SCANNING THERMAL MICROSCOPY OF 2D MATERIALS IN HIGH VACUUM ENVIRONMENT

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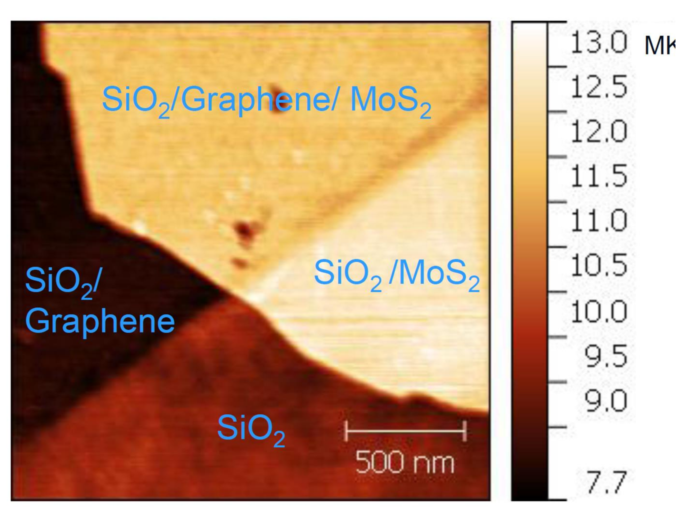
Introduction

We target a major challenge of understanding and measuring the thermal transport in 2D materials, their nanostructures and the heterostructures. We employ a nanoscale scanning thermal microscopy (SThM) under high vacuum (HV) conditions to directly map the thermal transport in exfoliated InSe flakes and InSe nano-wedge structures.



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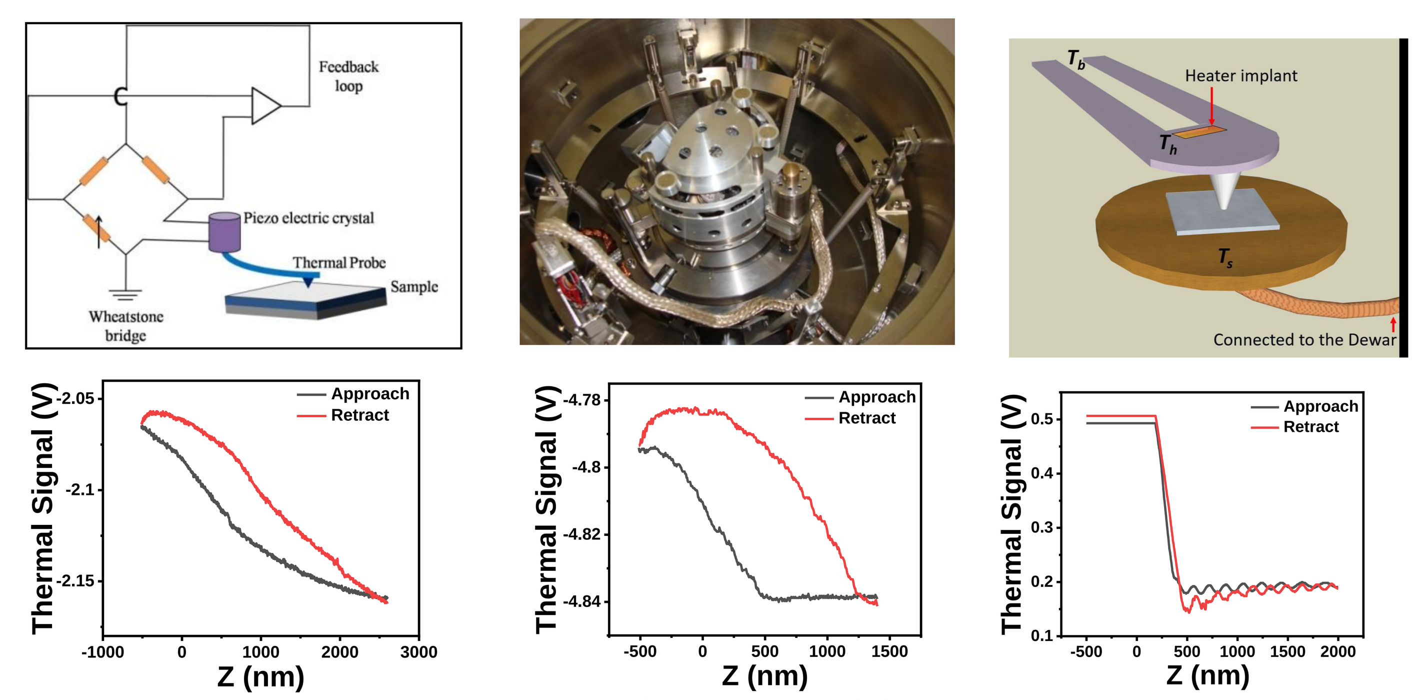
SThM can map the effective thermal resistance (inverse of thermal conductance) of Graphene, MoS_2 and Graphene/MoS_2 heterostructures.

Methodology



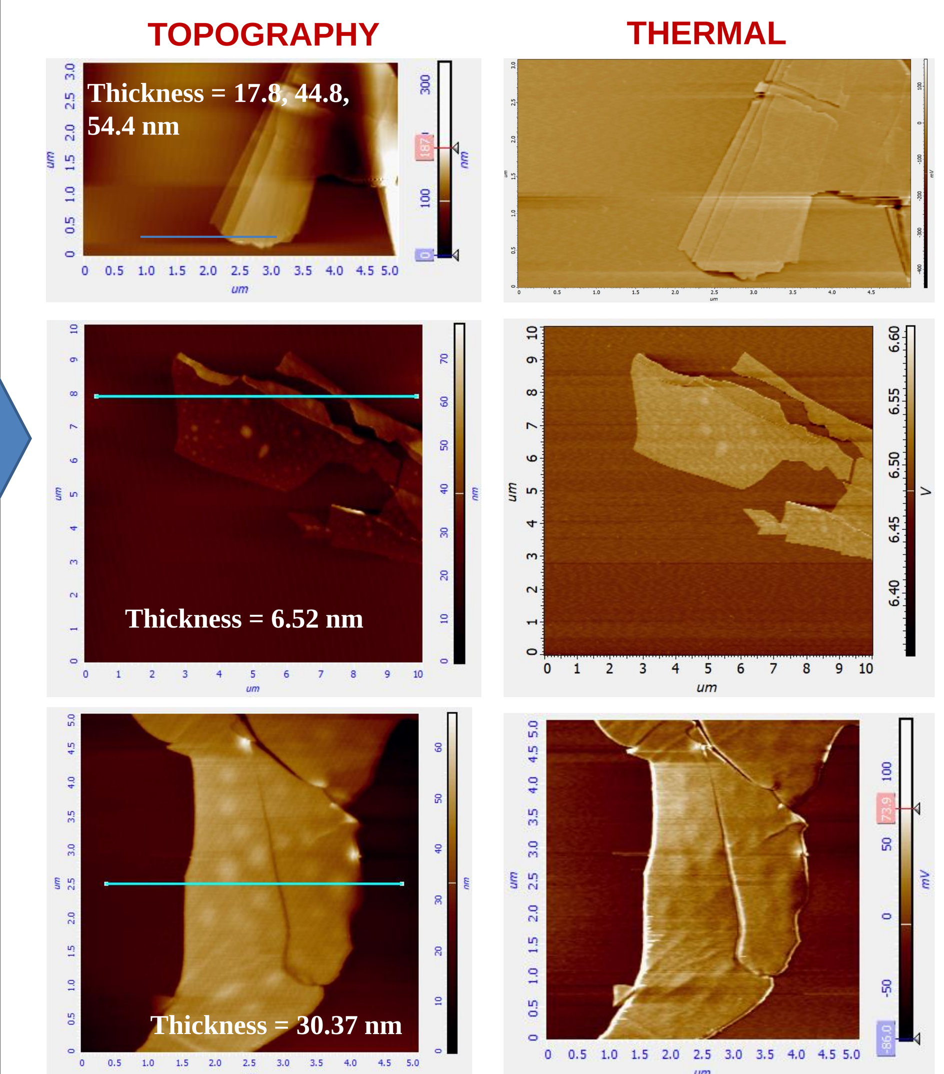
Approach-Retract curve on CNT sample in Air

Approach-Retract curve in dark mode on CNT sample

Approach-Retract curve in vacuum on CNT sample

SThM studies are often performed in ambient conditions in air and at room temperature (RT), these measurements can suffer from spurious effects of the through-the-air heat transport impeding quantitative studies of the nanoscale thermal transport in nanostructures.

Results

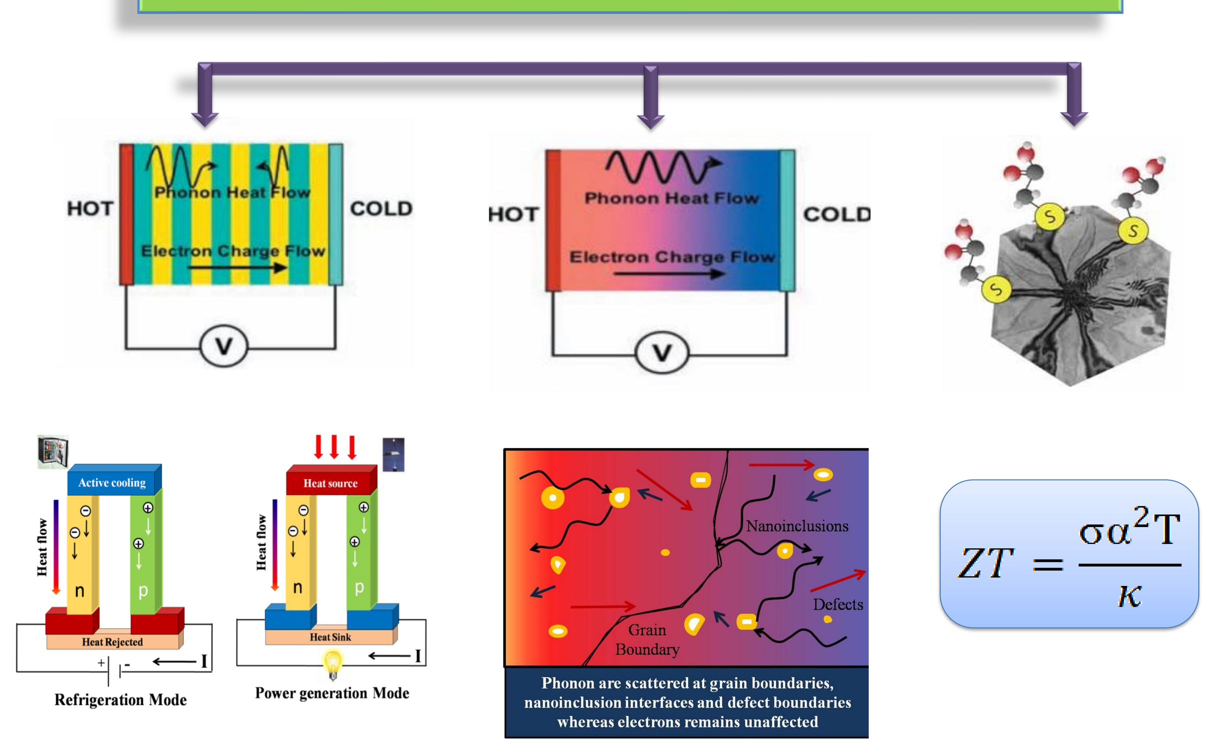


Topographical and thermal images of InSe flakes on Si substrate having different thickness to understand the thermal transport of 2D materials.

We use SThM to image and quantify the nanoscale thermal transport from single to few-layer to bulk InSe flakes in high vacuum (HV) of 10^{-6} torr.

Thickness (nm)	V_{NC}	V_{CF}	V_{CS}
5.47	355.24	347.64	346.24
6.52	343.76	333.68	332.44
12.22	409.48	382.84	382.26
27.11	331.05	325.5	325.58
30.37	319.68	308.74	307.86
124.4	332.76	320.10	318.06

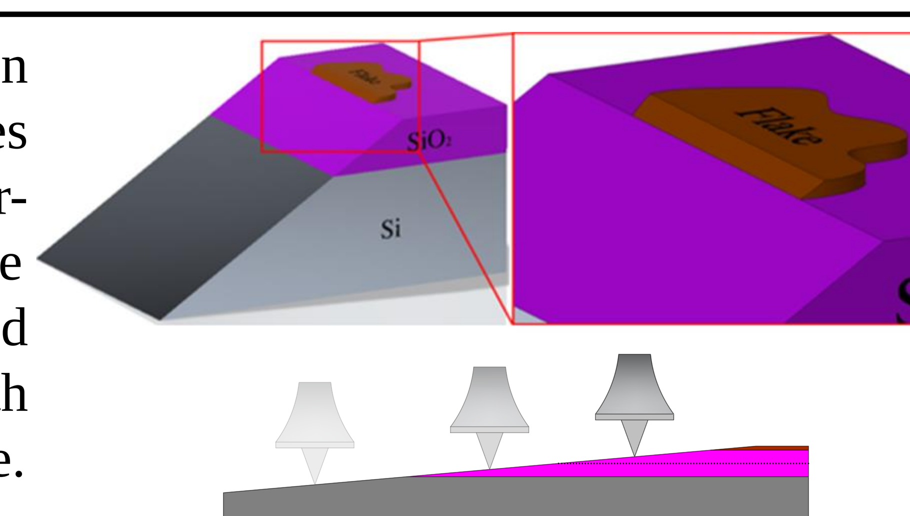
Approaches Employed for Enhancing ZT



$$ZT = \frac{\sigma\alpha^2 T}{\kappa}$$

The thermoelectric (TE) efficiency could be greatly enhanced through nanostructuring. 2D materials nano-inclusions can restrict short and mid-range wavelength phonons while allowing electrons to propagate unscattered, enhancing a key "ZT" TE parameter.

Beam exit cross-section polishing (BEXP) uses Ar ions to create a near-atomically flat low angle (1 to 5°) wedge shaped oblique cut with minimal sample damage.



The measurement of thermal resistance on wedge samples allows to separate the contribution from the interfacial thermal resistance and to quantify anisotropic values of thermal conductivity via analytical model.

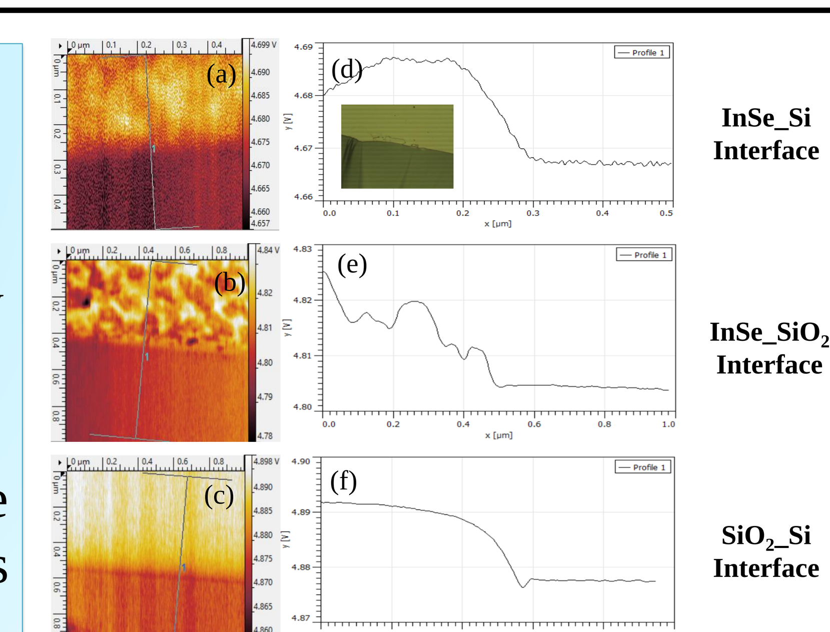
Spièce, J. et al Nanoscale 2021.

For bulk isotropic material and a contact radius above the phonon mean free path, the thermal spreading resistance is given by $R_S = \frac{1}{4\kappa a}$ .With small angle wedge cut each InSe measurement point can be approximated as a layer of variable thickness. We van then use the tranverse isotropic model for R_S for the heat spreading within the layer on a substrate

$$R_{S(t)} = \frac{1}{\pi \kappa_1 a} \int_0^{\infty} \left[\frac{1 + K exp\left(-\frac{2\xi teff}{a}\right)}{1 - K exp\left(-\frac{2\xi teff}{a}\right)} \right] J1(\xi) \sin(\xi) \frac{d\xi}{\xi^2}$$

Muzychka, Y. S., et al. (2004). J Thermophys Heat Transfer 18(1): 45-51.

We measured the thermal conductance of wedge-shaped BEXP cut InSe samples on high (Si) and low (SiO_2) thermal conductivity using high vacuum SThM.. Thermal conductance vs InSe thickness allows to deduce its in-plane and cross-plane thermal conductivity.



Thermal images and profiles of (a,d) InSe_Si, (b,e) InSe_SiO_2 and (c,f) SiO_2_Si interfaces.

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