Energy in Nanoelectronics and Nanomaterials

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Abstract:

This talk will present recent highlights from our studies at the intersection of energy, nanomaterials, and nanoelectronics. We have investigated thermoelectric effects in graphene transistors and phase-change memory (PCM) elements for low-power electronics [1,2]. We find that low-power transistors and memory could be enabled by built-in thermoelectric effects which are particularly pronounced at nanometer length scales. We have also examined heat flow anisotropy in 2-dimensional (2D) graphene films and uncovered the fundamental (ballistic) limits of heat conduction [3,4]. These results suggest applications of 2D materials both as heat spreaders, thermal barriers, or thermoelectrics, depending on the combination of in-plane and out-of-plane properties which could be independently tuned. We have also begun examining thermal, electrical and thermoelectric properties of carbon nanotube composites for light-weight, flexible thermoelectric applications. In addition to the fundamental knowledge gained regarding electron and phonon flow from nanometer to centimeter length scales, these preliminary studies also outline how micro- to milli-Watts of power could be harvested from such diverse environmental sources like the human body. Taken together, our studies reveal fundamental limits and new applications that can be approached through the co-design of geometry and nanomaterials.

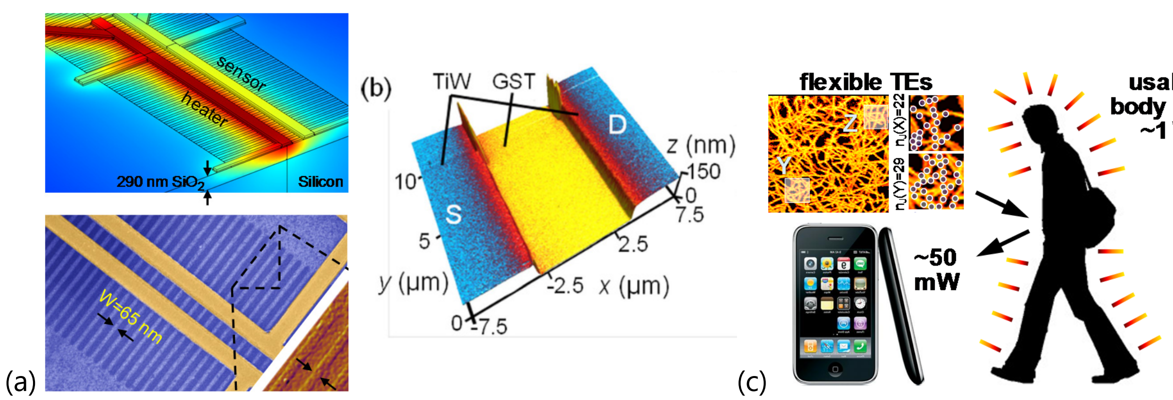

Fig 1. (a) Study of nanoscale heat flow in graphene revealed fundamental (ballistic) limits of phonon conduction in this 2D material [1,3,4]. (b) Thermal imaging of active PCM devices revealed key roles of thermoelectric effects at nanometer length scales [2]. (c) Flexible thermoelectrics (TEs) could be used to harvest power from the human body.

References:

[1] K.L. Grosse, M.-H. Bae, F. Lian, E. Pop, W.P. King, "Nanoscale Joule heating, Peltier cooling and current crowding at graphene-metal contacts," *Nature Nanotechnology* 6, 287 (2011).

[2] K.L. Grosse, F. Xiong, S. Hong, W.P. King, and E. Pop, "Direct Observation of Nanometer-Scale Joule and Peltier Effects in Phase Change Memory Devices," *Appl. Phys. Lett*. 102, 193503 (2013)

[3] E. Pop, V. Varshney, A.K. Roy, "Thermal Properties of Graphene: Fundamentals and Applications," *MRS Bulletin* 37, 1273 (2012)

[4] M.-H. Bae, Z. Li, Z. Aksamija, P. Martin, F. Xiong, Z.-Y. Ong, I. Knezevic, E. Pop, *Nature Comm*. 4, 1734 (2013)

Bio: Eric Pop is an Associate Professor of Electrical Engineering (EE) at Stanford. He was previously with the University of Illinois Urbana-Champaign (UIUC), first as an Assistant then as an Associate Professor of Electrical & Computer Engineering (2007-13). His research spans energy conversion systems, nanomaterials, and nanoelectronics. He received his Ph.D. in EE from Stanford (2005), the M.Eng./B.S. in EE and B.S. in Physics from MIT. He was a postdoc at Stanford and worked at Intel before joining UIUC. His honors include the Presidential Early Career (PECASE) Award, and Young Investigator Awards from the ONR, NSF, AFOSR and DARPA (2008-2010). He is an IEEE Senior member, a member of APS and MRS, and the Technical Program Chair of the IEEE Device Research Conference (DRC). More information about the Pop Lab can be found online at http://poplab.stanford.edu