# Field-Effect Transistors Based on Few-Layered $\alpha$–$MoTe_2$

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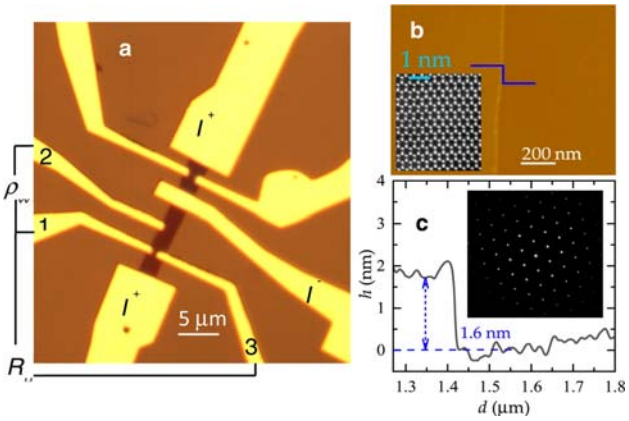
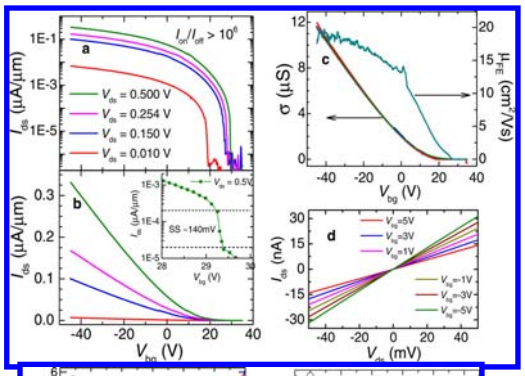
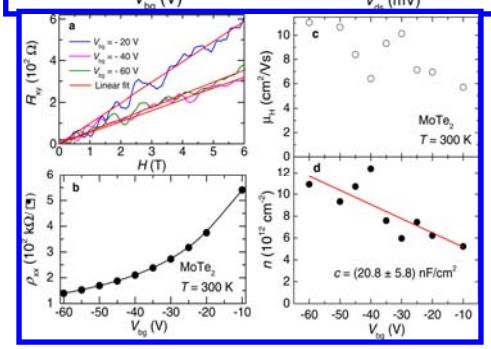
## Introduction

Several semiconductor transition metal dichalcogenides ($TMX_2$, TM=Mo, W, Re, Nb, etc and X=S, Se, Te) are layered materials comprised with van der Waals inter layer coupling and strong in-plane covalent bond, makes them easier to exfoliate to form two dimensional planner geometry. Their sizable and controllable layer dependent band gap makes them out perform graphene-based field-effect transistor (FET). $MoTe_2$ is one of the materials of band gap ranges from 0.7 to 1.2eV from bulk to single atomic layer form. Here we present the FET properties of vapor transport grown, few layers $\alpha$-$MoTe_2$, exfoliated onto $SiO_2$ substrate. Our $MoTe_2$ FET are observed to be hole-doped, displaying current ON/OFF ration surpassing $10^6$ and typical subthreshold swings 140 mV/decade. Both room temperature field-effect and Hall motilities indicates maximum values approaching 10 - 20cm$^2$/Vs, which are comparable to single or bi-layer $MoS_2$ FET at room temperature.




(**a**) Optical micrograph of one of our bilayer $MoTe_2$ FET in Hall measurement configuration. (**b**) AFM image of FET shown in fig. (**a**). Inset: TEM image showing the atomic resolution within a plane perpendicular to the interlayer direction. (**c**) Height of the flake shown on atomic force microscopy image indicates bi-layer flake. Inset: Electron diffraction pattern shows well-defined Bragg peak, thus confirming the high level of crystallinity in our $MoTe_2$.




**Right Top Panel**: (**a**) Drain to source current $I_{ds}$ (in log scale) as a function of gate voltage $V_{bg}$ for FET based on bi-layer $MoTe_2$ and for several values of drain-source excitation voltage $V_{ds}$. A sizable current observed for $V_{bg}$< 0V indicates $MoTe_2$ crystals are hole doped. The ON/OFF current ratio of FET is > $10^6$. (**b**) Linear scale data of (**a**) and inset shows the $I_{ds}$ vs $V_{ds}$ in a limited scale, indicating a subthreshold swing SS~140 mV/decade. (**c**) Left axis: conductivity $\sigma = SL/w$, where the conductance $S = I_{ds}/V_{ds}$ as a function of $V_{bg}$, $L$ = length and $w$ = width of the channel. Right axis: FET mobility $\mu_{FE} = (1/c)(d\sigma/d V_{bg})$ as a function of $V_{bg}$ , where $c = \varepsilon_o\varepsilon_r/d$ is the gate capacitance and $d$ is the thickness of $SiO_2$ layer. (**d**) $I_{ds}$ as a function of $V_{ds}$ for several gate voltage $V_{bg}$, shows the ohmic behavior of FET despite of their schottky barrier between the metal and semiconductor interface.

**Right Bottom Panel**: Hall resistance Rxy vs magnetic field H for bilayer $MoTe_2$ FET at room temperature. Extracted Hall resistance from the linear fit and estimated the charge carrier density from $R_H$=1/$ne$ shows in (**d**) as a function of $V_{bg}$. (**b**) Sheet resistance $\rho_{xx}$ as a function of $V_{bg}$ (**c**) Hall mobility $\mu_H = R_H/\rho_{xx}$ as a function of $V_{bg}$.

## Conclusions

Few-layered $MoTe_2$ FET shows p-type behavior with Hall and field-effect mobility ~10-20 cm$^2$/Vs. High ON/OFF current ration ($10^6$) at room temperature and the subthreshold swing 140mV/decade makes promising candidate for 2D transparent, flexible FET.

## Acknowledgements

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**References** [1] R. Pradhan, D. Rhodes, S. Feng, Y. Xin, S. Memaran, B. H. Moon, H. Terrones, M. Terrones and L. Balicas, ***ACS Nano*** 8, 5911-5920 (**2014**)