Using optomechanical AFM probes for nanoscale imaging of thermal conductivity and interfacial thermal conductance

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Atomic-force-microscopy (AFM) plays a critical role in most of the branches of modern science as a powerful characterization tool. The continuous development of material science and nanotechnology drives the research to atomic scales demanding even faster and more sensitive characterization approaches. In this work, we demonstrate an optomechanical AFM probe of a combination of state-of-the-art metrics, such as ≈ 10 ns temporal resolution, ≈ 35 nm spatial resolution, and high sensitivity, arising from its low detection noise ≈ 0.4 fm/Hz$^{1/2}$ over a wide (> 100 MHz) bandwidth. The probes are fabricated from standard silicon-on-insulator wafers where their geometry is defined by electron-beam lithography and later refined by focused ion-beam. The well-defined optical and mechanical structures guarantee the sensitivity and spatial/temporal resolutions of the probes.

We adapt this probe to a commercial AFM-IR setup to demonstrate its capability in the high-precision measurement of fast mechanical dynamics at the nanoscale. The AFM-IR setup is based on the photothermal-induced-resonance (PTIR) technique [1,2] where an AFM probe is used to transduce the photothermal expansion of a sample due to the absorption of mid-IR nanosecond laser pulses. Conventional AFM probes do not have enough sensitivity and bandwidth to track the fast (~ ns) and weak (~fm) thermal expansion and relaxation process of nanometer-thin films. In stark contrast, our optomechanical probes demonstrate their capability to measure the thermal dynamics of ~2 nm thick octadecylchlorosilane (OTS) monolayer and ~5 nm thick SU-8 films. With the locally measured thermal relaxation signal, we perform nanoimaging of the sample's thermal conductivity (η) and interfacial thermal conductance to the substrate (G). As a proof-of-principle demonstration, we measured the map of η, G on a SU-8 film with thickness continuously varying from 0 nm to 220 nm. Thanks to the high sensitivity and bandwidth of the probe, the throughput of η and G nanoimaging is ≈ 6000 × faster than the state-of-the-art time-domain thermoreflectance (TDTR) method and ≈ 500000 × faster than the measurements using conventional AFM cantilevers. Furthermore, its nanometer-scale spatial resolution is far beyond the micron-scale one of TDTR. This work paves the way to study fast thermal dynamics in materials and devices with nanoscale resolution, which is critical, for example, to study the thermal properties of grain boundaries and of filaments in memristive devices.

References

[1] Centrone, A., *Annu. Rev. Anal. Chem.* **2015,** *8* (1), 101-126.
[2] Kurouski, D. ; Dazzi, A.; Zenobi, R. ; Centrone, A, *Chem. Soc. Rev.*, **2020**, 49, 3315-3347

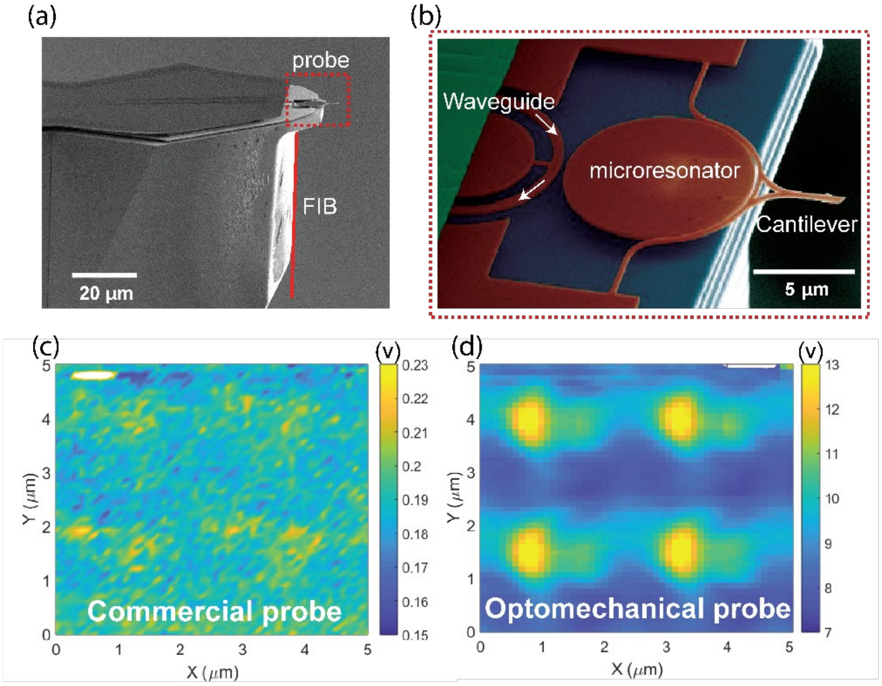

Fig. 1 Micrograph of optomechanical AFM probe (b) on chip (a). The FIB process is used for milling the substrate of the chip and sharpening the cantilever of the probe. IR-absorption image of the same device taken by a commercial probe (c) and optomechanical probe (d).

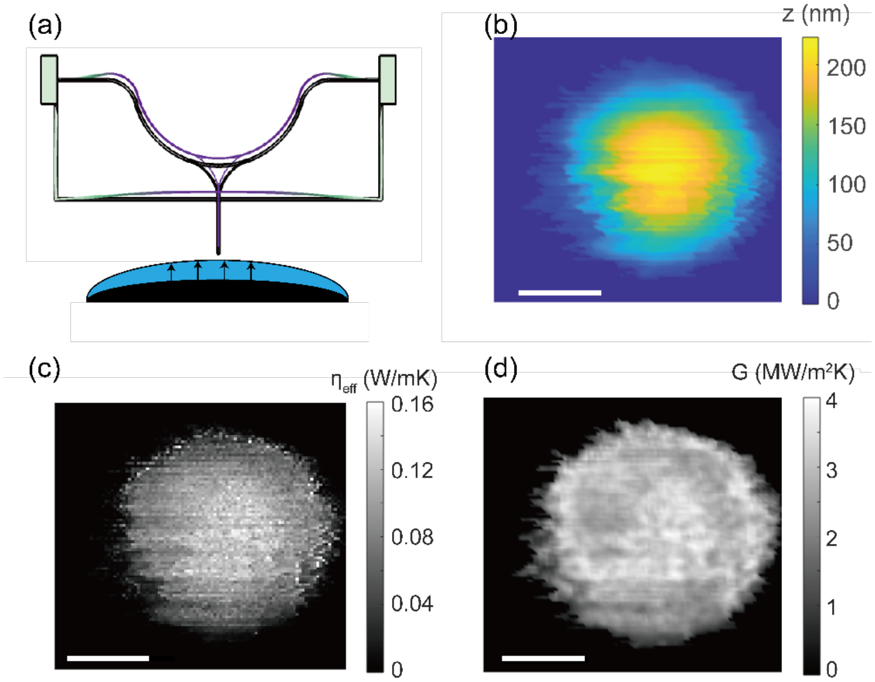

Fig. 2. (a) Schematic of the PTIR measurement. (b)-(d) are measured topography, effective thermal conductivity, and interfacial thermal conductance image of a SU-8 sample, respectively.