Optical tweezers microrheology maps micro-mechanics of complex systems

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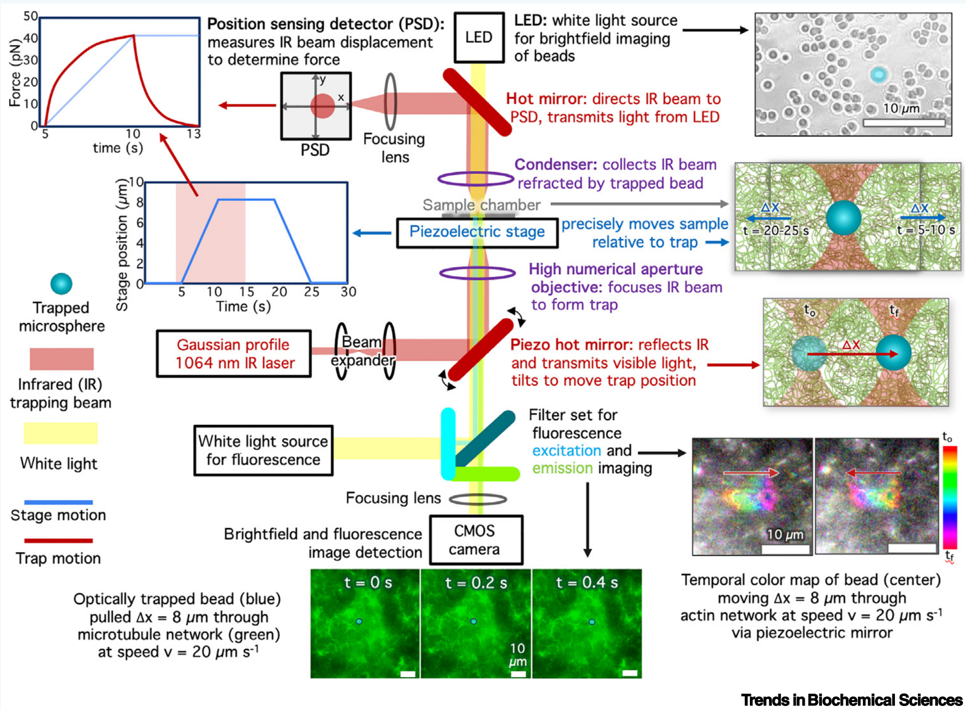
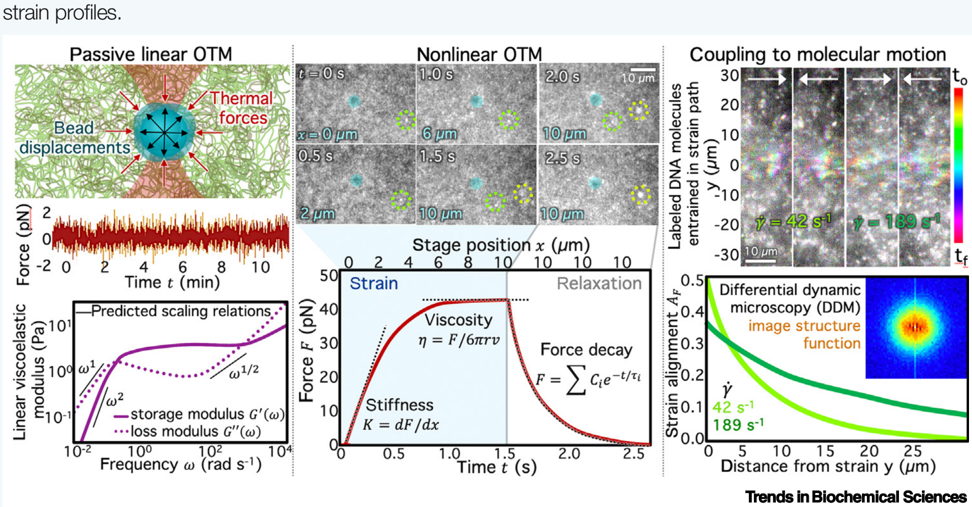


Biochemical systems, from cytoskeleton to mucus, exhibit complex mechanical responses critical to their function. Traditionally, these properties have been measured using rheometers that measure the bulk response of the entire sample, proving insufficient to characterize often heterogeneous and dynamic biochemical systems. Optical tweezers microrheology (OTM) measures microscale mechanical properties, similar to particle-tracking microrheology (PTM) that infers properties from the diffusion of embedded probes, while offering wider dynamic range and precise control over strain profiles.



OTM uses a focused laser to trap, manipulate, and measure forces exerted by the sample on embedded microspheres, enabling a broad range of strains and precision force measurements. Passive linear OTM measures thermal fluctuations of a stationary trapped bead, while in nonlinear OTM the trapped bead is moved relative to the sample at programmable rates and distances while the force is measured. Coupling OTM with fluorescence microscopy can determine macromolecular dynamics governing the force response.

ADVANTAGES:

Small samples sizes (~10 μl) compared with bulk rheology which requires ~10^2–10^3 μl, ideal for biochemical systems that are difficult and expensive to produce.

Bespoke strains with a range of rates, amplitudes, and patterns that span microscopic and mesoscopic scales and access nonlinear response features not possible with particle-tracking microrheology (PTM).

Measurements on dense and stiff systems inaccessible to PTM due to minimal particle mobility, and fluid-like systems that produce insufficient stress for accurate bulk rheology.

Long duration measurements in a single precise location, not limited to the time that a diffusing particle remains in view (as in PTM), to decouple spatial heterogeneities from time-varying mechanical properties.

Faster data acquisition rates (~100 kHz) than video-based PTM to resolve high frequency response.

Coupling to fluorescence microscopy to image labeled biomolecules or other constituents during straining to connect system structure and motion to stress response.

CHALLENGES:

Many single-location measurements are needed to span the sample to determine average properties and map spatial heterogeneities.

Maximum force (~100 pN) may be below strain-induced or internally-generated forces in very rigid or active systems.

Trapping requires the bead refractive index to be larger than the sample, which may not be the case for dense or opaque systems.

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Lack of accurate modeling of non-uniform flow-fields produced by the moving bead complicates data interpretation and comparisons with bulk rheology.

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Declaration of interests

The author declares no competing interests.

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