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Ballistic to diffusive crossover of heat flow in suspended graphene membranes

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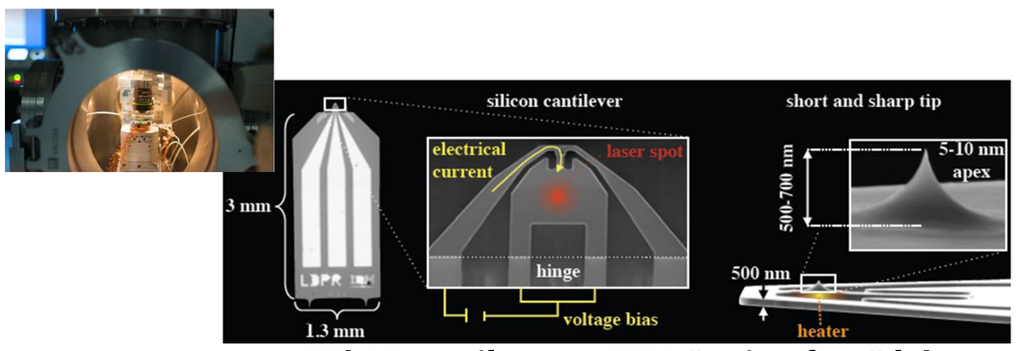
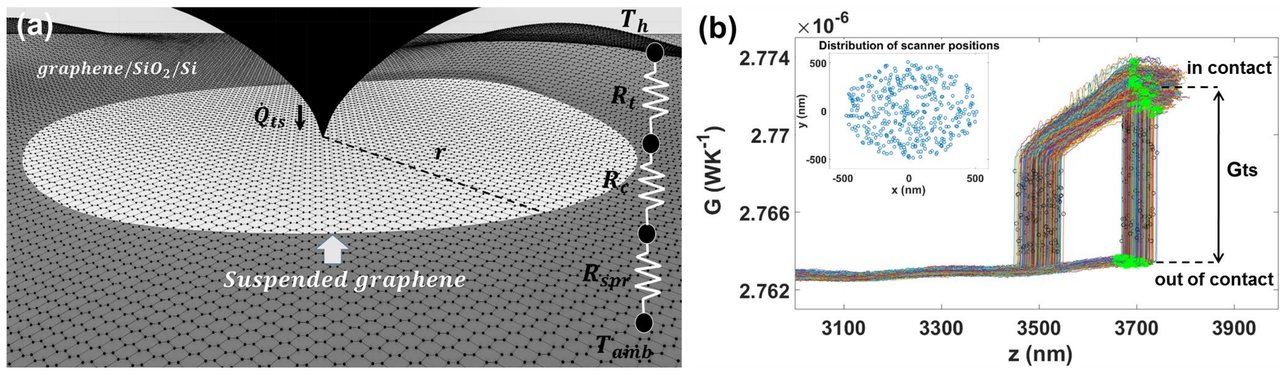
Introduction

We investigate the transport of phonons in suspended CVD single-layer graphene disks with radius between 150 and 1600 nm using a high-vacuum scanning thermal microscope. Our experimental results reveal a ballistic phonon transport and a decrease of the thermal contact resistance between tip and graphene with radius, r, up to 775 nm. In graphene discs with r >775 nm, the in-plane heat transport is suppressed by phonon–phonon scattering and the measured thermal contact resistance increases from 1.15 and 1.52×10^{8} KW^{-1}. These results suggest that the value of the average mean free path of acoustic phonons in clean suspended graphene that dominate heat conduction at room temperature is approximately 775 nm. Our approach [1] allowed the direct nanoscale thermal imaging of suspended graphene with spatially resolved heat flux measurements down to few-nanometre spatial resolution by simultaneously analysing the surface morphology of the graphene samples.

Instrumentation

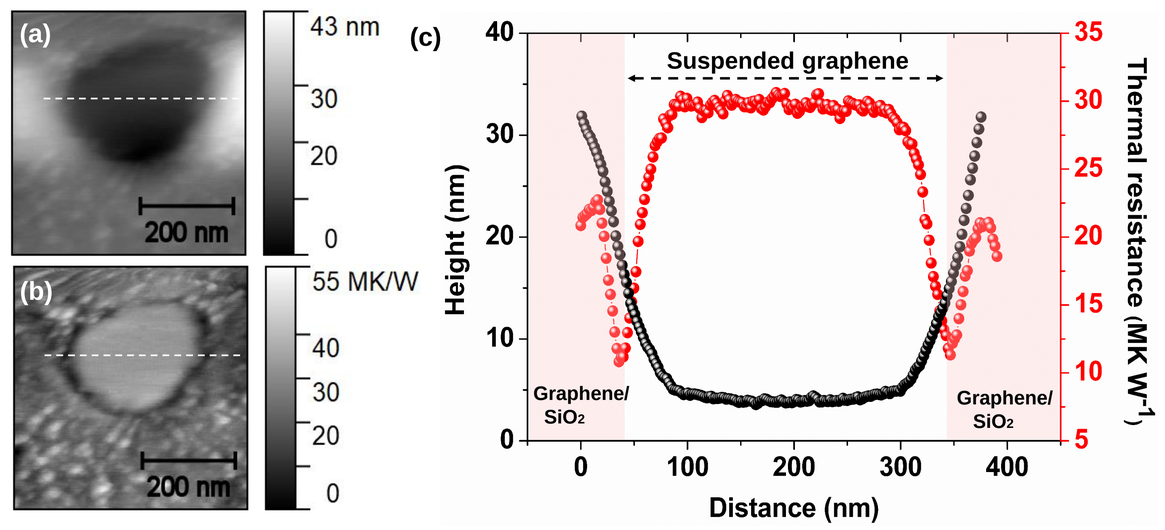


SThM cantilever - IBM "noise-free" labs

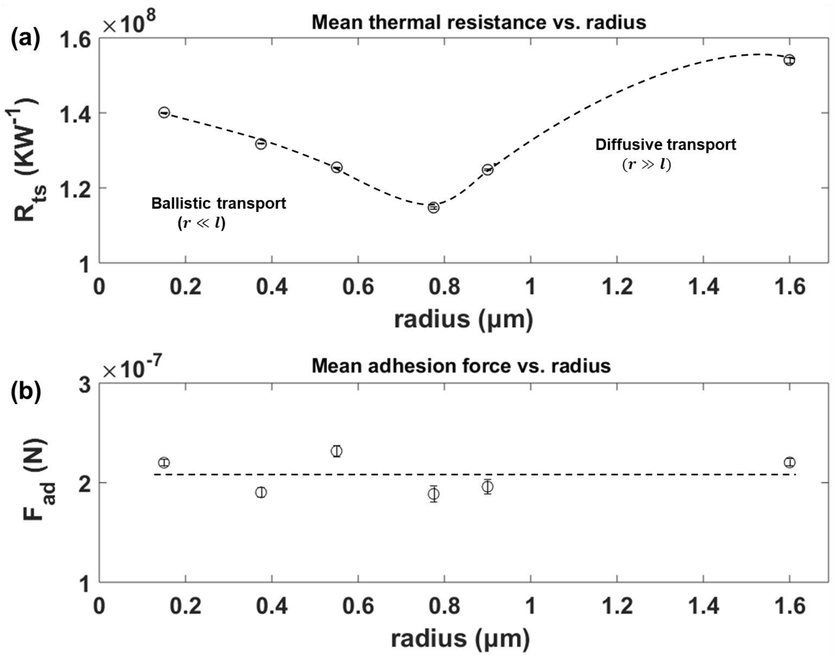


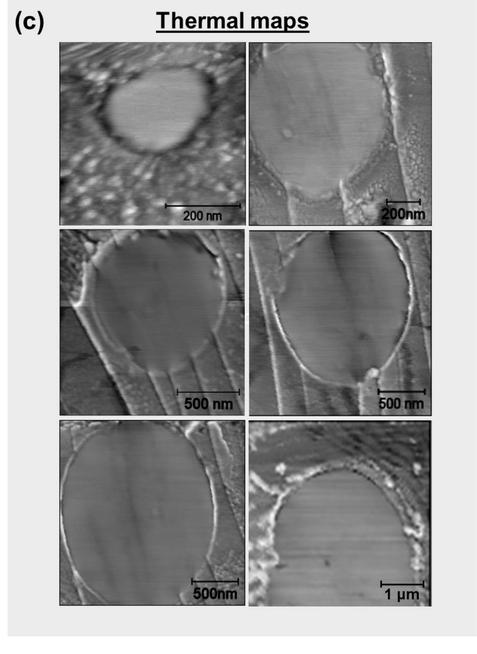
(a) Schematics of the nanoscopic tip-sample contact and the equivalent thermal resistance circuit; **(b)** a typical example of the measured thermal conductance signal during several tip-graphene point contacts.

Thermal and topography maps of suspended monolayer graphene



Thermal resistance measurements





Summary

- Direct thermal imaging of suspended graphene with spatially resolved heat flux measurements down to few-nanometer spatial resolution by simultaneously analyzing the surface morphology of the graphene samples.
- Ballistic acoustic phonons dominate in suspended graphene discs with a radius smaller than ~ 800 nm and the measured thermal contact resistance decreases with increasing radius.
- The average MFP of acoustic phonons in clean suspended graphene that dominate heat conduction at room temperature is approximately 800 nm.
- In graphene discs with radius >800 nm the in-plane heat transport is suppressed by phonon–phonon scattering.

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