EN07.16.04

Geometric Thermo Electricity (GTE) - Towards "Junction-Less" Unconventional Thermoelectric Devices

When and Where

Apr 26, 2024
9:45am - 10:00am

Room 327, Level 3, Summit

Presenter

Oleg Kolosov
Alexandros El Sachat
Charalambos Evangeli
Sergio Gonzalez-Munoz
Peng Xiao
Elisa Castanon
Edward McCann
Matthew Hamer
Johanna Zultak
Olga Kazakova
Roman Gorbachev

Co-Author(s)

Oleg Kolosov[1],Alexandros El Sachat[2],Charalambos Evangeli[1],Sergio Gonzalez-Munoz[3],Peng Xiao[4],Elisa Castanon[4],Edward McCann[1],Matthew Hamer[4],Johanna Zultak[4],Olga Kazakova[5],Roman Gorbachev[4]

Lancaster University[1],NCSR "Demokritos"[2],ICN2[3],The University of Manchester[4],National Physical Laboratory[5]

Abstract

Oleg Kolosov[1],Alexandros El Sachat[2],Charalambos Evangeli[1],Sergio Gonzalez-Munoz[3],Peng Xiao[4],Elisa Castanon[4],Edward McCann[1],Matthew Hamer[4],Johanna Zultak[4],Olga Kazakova[5],Roman Gorbachev[4]

Lancaster University[1],NCSR "Demokritos"[2],ICN2[3],The University of Manchester[4],National Physical Laboratory[5]

Traditionally, thermoelectric (TE) phenomena require junctions between two dissimilar materials to either generate the current when opposing junctions are held at two differing temperatures (Seebeck effect) or to cool and heat the opposing junctions when the external current is applied (Peltier effect). The two materials must have a different thermoelectric (Seebeck) coefficient, <i>S</i> (defined as the voltage <i>V</i> per temperature difference <i>ΔT</i>) in order to observe either Seebeck or Peltier effect. Nevertheless, the recently discovered phenomenon of “Geometrical Thermoelectricity", GTE [1] indicated that a nanoscale constriction (of the order of 50-200 nm) in the monolayer of two-dimensional material (2DM) graphene on the insulating SiO2/Si substrate acts as de-facto different material with the different Seebeck coefficient, changing the Seebeck coefficient solely by geometrical patterning and allowing to create TE devices out of a single material [2], avoiding the need for another material and a junction between two materials.
Here we investigate the origin of the GTE phenomenon using a well-defined structure of graphene encapsulated between hexagonal boron nitride (hBN) layers with asymmetric constrictions (flat-taper/flat-flat/taper-flat) and under different polarity of the carriers using the back-gating. By using Scanning Thermal Gate Microscopy (STGM) [3] where a heated nanoscale tip of an atomic force microscope is scanned across the material or device surface to produce a map of thermovoltage as a function of tip position, we established that the GTE modification of Seebeck coefficient does not a) depend of the symmetry of the junction nor b) on the polarity of the carriers (electrons or holes) and therefore c) is directly linked solely to the geometrical dimensions of the constriction.
Furthermore, we explored whether GTE can be used for modification of the Seebeck coefficient in the area of 2D material rather than for a single point (nanoscale constriction). We performed the FIB milling of arrays of holes of about 50 nm in diameter in a thick 50 nm layer of 2D material SnSe₂ using the varying pitch, density and ordering, showing that it is indeed possible to create multi-μm size areas of material with a very different Seebeck coefficient. By combining STGM with scanning thermal microscopy (SThM) [4] we found that the holes modify the heat transport on the distance of less than 20 nm, whereas the modification of the Seebeck coefficient is extended to the distances larger than 500 nm, suggesting the characteristic TE modification length is linked with the charge carriers.
In summary, we conclusively linked the GTE phenomenon to the geometrical factors and demonstrated that such an effect is present in other 2D materials such as dichalcogenide SnSe₂. We also showed the one can create large areas of multilayer 2D material building de-facto a new material with different TE properties while preserving its heat transport performance, paving the way for the much broader applications of GTE effect for the nanoscale and microscale cooling, heat manipulation and TE energy generation.

References
[1] A. Harzheim, J. Spiece, C. Evangeli, E. McCann, V. Falko, Y. W. Sheng, J. H. Warner, G. A. D. Briggs, J. A. Mol, P. Gehring, O. V. Kolosov, Nano Letters 2018, 18, 7719. https://doi.org:10.1021/acs.nanolett.8b03406
[2] A. Harzheim, F. Könemann, B. Gotsmann, H. van der Zant, P. Gehring, Advanced Functional Materials 2020, 30, 2000574. https://doi.org:https://doi.org/10.1002/adfm.202000574
[3] A. Harzheim, C. Evangeli, O. V. Kolosov, P. Gehring, 2D Materials 2020, 7, 041004. https://doi.org:10.1088/2053-1583/aba333
[4] S. Gonzalez-Munoz, K. Agarwal, E. G. Castanon, Z. R. Kudrynskyi, Z. D. Kovalyuk, J. Spièce, O. Kazakova, A. Patanè, O. V. Kolosov, Advanced Materials Interfaces 2023, 10, 2300081. https://doi.org:https://doi.org/10.1002/admi.202300081

Keywords

thermal conductivity | **thermoelectricity**

Symposium Organizers

Woochul Kim, Yonsei University
Sheng Shen, Carnegie Mellon University
Sunmi Shin, National University of Singapore
Sebastian Volz, The University of Tokyo

Session Chairs

Masahiro Nomura
Jae Sung Son
Sebastian Volz

In this Session

EN07.16.01
Si-Based Planar-Type Thermoelectric Generators over 1 μWcm^{-2}K^{-2}

EN07.16.02
Geometric Design and 3D Printing of Thermoelectric Materials and Devices

EN07.16.03
All-Silicon Micro-Thermoelectric Generator for IoT Applications

EN07.16.04
Geometric Thermo Electricity (GTE) - Towards "Junction-Less" Unconventional Thermoelectric Devices

EN07.16.05
Unusually Large Anomalous Nernst Effects in Partially-Crystallized Ferromagnetic Metallic Glasses

EN07.16.06
Advanced Energy Materials and Devices for Low-Grade Heat Harvesting and Flexible Thermal Sensing

EN07.16.07
Transient Characteristics and Thermal Boundary Effect in Standing-Wave Thermoacoustic Refrigerator

EN07.18.06
Thermal Characterization of GeTe PCM based Reconfigurable Devices