Measurements of Anisotropic Thermal Transport in γ-InSe via Quantitative Cross-Sectional Scanning Thermal Microscopy

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Van der Waals materials (vdW) and their heterostructures provide a versatile and tunable toolbox for nanoscale heat transport management and development of novel thermoelectrics [1]. For their effective use in such applications, one needs to characterise their intrinsically anisotropic heat transport, as well as account for the interfacial resistances between the material and its environment, with both tasks currently presenting a major challenge for the researchers, given the lack of effective approaches to perform this tasks in the nanoscale. Here, we report a novel method called cross-sectional scanning thermal microscopy (x-SThM), which uses the transition between the in-plane to across-the-plane thermal transport in a vdW nanolayer as its thickness changes, to map its thermal response and, ultimately, evaluate the anisotropic thermal conductivity and interfacial thermal resistances quantitatively, all this with a nanoscale resolution.

xSThM employs an Ar-ion beam exit cross-sectional polishing of vdW nanoflakes to generate a low angle near-atomic-scale flat wedge cut. By subsequently scanning the sample in xSThM in high vacuum conditions across the wedge surface, one effectively obtains the vdW material thermal conductance as a function of thickness eliminating the artefacts caused by the air thermal convection transport. Using an analytical model [2] confirmed via Finite Elements Analysis (FEA) simulations, we can fit these data to obtain quantitative values for the anisotropic thermal conductivity (in-plane, k_{xy} and across-the-plane, k_z) as well as the interfacial thermal resistance between the vdW material and a substrate (r_{int}) and between the tip and the vdW nanolayer (R_c). This approach is used on gamma indium selenide, a material with a high thermoelectric potential thanks to its highly tunable electrical conductivity [3], to obtain an anomalously low anisotropic thermal conductivity of k_{xy} = 2.16 $Wm^{-1}K^{-1}$ in-plane and k_z = 0.89 $Wm^{-1}K^{-1}$ cross-plane with a corresponding $r_{int} = 9.60\times10^{-11}$ Km^2W^{-1} and $R_c = 45.81\times10^6$ KW^{-1} in a thickness range of up to 80 nm.

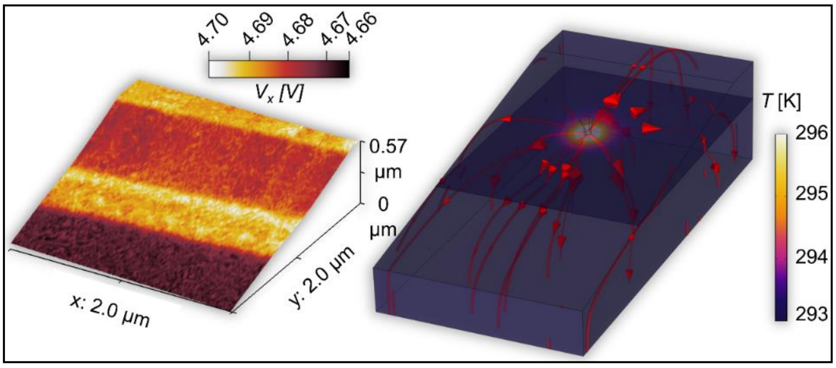

Fig. 1. (Left) 3D InSe wedge cut topographic angle with the thermal SThM signal; (Right) 3D InSe wedge cut FEA simulation of the temperature distribution and the heat flow lines.

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[2] Spièce, J. et al, Nanoscale, 13, 10829-10836 (2021).
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