Photo-acoustic subsurface atomic force microscopy

– making the invisible visible –

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The development of acoustic subsurface atomic force microscopy, which promises three-dimensional imaging with single-digit nanometer resolution by the introduction of ultrasound actuations to a conventional atomic force microscope, has come a long way since its inception in the early 1990s [1,2,3]. Recent advances provide a quantitative understanding of the different experimentally observed contrast mechanisms, which paves the way for future applications. Here, I first review the different subsurface atomic force microscope modalities (Figure 1a-g). Then, I argue why photo-acoustic subsurface atomic force microscopy is most promising in achieving true three-dimensional imaging with single-digit nanometer resolution in opaque samples[4] and show recent developments we made in realizing this. Finally, I discuss open problems in the field and motivate the importance of new actuators, near-field picosecond ultrasonics (Figure 1g), and integration with other techniques for multi-functional non-destructive three-dimensional nanoscale imaging.

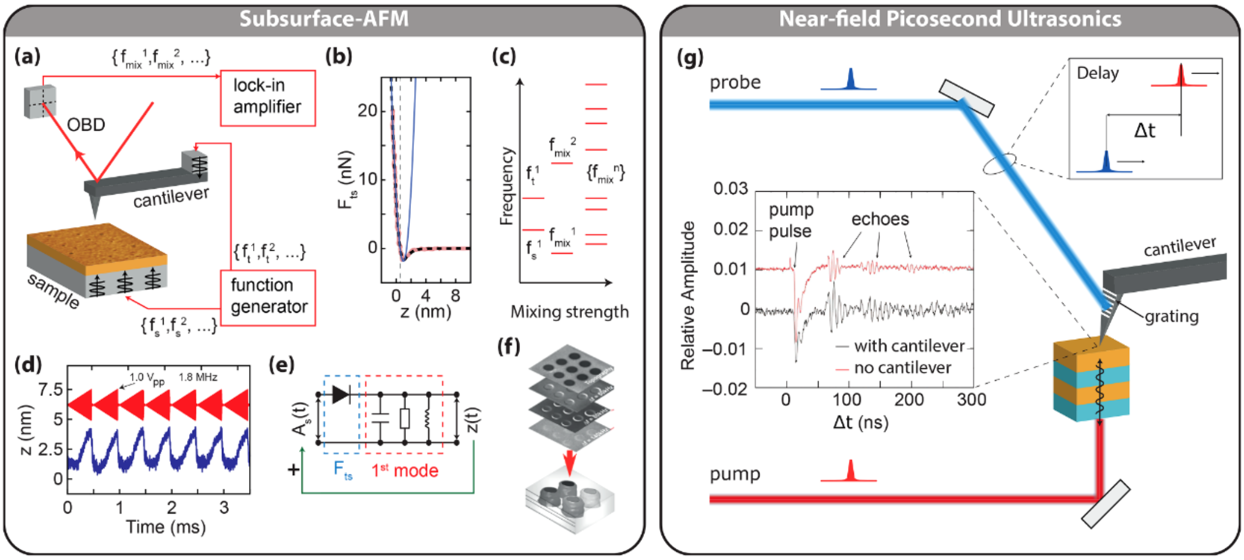

Figure 1. (a) Acoustic subsurface AFM uses ultrasound excitations of the sample and/or cantilever and records the cantilever motion at their mixing frequencies using the optical beam deflection (OBD) method. These mixing frequencies are generated by the nonlinear tip–sample force F_{ts}, as depicted in (b) and (c). (d) UFM uses amplitude modulated excitation signal on the sample (red) while cantilever only follows the modulation frequency, resulting in a rectifying effect (blue). (e) The cantilever response z(t) also modulates F_{ts}; couples back into the F_{ts} (green arrow) complicating modeling of acoustic subsurface AFM. (f) By combining signals from different mixing frequencies, it is under certain conditions possible to reconstruct a 3D image of the measured device. (g) Near-field picosecond ultrasonics uses an ultrashort laser pump–probe technique and a cantilever probe in order to perform pulse-echo measurements in the nanoscale (inset). By varying the delay Δt between the pump and probe pulse, the measurement depth can be controlled.

[1] K. Yamanaka, H. Ogiso, and O. Kolosov, Appl. Phys. Lett. 64, 178–180 (1994).
[2] O. Kolosov and K. Yamanaka, Jpn. J. Appl. Phys. 32, L1095 (1993).
[3] R. Garcia and E. T. Herruzo, Nat. Nanotechnol. 7, 217 (2012)
[4] H.J. Sharahi, M. Janmaleki, L. Tetard, S. Kim, H. Sadeghian, and G.J. Verbiest, J. Appl. Phys. 129, 030901 (2021)