Scanning Thermal Microscopy (SThM) of vdW Materials for Discovery of Non-conventional Thermoelectricity

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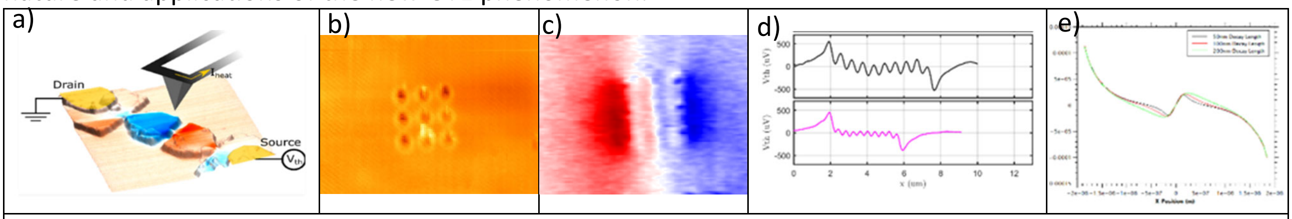
Abstract. Scanning probe microscopies (SPMs) hold a major advantage compared to light and electron microscopies, in that SPMs can directly map with nanoscale resolution diverse physical properties of an materials and devices - mechanical, electrical and thermal. In particular, scanning thermal microscopy (SThM) and its modifications allow to measure both local thermal conductivity of material and its thermoelectric (TE) properties (Seebeck coefficient) with a resolution of a few tens of nm. Our recent work using SThM allowed to design a record-breaking thermoelectric combining two-dimensional MoS_2 and conventional thermoelectric (Sb_2Te_3) in a superlattice reaching dimensionless figure of merit above 2.0 at room temperature [1].

Here we use scanning thermal gate microscopy (STGM) [2] to explore a novel phenomenon of geometric thermoelectricity (GTE) in van-der Waals (vdW) materials. GTE phenomenon was observed in narrow "necks" of graphene layers and was linked with the energy-dependent modification of electron mean-free path [3], opening a non-conventional paradigm for TE heat management in electronic devices and use in sensors by a single vdW material solely by varying its geometry, rather than classical requirement of a junction of two dissimilar materials (hence name of "thermocouple").

We encapsulated graphene between two thin layers of insulating hexagonal boron nitride, hBN, and patterned it creating symmetric and asymmetric narrowing. By using STGM we confirmed the exclusively geometric nature of the GTE, excluded the effects of edge or surface doping, showed that it is dimension of the "neck" rather than asymmetry of geometry provide changes in the Seebeck coefficient, and quantify the change of the Seebeck coefficient.

We then use focused ion beam (FIB) to create patterns of holes of varying pitch, number and diameters in another vdW material – SnSe2, and showed that the Seebeck coefficient can be modified over any desired area. By comparing STGM TE measurements, SThM thermal transport measurements, and FEA modelling we found that the modification of TE Seebeck coefficient has the characteristic "decay length" of about 1 um, significantly larger than the thermal transport length of few tens of nm, providing significant insight into the nature and applications of the new GTE phenomenon.



a) STGM illustration for symmetric/asymmetric "necks" in the hBN encapsulated graphene device - hot tip creates the experimentally measured thermovoltage in the device (colour) that is mapped vs the position of the tip. b) Thermal and c) STGM thermovoltage image of the $SnSe_2$ patterned sample, d) thermovoltage profile measured for multiple holes. e) FEA modelling of the thermovoltage dependence of the TE "decay length".

References:

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