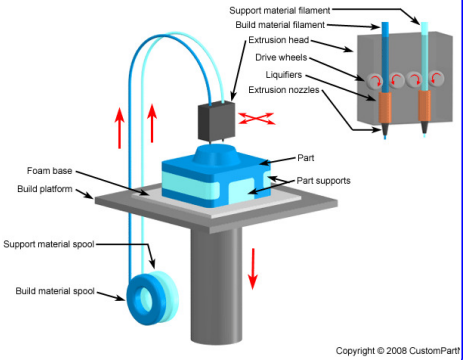
INSPECTED BY 10/13/2014 DATE

MICRO STAR TECHNOLOGIES

Stratasys Fortus 250mc 3D printer: for models with dimension of up to 254 x 254 x 305 mm, with 178 μm layer thickness and positioning accuracy of 240 μm.
2 heads (building and support material).
FDM (Fused Deposition Modelling) technology (heating and extrusion of thermoplastics); material: ABSplus (acrylonitrile butadiene styrene).
Import of STL (Standard Tessellation Language) 3D models from CAD + SW for printing process optimization (including support structure optimization).
An additional 3D printer (Stratasys Connex 500), capable of using up to 14 different materials with different stiffness properties, available at the Faculty of Civil Engineering on same U. of Rijeka campus → PolyJet technology: similar to desktop inkjet printers, with photo polymer material hardened under UV light; printing resolution down to 16 μm.

[www.stratasys.com]

FDM process:
- Advantages: laser not needed, fast and secure procedure, lower power consumption, unnecessary cooling and ventilation, simple usage, low investment, low maintenance costs, small size (additional room not needed), warping effect minimised.
- Disadvantages: surface can be rough and models can have a certain porosity, model functionality is limited by the used material, in many cases the support structure has to be used, additional mechanical processing needed, lines between layers can physically be seen, hardness of the product is lower in the direction of the printed layers, oscillations in temperature during the printing process can lead to delamination of the product; upon warming, melting and solidification processes, ABS can shrink up to few %.

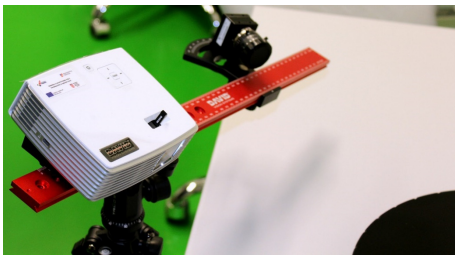


[Godec et al., TehnZnan HATZ, 2015]

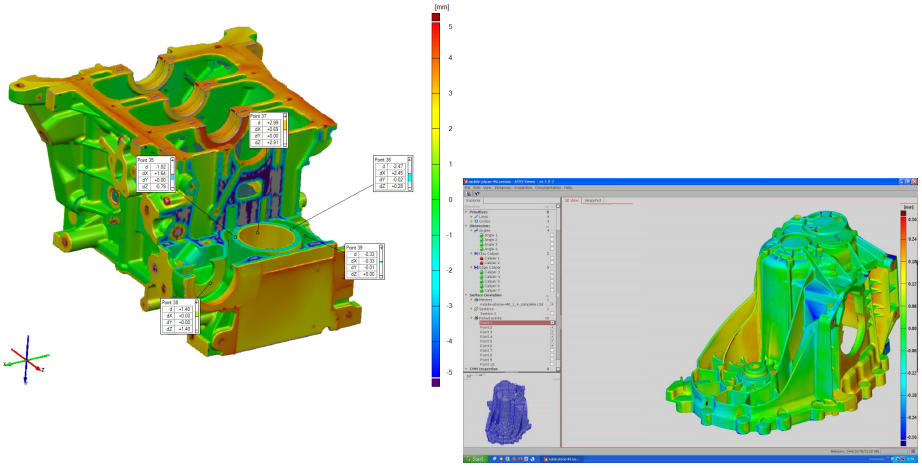
Modern 3D (non-contact) scanners are the basis for reverse engineering (and, in combination with above 3D printers, of rapid prototyping).

At CMNST: DAVID SLS-2 (Structured Light Technology): the distance and the angle of the camera with respect to the projector are known, i.e. distortion of the reflected light pattern (fringes) depends on object's geometry. Projector + camera + calibration panels + rotating table.

500 mm scanning area, resolution/ accuracy 1‰ of the object size, includes SW environment, mobile with tripod, enables exporting data to formats compatible with standard CAD SW (e.g. STL):



Post processing: 3D software which uses cloud of points to generate a mesh for 3D inspection, i.e., the analysis of the components (e.g. comparison with nominal 3D shapes and dimensions – including sections):



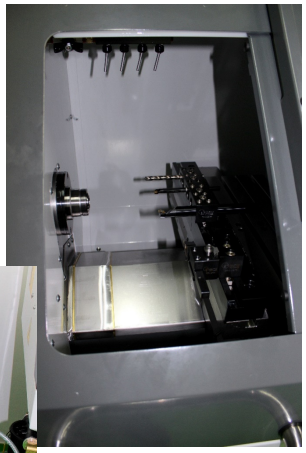
[www.gom.com]

CNC machine tools for sample preparation: Haas Office series machine tools characterized by small dimensions as well as outstanding performances and exceptional benefits for the end users; include user-friendly interface, HAAS/Fanuc control unit as well as technical support from the Croatian representative company Teximp d.o.o.

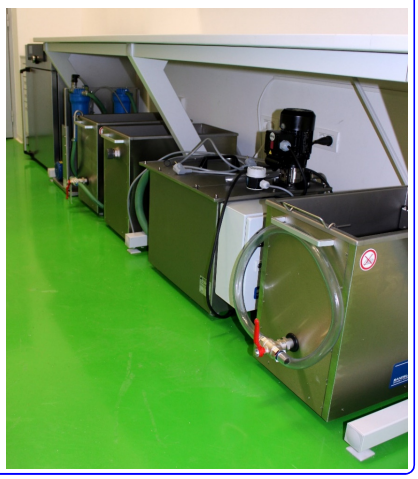
[int.haascnc.com]

Haas Office OM-2A milling machine: dimensions within an 1.7 x 0.84 x 1.9 m envelope; enables a 5-axes machining with up to 20 automatically interchangeable tools; machining volume 305 x 254 x 305 mm; 1 µm displacement resolution; spindle velocity of up to 30'000 rpm and 3.7 kW power:

Haas Office OL-1 lathe: dimensions within an 1.3 x 0.84 x 1.8 m envelope; 4-axes, 12 tools; turning diameter of up to 250 mm, 1 µm displacement resolution; spindle velocity of up to 6'000 rpm and power of up to 5.6 kW:

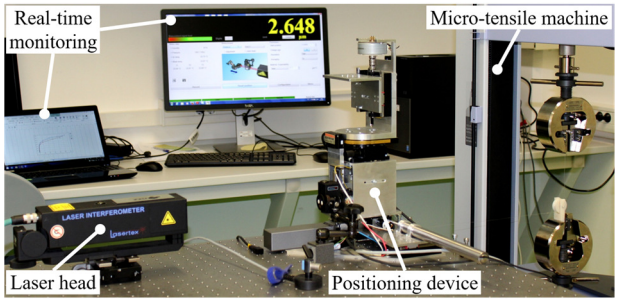


A system for ultrasonic cleaning of samples for (ultra-high) vacuum: heated (up to 70 °C) prewash with oil separation → ultrasound (10 PZT inverters, 40 kHz, 500 W continuous and 2 kW peak power) 45 l heated stainless steel bath for cleaning with a "soft" (pH 9.9) detergent and with filtering of media (particles' separation) → 2 baths for rinsing in demineralized water with heating (1.2 kW, 30 … 80 °C) → drying with hot air (up to 300 °C):



Micro-tensile machine (up to 5 kN, resolution 2 mN and 10 μm, for metals, ceramics, polymers, rubber and composites) – Shimadzu Autograph AGS-X:

Optical table and opto-mechanics from Newport:



Other laboratories of the CMNST (total value of equipment > 4 M EUR):

- Scanning electron microscope, secondary ion and neutron mass spectrometry, surface profilometer, atomic layer deposition system, vacuum compatible equipment (LSPM).
- Thermogravimetric analyser, dynamic mechanical analyser, IR spectrometer, chromatograph, laboratory tensile machine for macromolecules, double roller mill, gas adsorption porosimeter, press with heated plates, UV system for photo polymerization, dry chamber (LMR).
- Spectroscopic ellipsometer, measurement of electrophoretic mobility/analysis of the size of (nano)particles, cyclic voltammetry and electrochemical impedance spectroscopy, cleansing and deionization of taped water, precise laboratory scales (LCPI).
- Digitizing and data processing devices, data acquisition electronics, coherent light source – lasers, optics and opto-mechanics (LQNO).

Precision Engineering Laboratory at the Faculty of Enginnering of the University of Rijeka: optical table and data acquisition and control hardware for ultra-high precision positioning acquired trough the SCOPES program of the Swiss National Science Foundation, educational STM and laser vibrometer funded via Croatian Ministry of Science, laser interferometric system and stereomicroscope acquired with funds of the Croatian National Science Foundation.

Systems for precision mechanical engineering design, measurement, manipulation and assembly of microparts, energy harvesting, ... for testing, optimization, …

→ precenglab.riteh.uniri.hr