NanoScience Solutions

Fourier Transform Nano-Dynamical Mechanical Analyzer

A nanoindenting AFM extension, the Fourier Transform Nano-Dynamical Mechanical Analyzer (FT-nanoDMA) is a new generation of high-performance scientific instrumentation for materials research and analysis at nanoscale. As a radical departure from existing nanoindenters, NSS made FT-nanoDMA:

- Provides a substantially higher spatial resolution (50-150x for lateral and 30-150x for vertical). Such an improvement is comparable to the evolution from optical to electron microscopy for soft materials.
- Increases the speed (70-180x) of mapping viscoelastic properties of soft materials. This means reduction in measurement time from hours and weeks to minutes and hours.
- Makes it possible to measure mechanical properties of many biological materials, for which measurement time is limited.
- Allows testing of the linearity of strain-stress relation at the nanoscale.
- Provides highly quantitative results.

FT-nanoDMA represents a novel method of studying the dynamic mechanical spectra (DMS) of soft materials (the static elastic modulus <10 GPa) with resolutions substantially superior to existing state of the art nanoindenters. This allows extension of DMS measurements to the scales previously inaccessible (for example, the study of individual biological cells). This method can be used in virtually any environment suitable for the AFM operation.

FT-nanoDMA's highly accurate technique is based upon a combination of three different methods:

– quantitative nanoindentation (nanoDMA);
– gentle force and fast response of atomic force microscopy (AFM); and
– Fourier transform (FT) spectroscopy.

FT-nanoDMA redefines AFM speed and sensitivity thereby facilitating dynamic mechanical spectroscopy imaging of nanointerfaces; i.e., single cells, while attaining approximately 100x improvements regarding polymers in both spatial (to 10-70 nm) and temporal resolution (to 0.7s/pixel) compared to existing state of the art nanoindenters. Multiple frequencies are measured simultaneously.

FT-nanoDMA method is quantitatively verified using various polymers and demonstrated on cells and polymer blends. This analysis shows the superiority of FT-nanoDMA over other spectroscopy methods.

FT-nanoDMA's spectroscopy can be successfully implemented in existing AFMs.

Linearity of developed system, lack of cross-talk between different frequencies and negligible contribution of hydrodynamic coupling in liquid environments when using sufficiently small amplitudes has been demonstrated.

This method was verified using multiple polymer samples such as: PDMS, polyurethane, LDPE, etc. Maps of various mechanical properties, including the storage and loss moduli, have been demonstrated on complex biological samples, i.e., corneocytes open to the atmosphere and pumpkin seed membrane cells submerged in water.

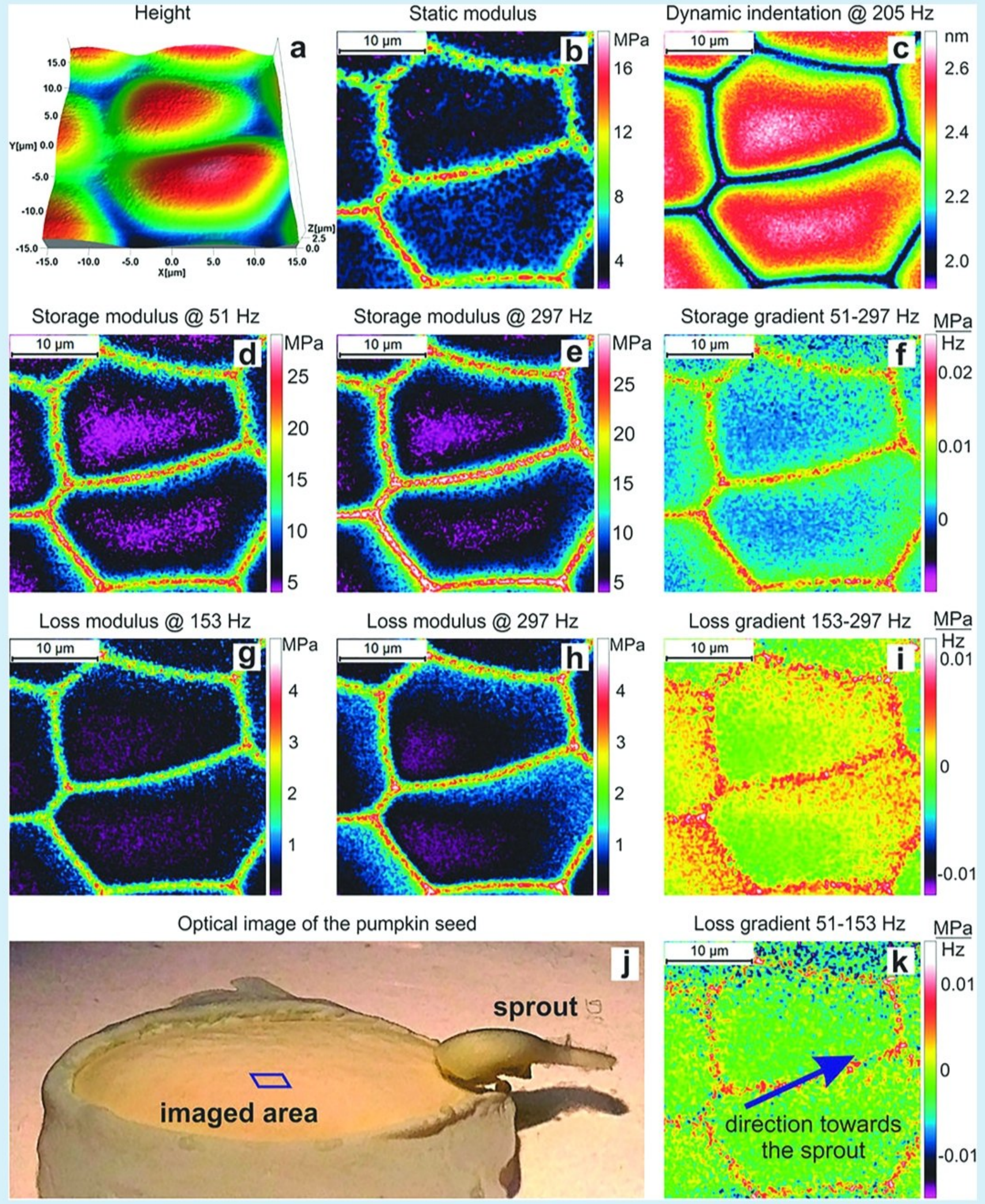

Figure: 30 × 30 μm^2 (150 × 150 pixels) dynamical mechanical maps of membrane cells of inner part of a pumpkin seed imaged in water after developing a sprout of ~1 mm in size.

New interesting information seen in the above mechanical maps demonstrates the capability of the FT-nanoDMA method. It dramatically opens a new dimension of study in the mechanics of soft materials at the nanoscale, especially with nanobiomaterials. FT-nanoDMA method also expands the knowledge bases to a scale previously inaccessible. Study of such properties will contribute to achieving fundamental understanding and future advances in development of new heterogeneous polymers, nanocomposites, biomaterials and cell mechanics.

Table 1: Comparison of FT-nanoDMA method with existing nanoindenter-based method.

Property	TI 950 Hysitron nanoindenter-based nanoDMA	AFM-based FT-nanoDMA
Contact diameter	22,000 or 33,000 nm (PDMS) 9,000 or 15,000 nm (polyurethane)	160 or 230 nm (PDMS) 140 or 170 nm (polyurethane)
Minimum vertical indentation	1000 or 2600 nm (PDMS) 100 or 300 nm (polyurethane)	100 or 400 nm (PDMS) 5 or 10 nm (polyurethane)
Total measurement time at one point of the surface	>200 sec (for 10 frequencies)	~0.7–1 sec (for 10 frequencies though the number of frequencies is not a limiting factor)
Time to record 100 × 100 pixel map	23 days (impractical)	1.9 hours
Ability to study individual biological cells	no	yes
Frequency range	Up to 300 Hz	Up to 300 Hz

The comparison is done on the same samples of two polymers: PDMS resin (the Young's modulus of 1.5 MPa) and polyurethane (the Young's modulus of 0.63 GPa).

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