Gate Tunable MoS_2-based Thermoelectric Devices

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Two dimensional semiconductors and especially MoS_2 have gained a lot of attention due to their unique properties. Finite bandgap, large I_{on}/I_{off} ratio, good mobility, and nearly perfect subthreshold slope are among some of the features that make these materials attractive to researchers. While electrical transport has been studied extensively on single and multilayers of these Transition Metal Dichalcogenides (TMDs) [1,2], to the best of our knowledge, there has been no experimental study on their thermoelectric properties. Recently, it has been predicted that few layers of TMDs can provide extremely large power factor ($S^2\sigma$) and thus large ZT making them promising candidates as the future thermoelectric devices [3]. Here, for the first time, we explore gate-dependent thermoelectric properties of multilayer MoS_2. As one of the important figures of merit for thermoelectric devices, we also calculate power factor which can then be used to find ZT.

Multilayer MoS_2 flakes (~ 8 nm) were prepared through standard scotch-tape exfoliation and then transferred onto the highly doped silicon substrate with 300 nm SiO_2 layer on top (which can then be used as the back gate to tune the chemical potential inside the flake). E-beam lithography was then utilized to design the contact probes, heater, and also thermometers followed by deposition of Sc/Ni (30 nm/40 nm) as contacts (it has been previously demonstrated that Sc/Ni would provide ohmic contacts to MoS_2 [4]).

Fig. 1a shows room temperature transfer characteristic of the fabricated device where R_1 and R_2 are used as source and drain contacts, respectively. Output characteristic of the same device is depicted in Fig.1b where linear behavior for drain current versus drain voltage is observed confirming the presence of good ohmic contacts.

The sample was then transferred to a vacuum stage where a temperature gradient was created between R_1 and R_2 through AC heating of the heater and then the 2ω voltage signal was measured between R_1 and R_2 using SRS-830 lock-in amplifier. Temperature gradient across the flake as a function of heater current is plotted in Fig. 2a showing a nice quadratic behavior. Gate-tunable Seebeck coefficient alongside four-probe electrical conductivity of the device is demonstrated in Fig. 2b. Large thermopower is expected in these devices due to the presence of bandgap. As can be seen from Fig. 2b, maximum Seebeck coefficient of around -600 μV/K is observed in our experiment at back gate voltage of 5 V which is quite large compared to the conventional thermoelectric devices based on Bi_2Te_3. However, electrical conductivity of these devices is much smaller than their Bi_2Te_3's counterparts. Gate-dependent power factor of our device is plotted in Fig. 2c showing promising value of 10 $\mu Wcm^{-1}K^{-2}$. It should be mentioned that we have not observed a peak in our power factor versus back gate voltage. This implies that through stronger gating one could possibly observe even larger power factors. In order to have a better insight about the true potential of TMDs for thermoelectric applications, we are investigating thermal conductivity of these materials to have better estimate of their actual ZT values. Our results presented here provide first steps towards utilizing these newly discovered 2D semiconductors for thermoelectric applications.

References:

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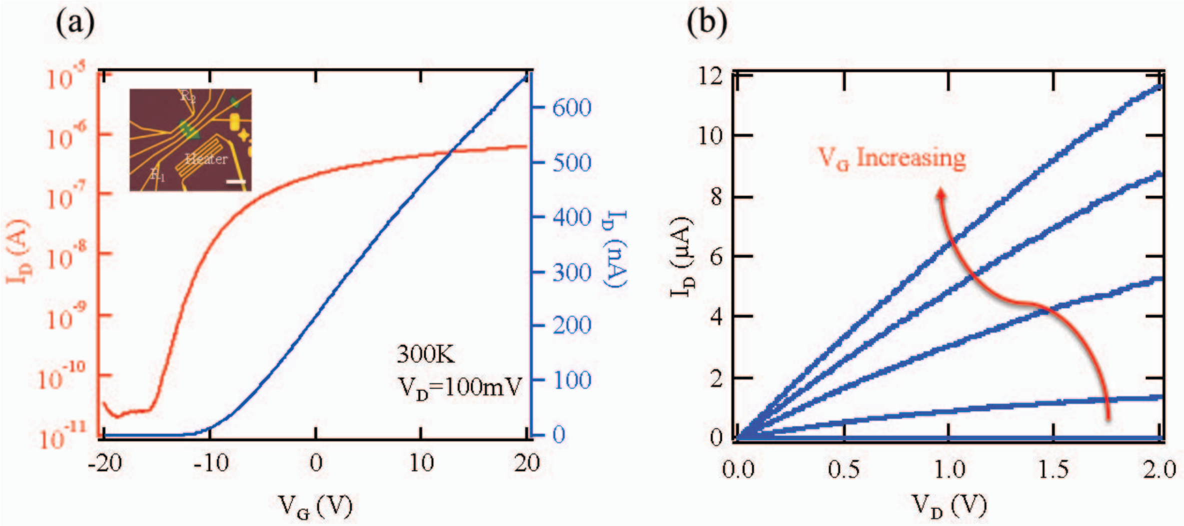

Fig. 1. (a) Drain current versus back gate voltage (transfer characteristic) showing the subthreshold and linear regions for 8 nm thick MoS_2 field effect device. R_1 and R_2 function as source and drain, respectively. Inset shows an optical image of the fabricated thermoelectric device based on MoS_2 with Sc/Ni contacts (scale bar is 10 μm). (b) Drain current versus drain voltage (output characteristic) of the same device for different gate voltages confirming the presence of ohmic contacts. Gate voltage is varying from -20 V to 20 V in steps of 10 V.

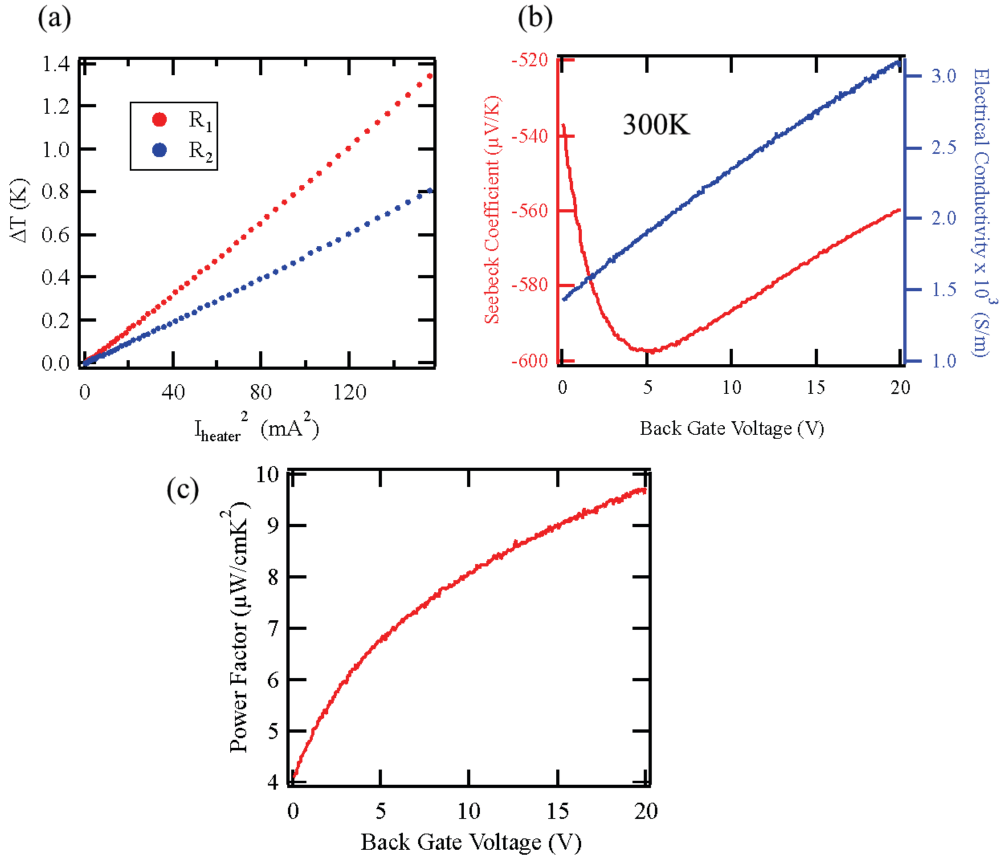

Fig. 2. (a) Temperature gradient across the channel measured through two thermometers (R_1 and R_2). In order to make sure that the Seebeck coefficient is accurate, R_1 and R_2 act as both thermometer and voltage probes for Seebeck measurement. (b) Gate-dependent Seebeck coefficient (left axis) and four-probe electrical conductivity of the same device (right axis). Seebceck coefficient shows a maximum of -600 μV/K at back gate voltage of 5 V while electrical conductivity shows rather a linear behavior versus applied back gate voltage. (c) Themoelectric power factor for the same device tuned by back gate voltage revealing a promising value of 10 $\mu Wcm^{-1}K^{-2}$. It can also be interpreted from the same figure that stronger gate might be needed to investigate the true potential of this device for thermoelectric applications.

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