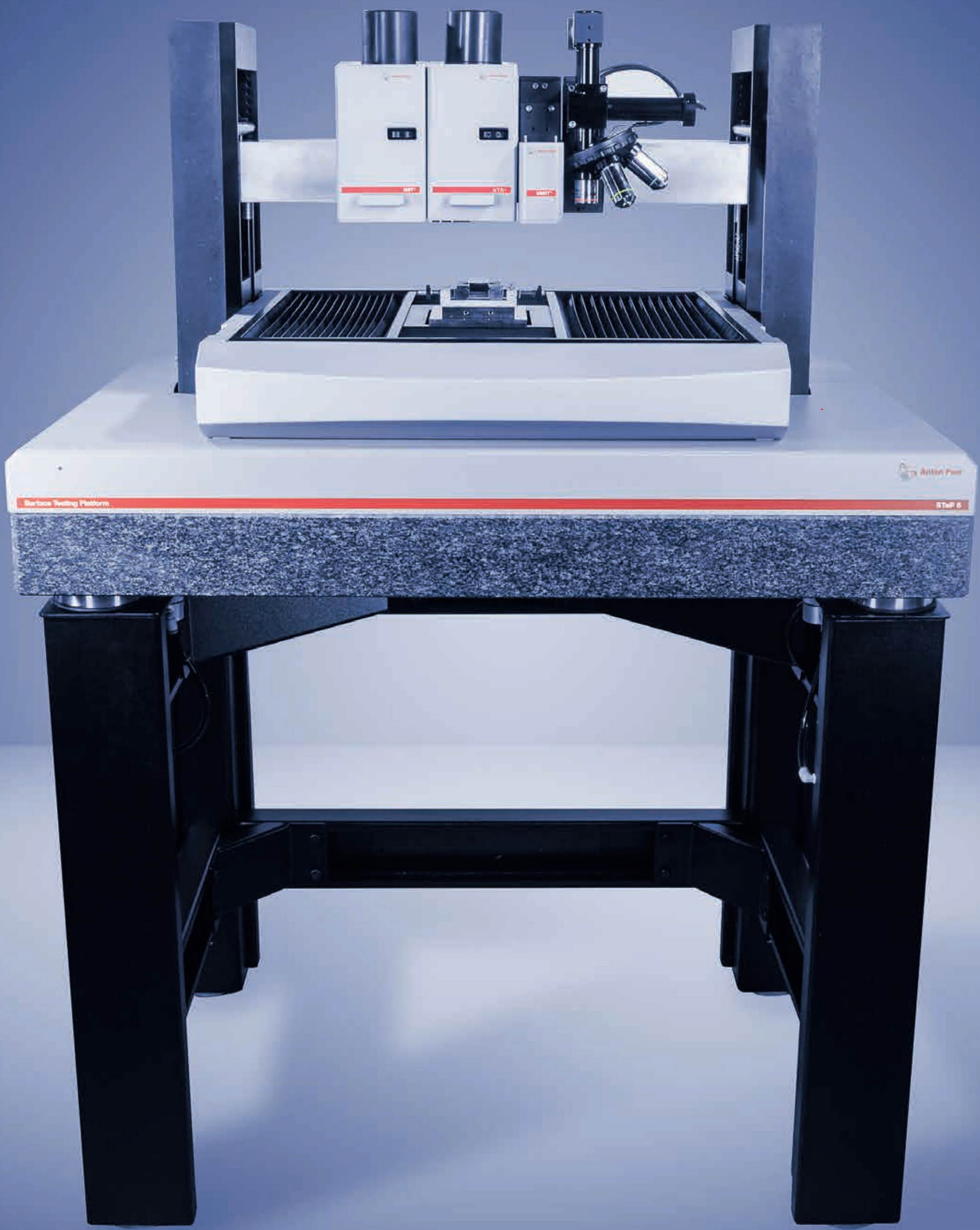
Anton Paar

Mechanical Surface Characterization



Instrumented Indentation Testers
Scratch Testers
Nano Tribometers
Coating Thickness Testers

A new era of precision

The third generation of Anton Paar's mechanical surface testers measure a wide range of mechanical properties of materials ranging from the hardest diamond-like carbon (DLC) coating to the softest hydrogel. The high-precision instruments measure what others estimate.

Anton Paar covers four of the most important test methods for mechanical surface characterization. Instrumented indentation testers provide mechanical properties of thin films, coatings, or substrates such as hardness and elastic modulus, creep, fatigue, stress-strain, elastic and plastic energies. Scratch testers are used to characterize film-substrate systems and to quantify parameters such as adhesive strength and friction force for determining coating adhesion, scratch resistance, and mar resistance for research and quality control. With tribometers you can study friction, wear, lubrication, and abrasion. Additionally, abrasion testers like Calotest provide quick, simple, and inexpensive determination of coating thicknesses.

We measure what others estimate

Anton Paar is the only company to provide high-resolution nanoindentation and nano scratch testers with a real force sensor. This means that the force is really measured continuously with a direct sensor and not estimated from a derivative coming from an actuator.

Instrument portfolio

The state-of-the-art design of Anton Paar's mechanical surface testers enables accurate and efficient testing solutions in a compact and modular format. In fact, different modules (scratch, indentation, microtribology) can be easily combined on one testing platform. Depending on your requirements and application you can combine different testing modules on one platform or you can use a single test method with a stand-alone device – just choose whatever you need.

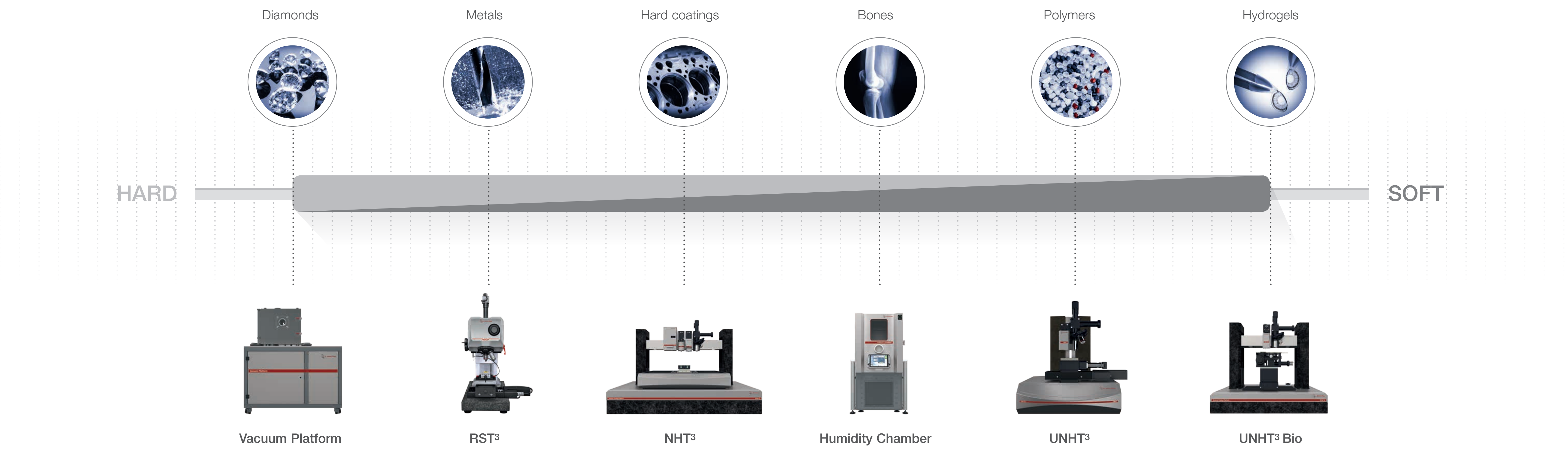
Applications & industries

High productivity and high throughput for both academic and industrial applications.

The materials tested come from a very wide range of industrial applications, e.g. the cutting tools, automotive, electronics, biomedical, semiconductor, polymer, optics, civil nuclear, MEMS, and watch industries.

These instruments are also used in various research areas:

- Viscoelastic properties
- Stress-strain curves
- Strain hardening
- Fracture toughness
- Surface mapping
- Depth profiling



Measuring parameters & standards

Scratch testing

Measuring parameters
Adhesive strength, friction force, coating adhesion, scratch, and mar resistance

Standards

ISO 20502
Fine ceramics – determination of adhesion of ceramic coatings by scratch testing

ISO 1518
Paints and varnishes – scratch test

DIN EN 1071-3
Advanced technical ceramics
Determination of adhesion and other mechanical failure modes by a scratch test

ASTM C1624
Standard Test Method for Adhesion Strength and Mechanical Failure Modes of Ceramic Coatings by Quantitative Single Point Scratch Testing

ASTM D7027
Evaluation of Scratch Resistance of Polymeric Coatings and Plastics Using an Instrumented Scratch Machine

ASTM D7187
Standard Test Method for Measuring Mechanistic Aspects of Scratch/Mar Behavior of Paint Coatings by Nanoscratching

ASTM G171
Standard Test Method for Scratch Hardness of Materials Using a Diamond Stylus

Indentation testing

Measuring parameters
Hardness and elastic modulus, creep compliance, relaxation, Hertz analysis, dynamic mechanical analysis (E', E'', tan delta), stress-strain curve, fatigue

Standards

ISO 14577
Metallic materials – Instrumented indentation test for hardness and material parameters

ISO 6508
Metallic materials – Rockwell hardness test

ISO 6507
Metallic materials – Vickers hardness test

ISO 4516
Metallic and related coatings – Vickers and Knoop microhardness tests

ASTM E2546
New Standard Practice for Instrumented Indentation Testing

ASTM B933
Standard Test Method for Micro Indentation Hardness of Powder Metallurgy Materials

ASTM D785
Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials

ASTM E140
Standard Hardness Conversion Tables for Metals

ASTM E384
Standard Test Method for Microindentation Hardness of Materials

ASTM B578
Standard Test Method for Microhardness of Electroplated Coatings

Coating thickness

Measuring parameters
Coating thickness

Standards

ISO 26423:2009
Fine ceramics (advanced ceramics, advanced technical ceramics) – determination of coating thickness by crater-grinding method

ISO 1071-2
Methods of test for ceramic coatings – determination of coating thickness by the crater-grinding method

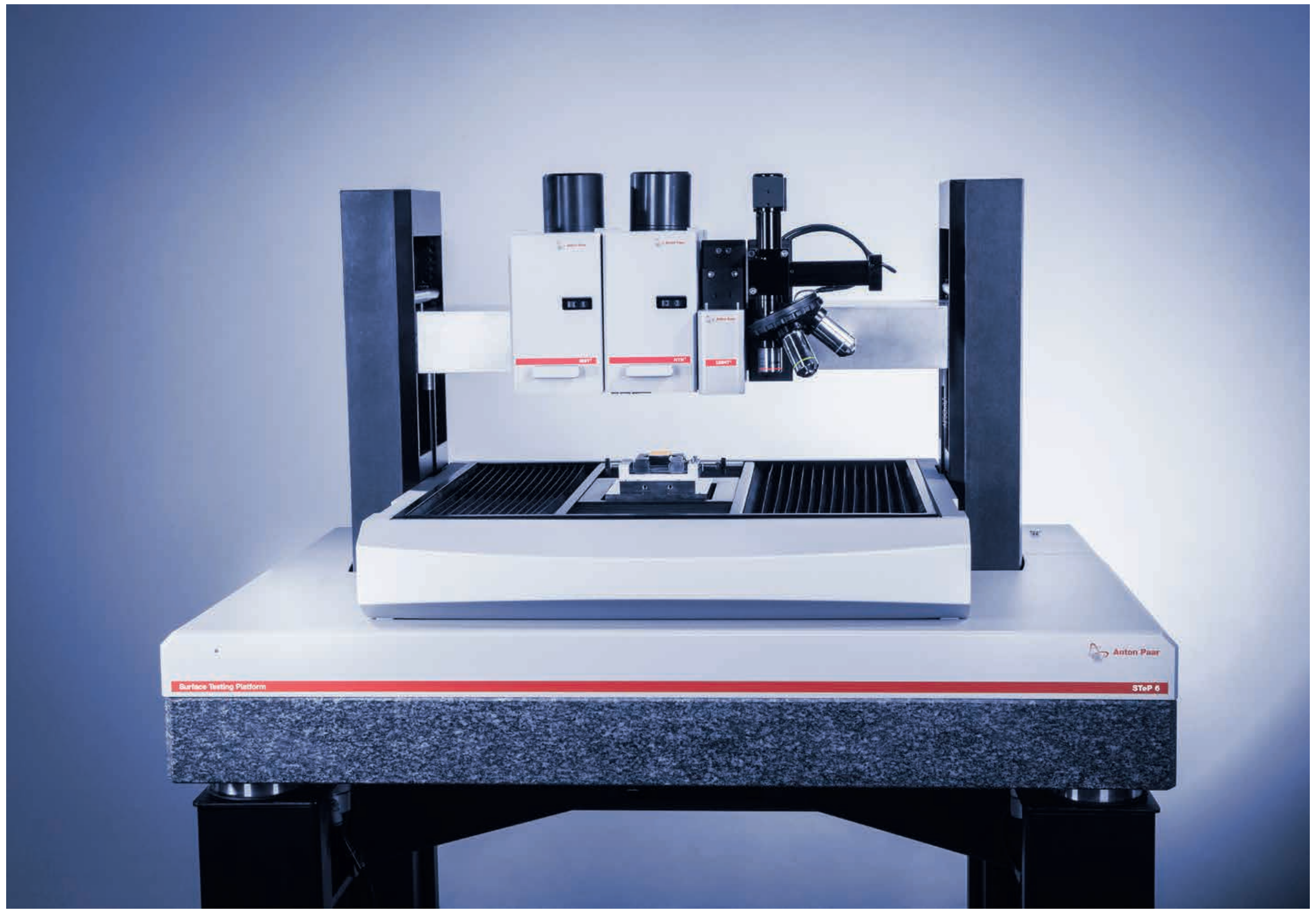
VDI 3198
Coating (CVD, PVD) of cold forging tools

Tribology

Measuring parameters
Friction coefficient, wear rate

Standards

ISO/TR 11811
Nanotechnologies – guidance on methods for nano- and microtribology measurements



Scratch testing: Features

Unique, patented synchronized panorama to be analyzed whenever, wherever

Anton Paar is the exclusive holder of the patents US 8261600, and EP 2065695. The scratch tester's panorama mode is the most important feature of the software. After the scratch, you have the option of recording the full panorama. When your panorama is recorded, you can re-analyze your results at any time.

Patented (US 6520004 and EP 1092142) true penetration depth measurements for advanced elastic recovery studies

The displacement sensor D_z monitors the surface profile of your sample before, during, and after a scratch. This means you can evaluate the penetration depth of the indenter during and after the scratch, for even more reliable insights into scratch and mar resistance. A unique feature of multi-post-scan with time is available for advanced studies on viscoelastic properties.

Active force feedback for full reproducibility

The system's active force feedback ensures reproducible scratch testing, even when you investigate more complex surface geometries like non-parallel, rough, or curved samples. Anton Paar's testers are the only commercially available systems that have active force feedback.

Automatic detection of critical loads to optimize the results

The scratch testers have auto-detection for the critical failures. Using the signal of friction force, penetration depth, or acoustic emission, an algorithm based on our experience is now able to fully automatically analyze the difference of signals and therefore to define the critical loads without any human factor.

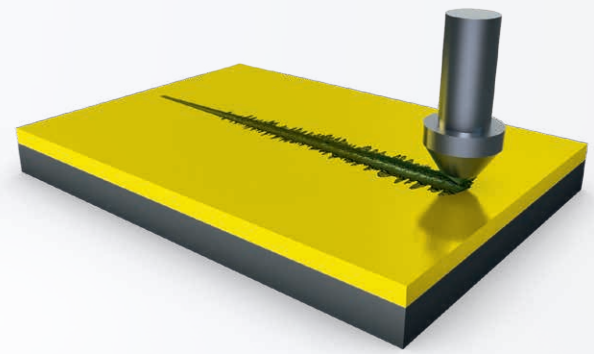
Measuring principles

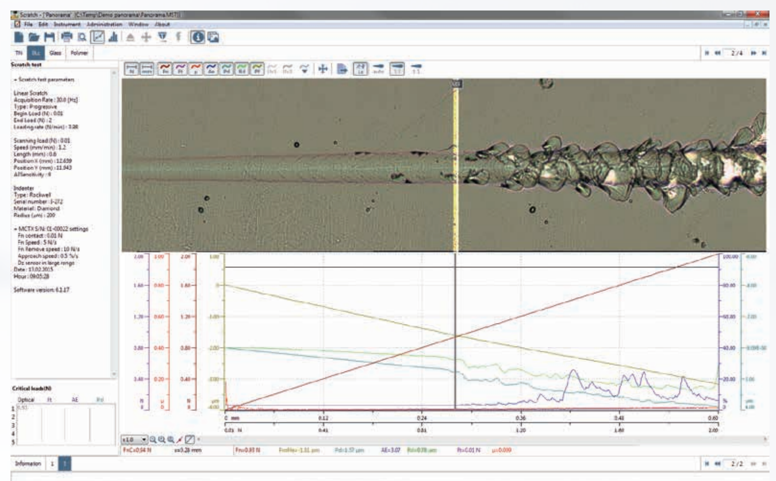
Scratch test principles

Anton Paar scratch testers (previously from CSM Instruments) are ideal instruments for characterizing the surface mechanical properties of thin films and coatings, e.g. the adhesion, fracture, and deformation.

The ability of the scratch tester to characterize the film-substrate system and to quantify parameters such as friction force and adhesive strength, using a variety of complementary methods, makes it an invaluable tool for research, development, and quality control. The technique involves generating a controlled scratch with a diamond tip on the sample under test.

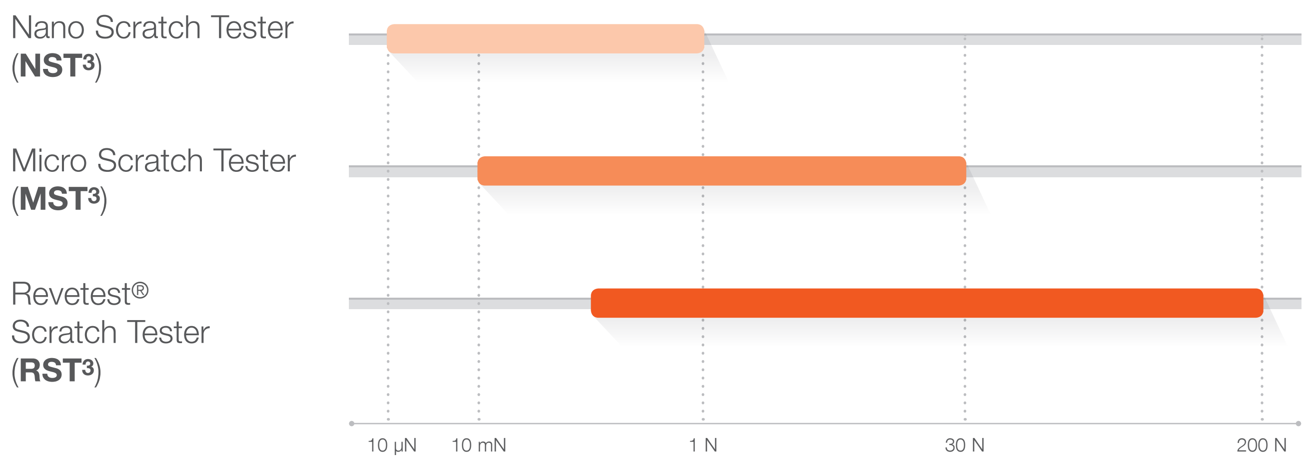
The tip is drawn across the coated surface under constant, incremental, or progressive load. At a certain load the coating will start to fail. Critical loads are very precisely detected by means of the tangential force, the penetration depth, and the acoustic emission sensors together with observations from a built-in optical microscope. The critical load data is used to quantify the adhesive properties of different film-substrate combinations by using different sensors (acoustic emission, penetration depth, friction force) and video microscope observations.

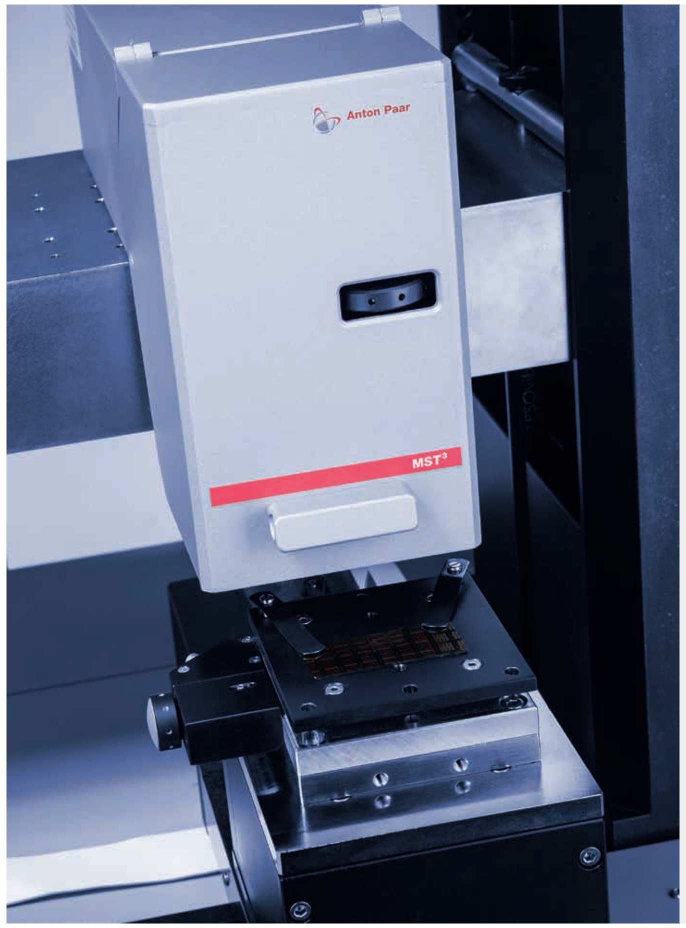




Scratch testing: Instruments

Measuring range of Anton Paar scratch testers



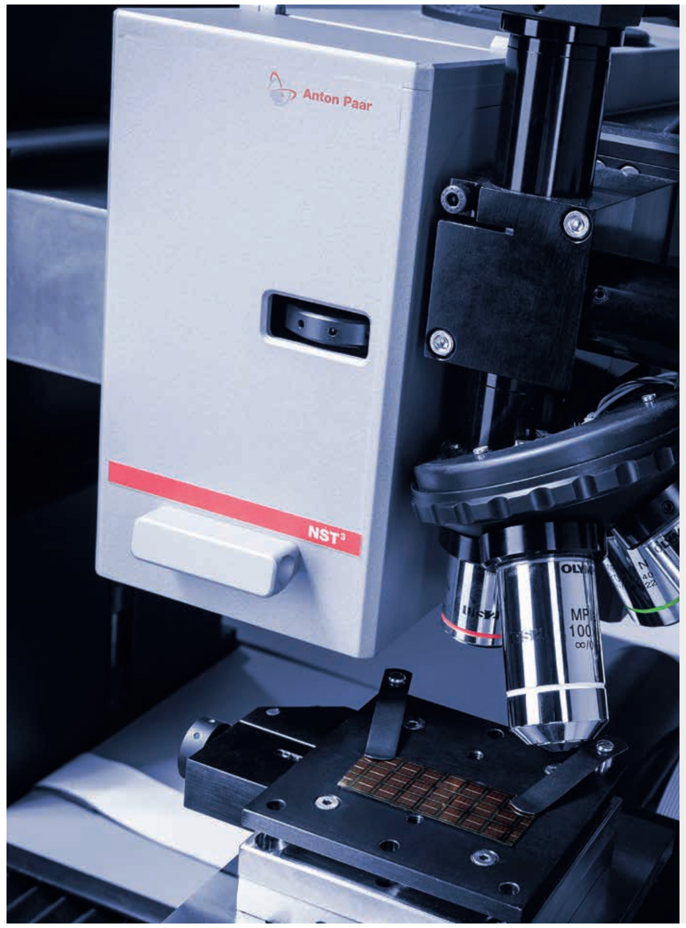


MST³ Micro Scratch Tester

The wide range tester for demanding users

The Micro Scratch Tester is widely used to characterize the practical adhesion failure of thin films and coatings with a typical thickness below 5 µm. The Micro Scratch Tester is also used in the analysis of organic and inorganic coatings as well as soft and hard coatings.

Applications include thin and multilayer CVD, PVD, PECVD, photoresist, lacquers, paints, and several other types of films. Research areas and industries utilize this instrument for microelectronics, optical coatings, protective and decorative surface coatings. Substrates may be soft or hard, including glass, semiconductors, refractive and organic materials.



NST³ Nano Scratch Tester

The most accurate nano scratch tester on the market

The Nano Scratch Tester is particularly suited for the characterization of the practical adhesion failure of thin films and coatings with a typical thickness below 1000 nm. The Nano Scratch Tester can be used to analyze organic and inorganic coatings as well as soft and hard coatings. The unique design of the nano-scratch measurement head includes two sensors for force and depth measurements associated with a state-of-the-art piezoelectric actuator. These unique features provide a fast response time (down to milliseconds), great accuracy, and great flexibility for all kinds of scratch measurements.

RST³ Revetest® Scratch Tester

The industry reference

The Revetest® scratch tester is a typical system designed for evaluating hard-coated material having a coating thickness of several microns. The coatings can be either organic or inorganic, which can be used for magnetic and decorative applications including CVD, PECVD, PVD, metallization and passivation layers, or friction-and-wear protective coatings. The substrates used can be refractive and organic materials, minerals, glass, semiconductors, alloys, and metals.

The Revetest® scratch tester comes with an external data acquisition unit and acoustic emission detection. It also meets the requirements of ASTM C1624 and EN 1071 standards. Anton Paar has sold over 1500 Revetest® scratch testers all around the world.

Indentation testing: Features

A wide range of testing possibilities: Hardness, elastic modulus, viscoelastic properties, creep compliance, and stress-strain curve

The wide ranges of load and penetration depth enable you to measure the mechanical properties of a large variety of materials. Soft and hard materials as well as thin and thick coatings can be tested. Hardness, elastic modulus, and other properties such as viscoelasticity, creep compliance, and stress-strain curve can be determined in a single measurement.

Maximum stability due to unique top surface referencing

Top surface referencing protects the tip from collision, provides a high thermal stability and a high frame stiffness. The reference probes the surface position while the indentation tip is testing the material. As a result, our instruments do not require any thermal drift correction.

"Quick Matrix" indentation mode for highly precise results within a few minutes

Anton Paar's indentation testers achieve a high sample throughput by performing up to 600 measurements per hour with full instrumented indentation curves.

Accurate motorized tables for precise positioning

Motorized tables move the sample in every direction with an accuracy of 1 µm. The sample moves from the microscope to the indentation tester with just one click. Automated matrices and multisampling testing are also available.

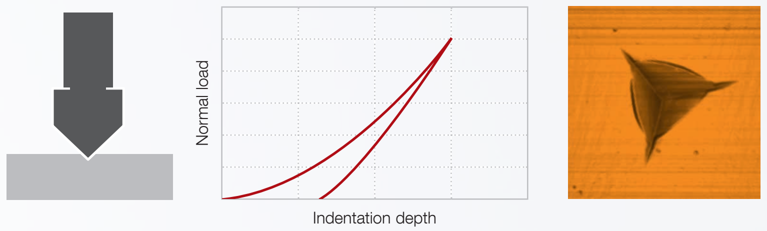
Multi-objective video microscope for a clear view of the sample

A high-quality multi-objective microscope provides a surface visualization before and after the indentation measurements. The turret holds up to 4 objectives. Visual matrices can additionally be defined under the microscope to run indentation measurements on areas of interest.

Measuring principles

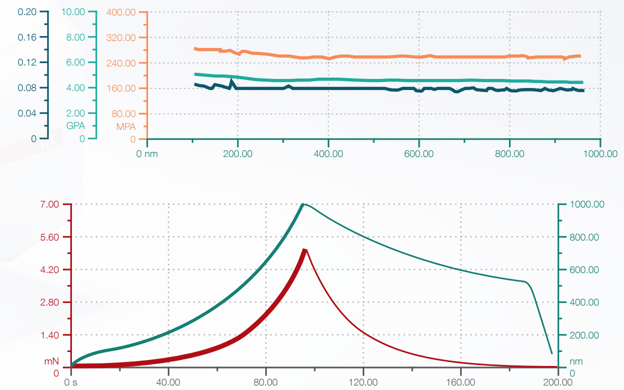
Measuring principles

The instrumented indentation technique (IIT) involves pressing an indenter of known geometry into the surface while both penetration depth and normal load are monitored. The indentation hardness (H_{IT}), elastic modulus (E_{IT}), and other mechanical properties are obtained from the force-displacement curve. The analysis of this curve is done automatically according to the ISO 14577 standard. This is a great advantage compared to classical hardness measurements in which each imprint has to be precisely measured separately with an optical microscope.



Dynamic mechanical analysis (sinus mode)

Dynamic mechanical analysis (DMA) uses sine wave loading curves to obtain a more complete analysis of the mechanical properties of viscoelastic or coated materials. This method allows for a continuous acquisition of hardness, elastic modulus, storage modulus, and loss modulus data as a function of indentation depth and the results can be advantageously used for the characterization of coated materials or polymers.



An example of sinus mode (dynamic mechanical analysis, DMA) performed by a nanoindentation tester.

Indentation testing: Instruments

UNHT³ Ultra Nanoindentation Tester

The ultimate high-resolution, high-stability nanoindenter

The Ultra Nanoindentation Tester with real force sensors examines the mechanical properties of a material at the nanoscale. The UNHT³ virtually eliminates the effect of thermal drift and compliance due to its unique and patented active surface referencing system (EP 1828744 and US 7685868). Therefore, it is perfectly suited for long-term measurements on all types of materials, from polymers to hard coatings.

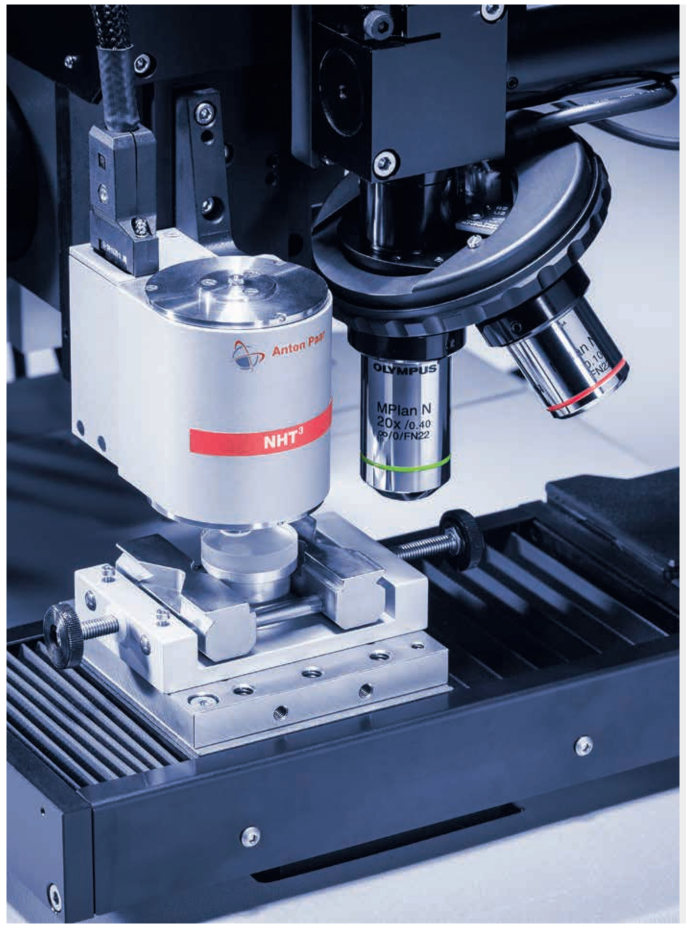
The UNHT³ includes advanced indentation modes such as sinus mode, load/depth control, constant strain rate, advanced matrix, and more. Its “Quick Matrix” indentation mode allows up to 600 measurements per hour with full nanoindentation curves. Its unique and active top referencing system is patented (EP 1828744 and US 7685868) and provides the highest thermal stability (raw drift rate down to 10 fm/s) on the market.

MHT³ Microindentation Tester

The higher force range of instrumented indentation testing (IIT)

The Microindentation Tester is ideally suited to the measurement of mechanical properties such as hardness and elastic modulus based on instrumented indentation testing (IIT). It is applicable to bulk samples and films, from soft to hard materials (metals, ceramics, polymers) with a high depth of measurements (up to 1 mm).

Optical Vickers hardness (HV) is possible to a maximum of 30 N and instrumented indentation testing (IIT) to a maximum of 10 N. Visual matrices of indentations and continuous multi cycles (CMC) allow you to measure the mechanical properties as a function of position on the surface and depth in the sample.

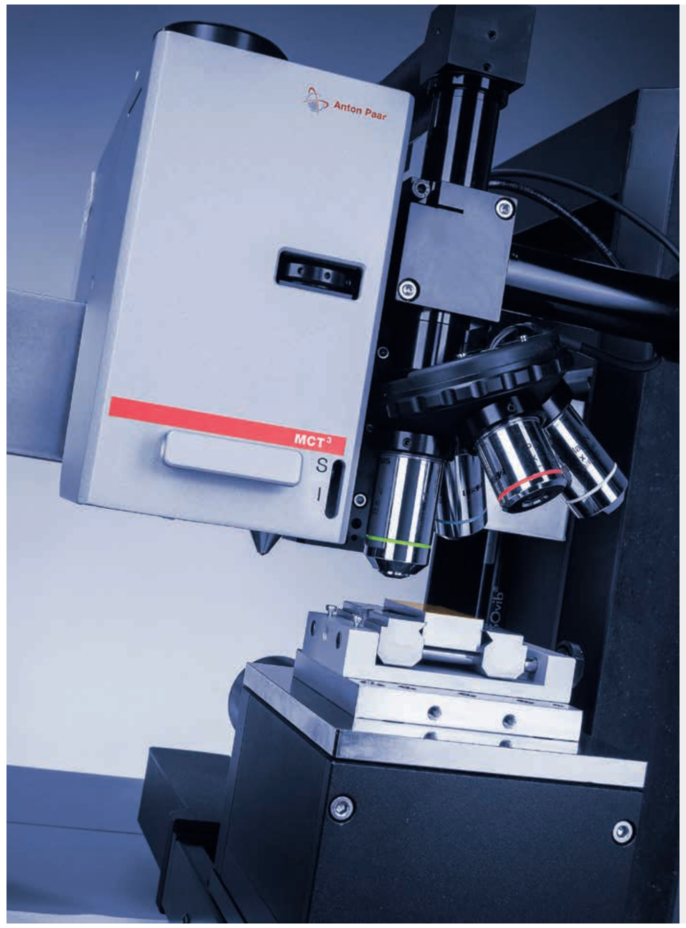


NHT³ Nanoindentation Tester

The most versatile and user-friendly nanoindenter on the market

The nanoindentation tester has a range from low loads (0.1 mN) to high loads (500 mN) and from shallow depths (less than 20 nm) to greater depths (up to 200 µm). It is not only robust but also fast and easy to use for multiple advanced indentation modes: Continuous multi cycles (CMC), user-defined sequences, sinus mode (optional), advanced matrix, and multi-sample protocols.

NHT³ is compatible with liquid testing. Its “Quick Matrix” indentation mode allows up to 600 measurements per hour with full nanoindentation curves. Its high load frame stiffness (10^7 N/m) and high thermal stability (raw drift rate <0.05 nm/s) result in high accuracy.



MCT³ Micro Combi Tester

The only available high-quality combined microindentation and micro scratch tester

The Micro Combi Tester directly measures the hardness and elastic modulus with high loads (10 N with instrumented indentation testing, 30 N with Vickers hardness). It is therefore even more valuable than conventional microhardness testers which only provide hardness measurement. It is applicable to many materials from bulk samples with rough surfaces to thin coatings. It features two independent sensors: one for force and one for depth.

The scratch mode of MCT³ also offers unique scratch testing features, including a patented synchronized panorama mode (US 8261600, and EP 2065695) from low loads (10 mN) to high loads (30 N) and wear testing capabilities.

Indentation testing: Instruments

UNHT³ Bio Bioindenter

The Bioindenter is a unique device for measuring local mechanical properties of soft and biological samples. It combines instrumented indentation with the requirements of testing of soft samples, samples immersed in liquid, and biological samples. The concept of UNHT³ Bio is based on the successful ultra nanoindentation technology with extended travel range, improved force resolution, and full compatibility of testing in fluids.
Easy characterization of time-dependent properties such as creep, flow properties, or poroelasticity are possible.

The integrated true force sensor is able to apply a maximum load of up to 20 mN adapted for soft materials. The displacement sensor allows a large travel range of 100 µm.

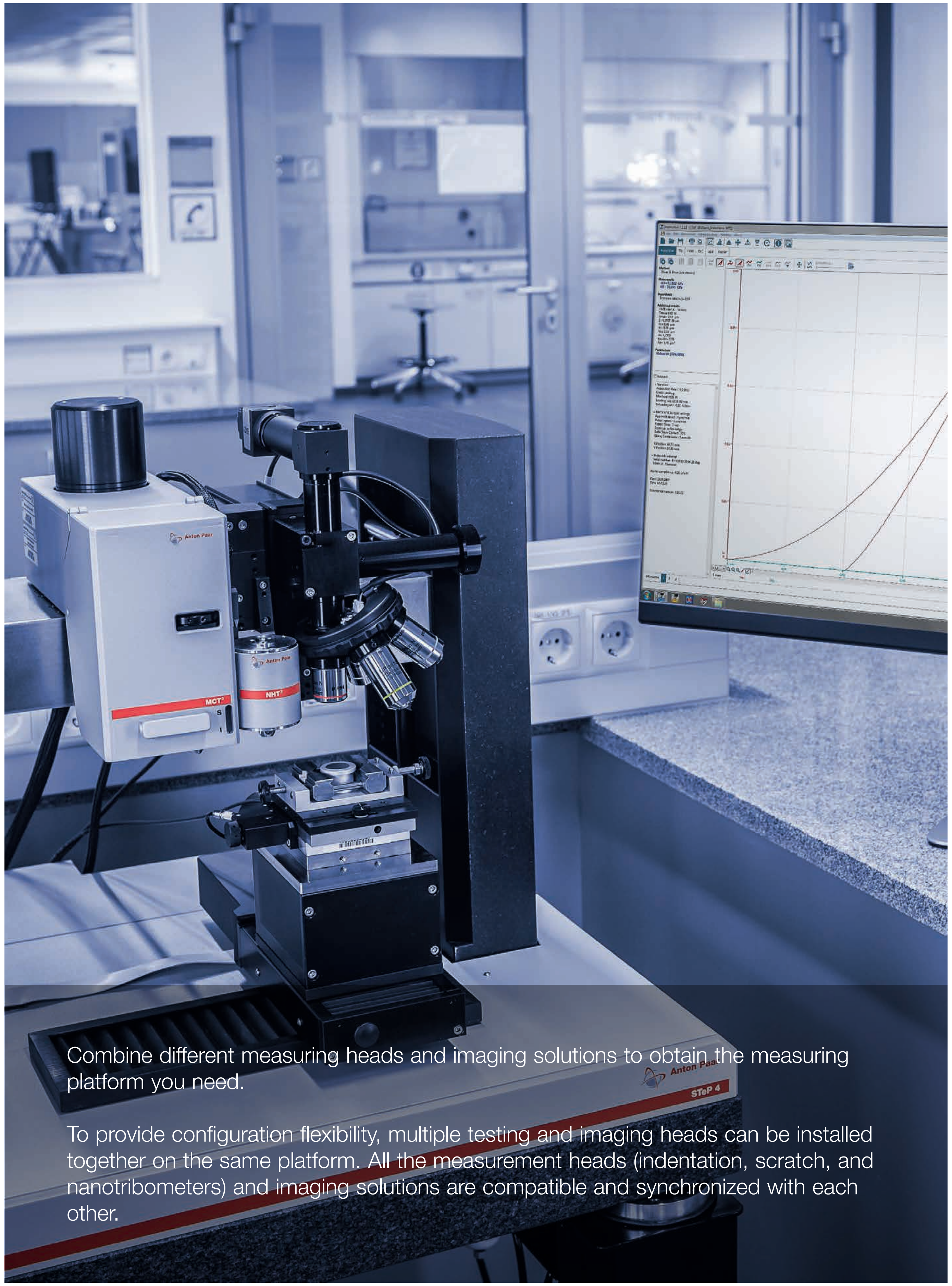
The elastic modulus can also be calculated from the loading part of the indentation curve using the Hertz's model, which is more appropriate for biological materials.

The Anton Paar Bioindenter™ works with different kinds of indenters.

UNHT³ HTV High-temperature Ultra Nanoindentation

Anton Paar is a pioneer in environmentally controlled, high-temperature instrumented indentation with various solutions up to temperatures of 800 °C and down to -150 °C. The actuating system is based on the patented technology (patent US 7685868 and EP 1828744) of the Ultra Nanoindentation Tester (UNHT³)
with two independent depth and load sensors combined with high-resolution capacitive sensors. Thermal barriers, water circulation and reflective mirrors prevent the head from heating, resulting in an unmatched stability.
In addition, a high vacuum chamber minimizes oxidation as well as heat loss from convection. The lowest thermal drift at ambient conditions (<0.5 nm/min) and over the entire temperature range (<3 nm/min) ensures a high reliability for the measurements.

Choose your perfect combination



Combine different measuring heads and imaging solutions to obtain the measuring platform you need.

To provide configuration flexibility, multiple testing and imaging heads can be installed together on the same platform. All the measurement heads (indentation, scratch, and nanotribometers) and imaging solutions are compatible and synchronized with each other.

Choose your perfect combination

The perfect platform for all measuring requirements in mechanical surface characterization

Measuring heads

MHT^3
Microindentation Tester
Max. load: 30 N

NHT^3
Nanoindentation Tester
Max. load: 500 mN

UNHT^3
Ultra Nanoindentation Tester
Max. load: 100 mN

UNHT^3 Bio
Bioindenter™
Max. load: 20 mN

UNHT^3 HTV
High Temperature
Ultra Nanoindentation
Max. load: 100 mN

NST^3
Nano Scratch Tester
Max. load: 1000 mN

MST^3
Micro Scratch Tester
Max. load: 30 N

MCT^3
Micro Combi Tester
Max. load: 30 N

NTR^3
Nano Tribometer
Max. load: 1000 mN

Imaging solution

VID
Optical Video Microscope

AFM
Atomic Force Microscope

VID
In-situ Video Microscope

Platforms

TTX
Table Top

STeP 4
Surface Testing Platform

STeP 6
Surface Testing Platform

Platform features

- Fully automated 3-axis motion control
- High positioning accuracy over a great length with a table top (TTX) and surface testing platforms (STeP 4 and STeP 6)
- One-click synchronization of position from video microscope to indenter tip
- High modularity with reversibly exchangeable measuring heads
- Customized synthetic granite for enhanced vibration damping
- Integrated anti-vibration table
- Optional acoustic enclosure
- Customized platforms for glove box and vacuum chamber available

Coating thickness: Features

Quick and simple determination of coating thicknesses

The Calotest instruments from Anton Paar provide quick, simple, and inexpensive determination of coating thicknesses. Employing the simple ball-cratering method, the thickness of any kind of single or multilayered coating stack is accurately checked in a short time, in full compliance with relevant international standards.

Easy and accurate evaluation of results

The video module in the form of a USB color camera with two kinds of objectives (5x and 10x magnification) supplies the software with the crater picture. Based on the pictures and by performing line measurements and also taking the contact geometry into consideration, the software can calculate the coating thickness of the sample. In this way single and multilayer analysis in accordance with ISO 1071-4 can be performed. Automatically generated user-defined reports provide complete documentation.

Measuring principles

Spherical abrasion test method

A small crater is ground into a coating with a ball of known geometry, providing a tapered cross-section of the film when viewed under an optical microscope. In this way Calotest instruments measure the thickness of coatings in a very short time of just 1 to 2 minutes.

CATc

The CATc is widely used for analyzing coatings with thicknesses between 0.1 µm and 50 µm. Typically measured materials include CVD, PVD, plasma spray coatings, anodic oxidation layers, chemical and galvanic deposits, polymers, paints, and lacquers. Flat, spherical, or cylindrical samples can be fixed in the sample holder.

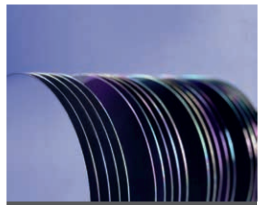
CATi

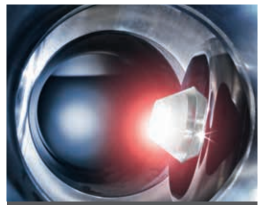
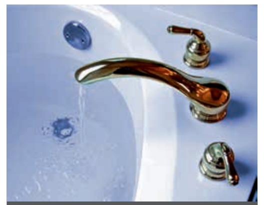
The CATi measures the thickness of coatings in a typical time of 2 to 5 minutes. In this industrial version the motor is fixed on a hydraulic arm, allowing you to target samples of unlimited size. It is the ideal instrument for quick and precise determination of coating thickness on common industrially coated components

CATcombo

The CATcombo is the perfect combination for testing both small and relatively large samples with one instrument and output device.

Applications & industries




	Hard coatings	Semiconductors	Biomaterials	Optical and glass	Decoratives
Type of analysis	- Hardness - Elastic modulus - Coating adhesion - Wear resistance of high-speed machining coatings - Coating thickness of coatings - High-temperature hardness of coatings	- Hardness of thin films - Elastic modulus - Coating adhesion of thin films - Wear resistance and friction coefficient	- Scratch resistance of stents - Wear resistance and friction coefficient of prosthesis - Hardness of tablets - Hardness of bones - Modulus of corneas - Friction coefficient of contact lenses	- Scratch resistance of optical components - Hardness of optical polymer coatings - Elastic modulus of optical polymer coatings	- Scratch resistance of surfaces - Hardness of surfaces - Hardness of wear-resistant coatings
How	- Nanoindentation - Micro scratch and Revetest scratch - High-temperature tribometer - Calotest - High-temperature ultra nanoindentation	- Ultra Nanoindentation - Nano scratch - Nanotribometer	- Nano scratch - Tribometer - Microindentation - Nanoindentation - Bioindenter - Nanotribometer	- Nano scratch - Ultra nanoindentation	- Nano scratch - Ultra nanoindentation - Microindentation
Example industries	- Cutting tools - Machines - Automotive - Aerospace	- Semiconductors - Automotive - Printing	- Biomedical - Pharmaceutical - Polymers	- Optical, glass - Watches - Semiconductors	- Watches - Home appliances
Example fields of use	- R&D characterization of new coatings - Quality control of DLC coating injectors - Mechanical properties of coatings at high temperatures	- R&D characterization of new wafers - Hard disk characterization - Quality control in wafer manufacturing - Quality control of low K dielectrics	- Wear of prosthetics and implants - Resistance of arterial implants (stents) - Hardness of tablets and pills - Studies of osteoporosis - Cornea elasticity - Contact lens friction	- Resistance of eyeglass lenses - Control of optical components for photography - Characterization of optical coatings	- Scratch tests on home appliance components - High-temperature indentation on frying pans
Samples	- TiN, TiC, CrN, AlTiCN - DLC coatings - PVD (ceramic coating) - CVD (ceramic coating) - Thermal/plasma spray (ceramic coating)	- Wafers and sensors - Hard disks - MEMS - Electrical/ electronics components	- Bones, tissue - Adhesive - Gels - Hair	- Polymeric coatings - Mineral glasses	- Smartphones - Evaporated metal coatings - Jewelry and watches

	Automotive	Ceramics	Metallurgy	Civil engineering	General engineering
Type of analysis	- Adhesion testing of coatings - Wear resistance of coatings - Friction coefficient of grease - Elastic modulus of tires	- Scratch resistance of bulk materials	- Hardness of the microstructure of alloys - Stress-strain research studies of surfaces	- Mechanical properties of cement with humidity	- Friction coefficient of fibers and hairs - Friction coefficient of lubricants - Scratch resistance of printing components - Friction properties of cheese
How	- Micro scratch or Revetest scratch - High-temperature tribometer - Tribometer - Ultra nanoindentation	- Micro scratch	- Nanoindentation	- Ultra nanoindentation	- Tribometer - Nanotribometer
Example industries	- Metallurgy - Polymers - Optical, glass - Automotive - Machines	- Ceramics	- Metallurgy	- Civil engineering	- Textiles - Cosmetics - Petroleum - Aerospace - Wood - Printing - Machines - Food
Example fields of use	- Quality control of DLC coating injectors - Brake pad wear resistance - Pistons, engine valves - Elasticity of tires	- Scratch resistance of tiles	- Mechanical properties of metallic components	- Nanoindentation on cement and concrete for buildings	- Friction of textile parts - Evaluation of friction in cosmetics (chemical products) - Lubricant properties in friction - Mechanical properties in aerospace components
Samples	- Coatings & paint - Varnish (coating, lacquer) - Plastic, resin, rubber - Metal, alloys - Lubricant oil & grease	- Ceramics	- Metal, alloys	- Cement, concrete	- Polymers - Wood - Organic components - Metal, alloys - Composites

Specifications

Scratch testing

	NST^3	MST^3	RST^3
Maximum load [N]	1	30	200
Load resolution [µN]	0.01	10	100
Load noise floor [rms] [µN]*	0.1	100	1000
Loading rate [N/min]	up to 100	up to 300	up to 300
Depth range [µm]	600	1000	1000
Depth resolution [nm]	0.1	0.05	0.05
Depth noise floor [rms] [nm]*	1.5	1.5	2.5
Data acquisition rate [kHz]	192	192	192
Scratch speed [mm/min]	0.1 to 600	0.1 to 600	0.4 to 600
Options			
Peltier heating up to 120 °C	✓	✓	✓
Heating stage up to 200 °C	✓	✓	✓
Heating stage up to 450 °C		✓	✓
Cooling down to -120 °C	✓	✓	✓
Electrical contact resistance (ECR)	✓	✓	✓
Liquid testing	✓	✓	✓

Indentation testing

	UNHT^3	NHT^3	MHT^3	MCT^3	UNHT^3 Bio	UNHT^3 HTV
Maximum indentation load [mN]	100	500	30,000	30,000	20	100
Load resolution [µN]	0.003	0.02	6	6	0.001	0.006
Load noise floor [rms] [µN]*	<0.05	<0.5	<100	<100	0.1	0.5
Maximum indentation depth [µm]	100	200	1000	1000	100	100
Depth resolution [nm]	0.003	0.01	0.03	0.03	0.006	0.003
Depth noise floor [rms] [nm]*	<0.03	<0.15	<1.5	<1.5	0.25	0.15
Options						
Sinus mode	✓	✓				✓
Liquid testing	✓	✓	✓	✓	✓	
Heating stage up to 100 °C	✓		✓	✓	✓	
Heating stage up to 200 °C	✓		✓	✓		
Heating stage up to 450 °C			✓	✓		
Heating stage up to 800 °C						✓
Petri dish holder					✓	

The raw acquisition rate of indentation testers is 192 kHz, which is then filtered down to 400 Hz maximum for display.

Additional options and accessories are available on specific request: Electrical contact resistance (ECR), cooling for low temperatures (-150 °C in vacuum), wafer holder, multiple sample holder, ...

*Noise floor value specified under ideal laboratory conditions and using an anti-vibration table.

✓ available option

Coating thickness testing

	Calotest Compact (CATc) | Calotest Industrial (CATi) | Calotest Combo (CATcombo)
Shaft speed [rpm]	10 to 3,000
Abrasion time ranges [seconds]	1 to 10,000
Standard ball diameters [mm]	10, 15, 20, 25.4, 30

Tribology

	Nanotribometer (NTR^3)
Normal force range [mN]*	1000
Normal force resolution [µN]*	0.003
Friction force range [mN]*	1000
Friction force resolution [µN]*	0.006
Rotating movement	
Speed [rpm]	1 to 200
Radius [mm]	0.1 to 20
Linear reciprocating movement 1)	
Stroke length [mm]**	up to 5
Speed [mm/s]**	up to 26.6
Frequency [Hz]**	0.01 to 10
Rotational reciprocating movement 2)	
Speed [rpm]	1 to 200
Angular amplitude [°]	±10 to ±150
Angular resolution [°]	0.1
Options	
Online wear depth [µm]	up to 250
Electrical contact resistance [Ohm]	up to 1000

* Nanotribometer normal load and friction load specifications depend on the choices of different cantilevers (high-resolution, standard, and high-load cantilevers).

** Nanotribometer linear reciprocating movement specifications depend on the choices of different linear stages.

1) Linear reciprocating movement specifications depend on the combination of stroke length, frequency, and mass on the stage.
2) Rotational reciprocating movement specifications depend on the combination of angular amplitude, frequency, and mass on the stage.

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