Supplementary Information for "Emergent phonon synchronization enhances heat transport in graphite"

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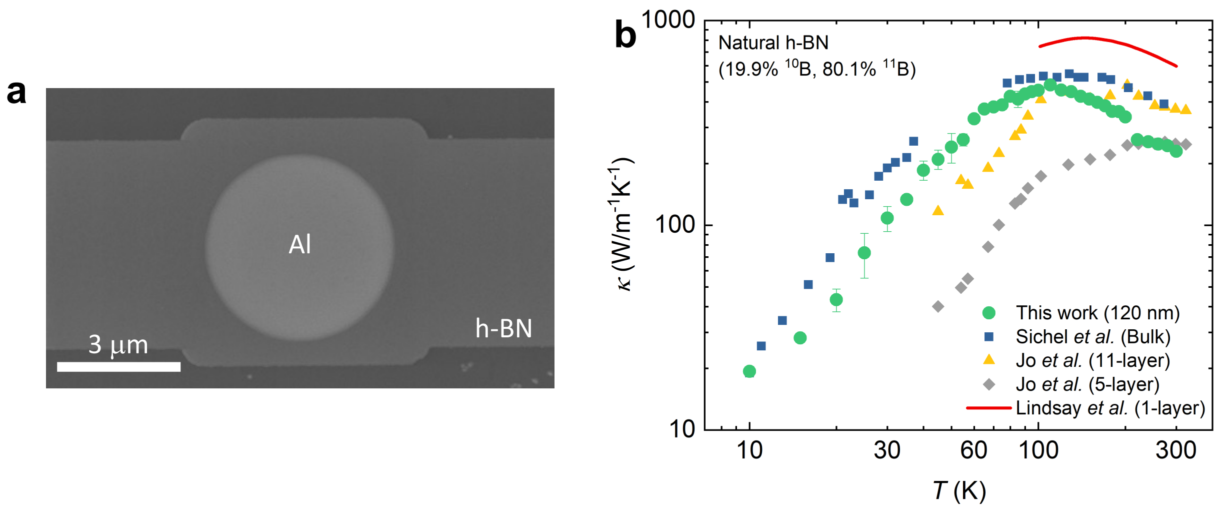
Characterization and thermal transport of h-BN reference samples

The h-BN samples serve as a reference layered material for comparison with graphite. Extended Data Fig. 1**a** shows a scanning electron microscope (SEM) image of the ribbon device, with a central aluminium transducer for thermoreflectance measurements. The h-BN ribbons are 30 μm long, 5 μm wide and 120 nm thick, and have a natural boron isotope composition (19.9% ^{10}B and 80.1% ^{11}B). Their in-plane thermal conductivity is determined using the microsecond time-domain thermoreflectance (μ-TDTR) method described in the Methods of the main text.

Extended Data Fig. 1**b** compares the measured thermal conductivity with published data and theoretical predictions. The conductivity increases at low temperatures, peaks near 100 K, and decreases upon further heating. Its magnitude and temperature dependence are broadly consistent with the bulk h-BN measurements of Sichel *et al.*[1], particularly near the conductivity maximum. Below and around this maximum, our values also exceed those reported for the five- and eleven-layer samples of Jo *et al.*[2]. These comparisons are consistent with good sample quality and thermal transport approaching bulk behaviour, although finite-size effects remain relevant. This agreement also supports the reliability of our thermal characterization.

The measured conductivity remains below the single-layer prediction of Lindsay *et al.*[3]. The enhanced conductivity predicted for single-layer h-BN is associated with reduced phonon–phonon scattering, so this curve is not a quantitative bulk benchmark. Boundary scattering in the finite ribbon geometry may further reduce the measured conductivity relative to bulk behaviour, particularly at low temperatures. Natural isotope disorder also provides a resistive scattering channel that limits phonon transport; its contribution to the difference from theory depends on the isotope composition included in the calculation. Together, the high measured conductivity and its correspondence with the bulk reference support the use of these h-BN ribbons as a reference material for the graphite comparison in the main text.



Extended Data Fig. 1 | Characterization and thermal conductivity of h-BN samples. a, Scanning electron microscope (SEM) image of a representative h-BN ribbon sample with an aluminium (Al) transducer. The scale bar is 3 μm. **b**, Temperature-dependent thermal conductivity of the h-BN sample measured in this work, compared with experimental results for bulk h-BN from Sichel *et al.*[1], five- and eleven-layer h-BN from Jo *et al.*[2], and the single-layer theoretical prediction of Lindsay *et al.*[3]. The sample measured in this work is 120 nm thick and has a natural boron isotope composition. Error bars represent the standard deviation of three to five measurements on the same sample.

References

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