Electronic, Thermal, and Unconventional Applications of 2D Materials

Eric Pop

Electrical Engineering, Stanford University, 420 Via Palou Mall, Stanford, CA 94305, USA
epop@stanford.edu

This talk will present recent highlights from our research on two-dimensional (2D) materials including graphene, h-BN, and transition metal dichalcogenides (TMDs). Results span from fundamental measurements, to devices, to system-oriented applications taking advantage of unusual 2D material properties. On the fundamental side, we measured record velocity saturation in graphene [1], and the thermal properties of graphene nanoribbons [2]. These are important for electronic applications, which can exhibit substantial self-heating during operation [3]. Taking advantage of low cross-plane thermal conductance, we found unexpected applications of graphene as ultra-thin electrode to reduce power consumption in phase-change memory [4]. We have also demonstrated wafer-scale graphene systems for analogue dot product computation (Fig. 1) [5].

We have grown monolayer 2D semiconductors by chemical vapor deposition over cm² scales, including MoS₂ with low device variability [6], WSe₂, MoSe₂ – and multilayer TMDs MoTe₂ and WTe₂ [7]. Importantly, ZrSe₂ and HfSe₂ have native high-K dielectrics ZrO₂ and HfO₂, which are of key technological relevance [8]. Improving the electrical contact resistance [9], we demonstrated 10 nm transistors using monolayer MoS₂, with the highest current reported to date (>400 µA/µm), approaching ballistic limits [10]. Using Raman thermometry, we uncovered low thermal boundary conductance (~15 MW/m²/K) between MoS₂ and SiO₂, which could limit heat dissipation in 2D electronics [11]. We are presently exploring unconventional applications including thermal transistors [12], which could enable nanoscale control of heat in “thermal circuits” analogous with electrical circuits. These studies reveal fundamental limits and new applications that could be achieved with 2D materials, taking advantage their unique properties.

References

Figures

Figure 1: Wafer-scale graphene dot product [5].

Figure 2: Cm-scale monolayer MoS₂ growth [6] and 10-nm scale transistor [9].

Figure 3: Raman thermometry of monolayer MoS₂ transistor during operation [11].