Electronic, Thermal, and Unconventional Applications of 2D Materials

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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 MoS_2 with low device variability [6], WSe_2, $MoSe_2$ – and multilayer TMDs $MoTe_2$ and WTe_2 [7]. Importantly, $ZrSe_2$ and $HfSe_2$ have native high-K dielectrics ZrO_2 and HfO_2, which are of key technological relevance [8]. Improving the electrical contact resistance [9], we demonstrated 10 nm transistors using monolayer MoS_2, 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 MoS_2 and SiO_2, 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

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Figures

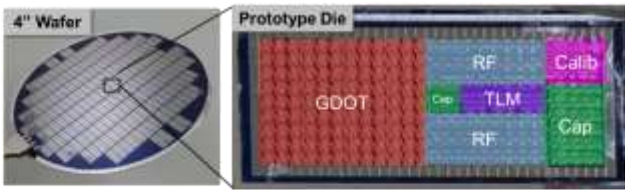

Figure 1: Wafer-scale graphene dot product [5].

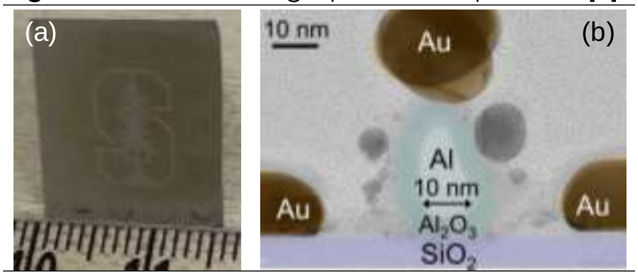

Figure 2: Cm-scale monolayer MoS_2 growth [6] and 10-nm scale transistor [9].

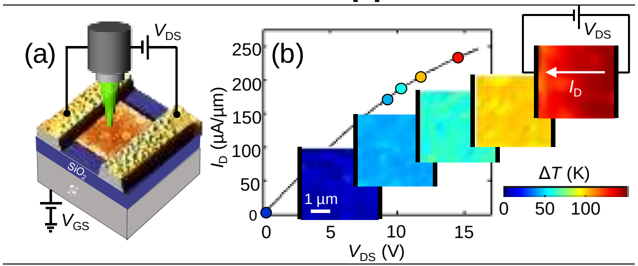

Figure 3: Raman thermometry of monolayer MoS_2 transistor during operation [11].