Unconventional Geometric Thermoelectricity in Nanopatterned vdW Materials

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Geometric Thermoelectricity (GTE) in van-der Waals (vdW) materials is a recently discovered phenomenon of significant modification of Seebeck thermoelectric (TE) coefficient in the nanoscale sized "constrictions" of uniform graphene layers [1]. The GTE is not linked with local doping or material change, signifying a radical deviation from conventional classic thermoelectric phenomena requiring a junction of two dissimilar materials (like a typical "thermocouple" or TE "junctions") with the underlying mechanism being the energy-dependent modification of electron mean-free path in the constriction [1]. GTE opens a new paradigm for creating TE devices solely by varying the geometry of two-dimensional van der Waals (vdW) material, drastically simplifying the design of TE devices.

This work addresses key questions whether it is possible to use GTE to modify large areas of vdW materials, rather than a single constriction, what is the ultimate performance of such devices, and what are the details of heat, electron transport and TE conversion mechanisms in GTE phenomenon. To answer these, we use scanning thermal and scanning thermal gate microscopies (SThM and STGM) with heated nanoscale tip in contact with the probed device to measure a local thermal transport in the device and a thermovolage generated by the device in response to the local raise of the temperature measuring local gradients of Seebeck coefficient [1]. We also used focused ion beam (FIB) to create different patterns of holes of varying pitch, number and diameter in the layer of vdW material – SnSe2.

First, we investigated the dependence of local Seebeck coefficient on the diameter of the features and the distance from them. We found that while thermal transport varies on distances of a few tens of nanometres, the modification of Seebeck coefficient expands on much larger distance with the characteristic Seebeck exponential "decay length" evaluated by comparison of experiment and FEA modelling being on the order of 1 um. By selecting appropriate density and diameter of the nanofabricated patterns, it was possible to create large areas of Seebeck coefficient modification.

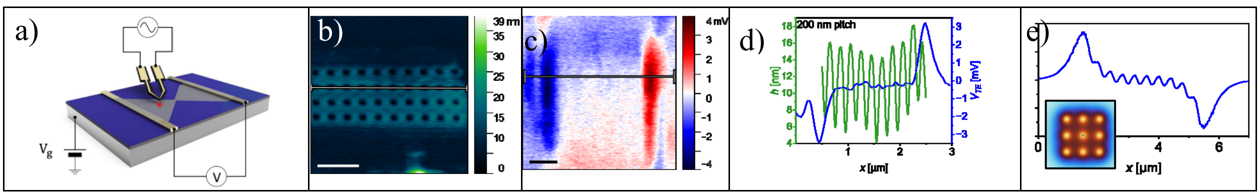

Figure 1: a) Schematics of STGM thermovoltage mapped as a function of hot tip position, b) Thermal and c) STGM thermovoltage image of the SnSe2 nanopatterned sample, d) thermovoltage (blue) and thermal signal (green) profiles for the device; e) FEA modelling of profile and area (inset) of the thermovoltage response.

[1] Harzheim, A.; Spiece, J.; Evangeli, C.; McCann, E.; Falko, V.; Sheng, Y. W.; Warner, J. H.; Briggs, G. A. D.; Mol, J. A.; Gehring, P.; and Kolosov, O. V., Nano Letters 2018, 18 (12), 7719-7725. DOI 10.1021/acs.nanolett.8b03406
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