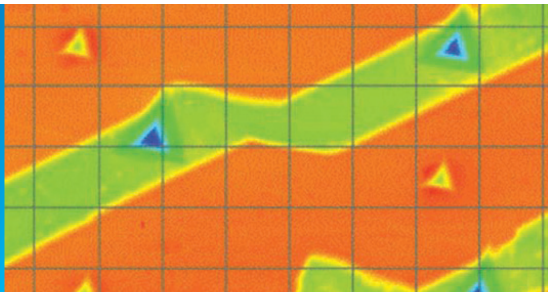
Continuous Stiffness Measurement (CSM)



Overview

Nanoindenters are accurate, flexible, user-friendly instruments for nanoscale mechanical testing. Electromagnetic actuation allows Nanoindenters to achieve high dynamic range in force and displacement. These instruments enable users to measure Young's modulus and hardness in compliance with ISO 14577 standards and deformation over six orders of magnitude, from nanometers to millimeters.

The accuracy and reliability of the results of nanoindentation testing depend on more than knowledge of the tip geometry and analysis of force vs. displacement curves. To accurately calculate mechanical property values, the contact area and stiffness of the contact between the indenter tip and the sample material must also be accurately determined. Nanoindenters from KLA characterize mechanical properties such as modulus of elasticity, loss factor, and fracture behavior with nanometer-range precision, using both quasi-static and dynamic depth-sensing indentation methods.

Quasi-Static and Dynamic Methods for Nanomechanical Characterization

In conventional quasi-static indentation testing, contact stiffness is determined by analyzing the force vs. displacement curve during unloading. This method provides a single result for a given indentation depth. The Continuous Stiffness Measurement (CSM) technique, compatible with both the XP and the DCM II indentation heads, satisfies application requirements that must take into account dynamic effects, such as strain rate and frequency.

The CSM option offers a means of separating the in-phase and out-of-phase components of the load-displacement history. Phase separation enables accurate determination of the location of initial surface contact, and continuous measurement of contact stiffness as a function of depth or frequency, eliminating the need for unloading cycles.

The CSM option is applicable for not only stiff materials such as metals, alloys and ceramics, but also for materials with compliant material properties, such as polymers, structural composites and biomedical materials. The Nano Indenter G200 equipped with the CSM option can fully characterize dynamic properties like strain rate sensitivity with nanometer precision. It can also provide values such as complex (dynamic) modulus for viscoelastic materials that exhibit a phase difference between stress and strain. Indentation tests using the CSM option can be controlled with a constant strain rate, a critical test mode for material systems such as pure metals or low melting point alloys, polymer films and film/substrate systems.

Features and Benefits

+ Accurate, repeatable results conforming to ISO 14577 standards
+ Dynamic properties characterization via continuous measurement of stiffness
+ Seamless compatibility with Nano Indenter XP and DCM indentation heads
+ Full characterization of dynamic properties with nanometer-range precision
+ Accurate characterization of viscoelastic materials
+ Ability to control indentation tests with a constant strain rate

Applications

+ Semiconductor, thin films, MEMS (wafer applications)
+ Hard coatings, diamond-like carbon (DLC) films
+ Composite materials, fibers, polymers
+ Metals, ceramics
+ Biomaterials

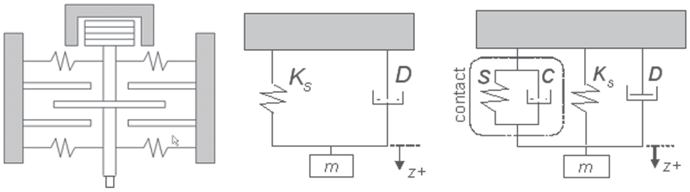


Figure 1. (a) Schematic of free-hanging indenter (b) Dynamic model of instrument alone (no contact) (c) Dynamic system model during testing

$$m\ddot{h} + D\dot{h} + kh = F(t)\text{, where } h = h_o e^{i(\omega t-\phi)} \text{ and } F(t) = F_o e^{i\omega t}$$

$$S_{contact} = \left[\frac{F_o}{h_o}\cos\phi + m\omega^2\Big|_{coupled}\right] - \left[\frac{F_o}{h_o}\cos\phi + m\omega^2\Big|_{inst.\,(free\,space)}\right]$$

$$E' = \frac{\sqrt{\pi}}{2}\frac{S_{contact}}{\sqrt{A}}$$

$$E'' = \frac{\sqrt{\pi}}{2}\frac{(D\omega)_{contact}}{\sqrt{A}}$$

$$\tan\delta = \frac{E''}{E'} = \frac{D\omega}{S}$$

Figure 2. CSM can accurately characterize viscoelastic materials, reporting values such as storage modulus and tanδ

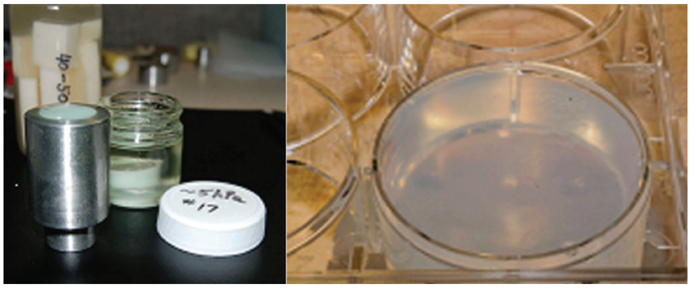


Figure 4 (above). (a) Concentric-cylinder sample holder and (b) Agarose gel as supplied in a well plate, for measurements shown in Figure 5

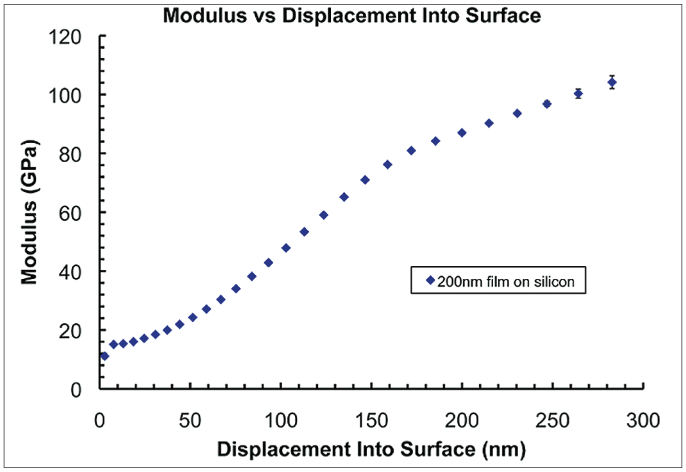


Figure 3. CSM characterization of modulus as a function of depth for thin film applied to sample

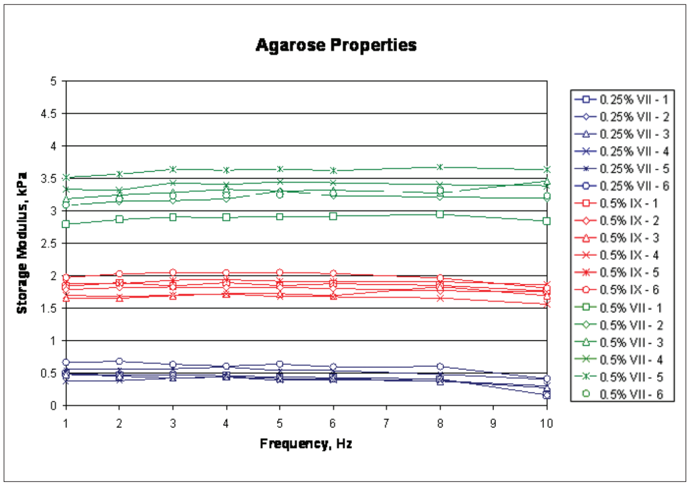


Figure 5 (right). Accurate measurement of mechanical properties of Agarose is very important because it has been found that the storage modulus of these gels affect the form and function of the resulting cells. Three different gels were tested and their viscoelastic properties were characterized down to E'= 500Pa

Load amplitudes

- DCM max 0.9mN
- DCM min 0.9nN
- XP max 5.0mN
- XP min 1.0nN

Specifications

Frequency range	0.001Hz to 120kHz
Load coupled frequency range	0.001Hz to 1kHz
Voltage sensitivity	2nV to 1V full scale
Typical operating frequency range	1Hz to 300Hz

KLA SUPPORT

Maintaining system productivity is an integral part of KLA's yield optimization solution. Efforts in this area include system maintenance, global supply chain management, cost reduction and obsolescence mitigation, system relocation, performance and productivity enhancements, and certified tool resale.

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