Non-local deformation sensing in nanoscale

Nanoindentation and pico-indentation based on atomic force microscopy (AFM) are commonly used for the evaluation of material mechanical properties using the depth-loading profile measured at a specific location of the material. However, the interpretation of the measurement results largely relies on the parameters of indentation such as the tip shape and material of the indenter, the indenting speed, the indentation environment, etc. Contact models are commonly used to deduce the mechanical properties of the materials by the best fit of the indentation depth-loading profile. However, determination on the correct contact model is not unambiguously determined by the local depth-loading profile. This ambiguity can be removed by using the extra data of the non-local deformation of materials. Such extra data can also be applied to understanding the deformation and impact transfer in heterogeneous structures, the elastocapillary effect at the interfaces, and how live systems respond to mechano-stimuli.

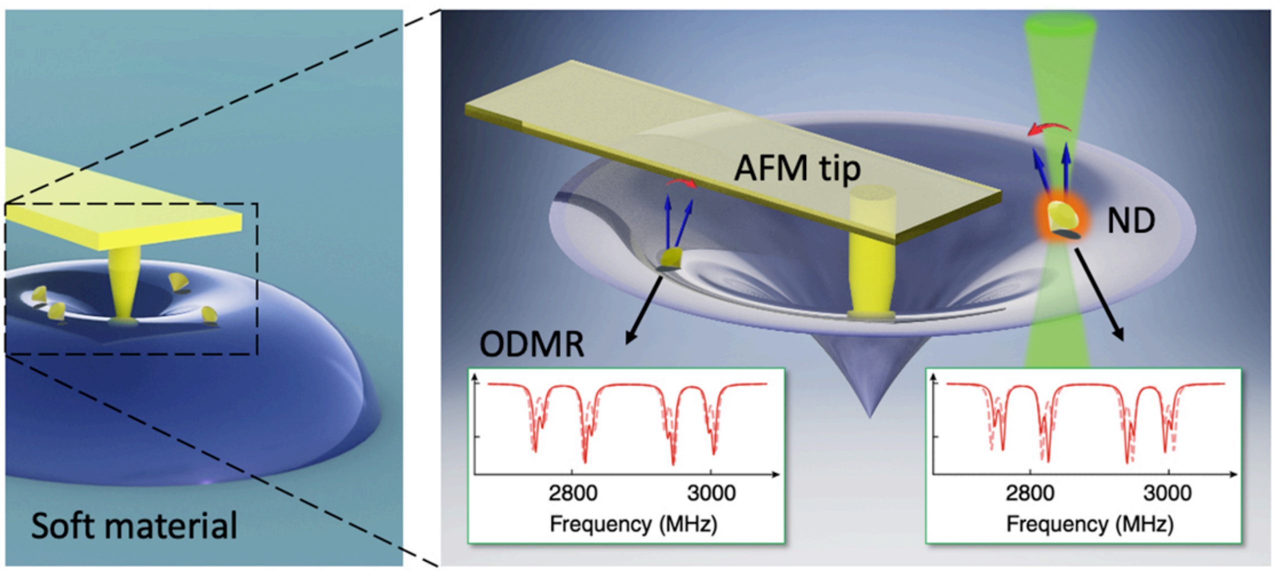

Fig. 1. Method of deformation reconstruction via the rotation of nanodiamonds (NDs) upon atomic force microscopy indentations. Insets are examples of the simulated optically detected magnetic resonance spectra of the two NDs on the surface without and with the indentation.

In our recent work, we develop a method that can reconstruct the nanoscale non-local deformation of materials by combining nanodiamond orientation sensing and the AFM-nanoindentation. The method exploits the superb sensitivity of diamond vector magnetometry and the high spatial resolution of AFM indentation. Loading on the material is carried out by the AFM tip, which causes material deformation and the rotation of the nanodiamonds (NDs) docked on the surface in the vicinity of the indentation location. Such rotation of the NDs can be precisely measured by the optical detected magnetic resonance (ODMR) of the nitrogen-vacancy centers inside the NDs. The material deformation upon an AFM indentation is then reconstructed by the gradient field on the surface deduced from the measured rotation of the NDs.

In the proof-of-the-concept demonstration, we reconstructed the deformation of a polydimethylsiloxane (PDMS) film with a 5 nm precision in the loading direction and an in-plane spatial resolution limited by the ND size (which is ~200 nm in the present experiments). The measured mechanical property of the PDMS film is well described by a linear elastic model with a harder surface layer; this good agreement validates the method. We further applied this technique to investigate the mechanical properties of a gelatin particle in water. Elastocapillary effects at the gelatin/water interface are disclosed by the non-local deformation sensing.

The work holds promises for the investigation of mechanical properties/mechano-response of soft materials in nanoscale. The low cytotoxicity and high photo-stability of NDs make NDs especially attractive for live cell investigations.

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