Applications of MoS_2 Transistors to Nonvolatile Memory

Shweta Modi,[1,2] Yamanaka Tomoki,[3] Nobuyuki Aoki,[3] and Jonathan Bird[4]

[1]*Department of Biomedical Engineering, Cornell University, Ithaca, NY, U.S.A.*
[2]*Nakatani RIES: Research & International Experiences for Students, Rice University, Houston, Texas, U.S.A.*
[3]*Graduate School of Advanced Integration Science, Chiba University, Inage-ku, Chiba, Japan*
[4]*Department of Electrical Engineering, University at Buffalo, The State University of New York, Buffalo, NY, U.S.A.*

Thermally-assisted memories are a growing area of study in nanotechnology, where heat is used to ease the switching between nonvolatile memory states [1]. Thermally-assisted switching provides high scalability, thermal stability, and low-power programming. Molybdenum disulfide (MoS_2), a transition metal dichalcogenide (TMDC), is a wide bandgap semiconductor with a direct band structure when isolated in monolayer form [2]. While previous studies have examined how the two-dimensional (2D) semiconductor MoS_2 displays a transfer curve with a pronounced hysteresis at high temperatures, there is little research which examines the temperature-dependent characteristics of MoS_2 field-effect transistors (MOSFET) [3]. Our interest is on data obtained at temperatures above 400 K, where our group has recently reported a novel form of hysteresis, behavior that has not been reported previously. The essential property that allows this memory behavior to be achieved is the hysteresis that appears in the transfer curve of the transistor when the temperature is increased [4]. At the highest temperatures studied (~500 K), the hysteresis exhibits a step-like change in drain current, induced when sweeping the gate voltage upwards from an initial negative value [4,5]. By using scanning probe microscopy, our study will explore the connection of this phenomenon to charge injection/release in the gate insulator, and will also investigate how the memory effect can be maintained by decreasing the temperature from 500 K to room temperature. The nonvolatile nature of this memory effect makes it potentially useful for memory technology.

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S. Modi,[1,2] M. Matsunaga,[3] A. Higuchi,[3] T. Yamanaka,[3] K. Kamiya,[3] N. Aoki,[3] and J.P. Bird[4]
[1]Department of Biomedical Engineering, Cornell University, Ithaca, NY, U.S.A.
[2]Nakatani RIES: Research & International Experiences for Students, Rice University, Houston, Texas, U.S.A.
[3]Graduate School of Advanced Integration Science, Chiba University, Inage-ku, Chiba, Japan
[4]Department of Electrical Engineering, University at Buffalo, The State University of New York, Buffalo, NY, U.S.A.

Introduction

- Thermally-assisted memories
  →Can provide high scalability, thermal stability, and low-power programming
- MoS_2: TMDC; wide bandgap semiconductor (monolayer: 1.8 eV, other forms: ~1.2-1.7 eV)

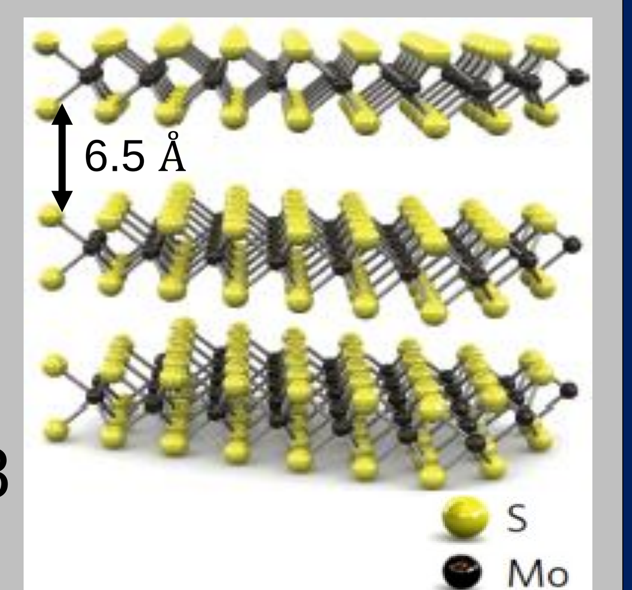
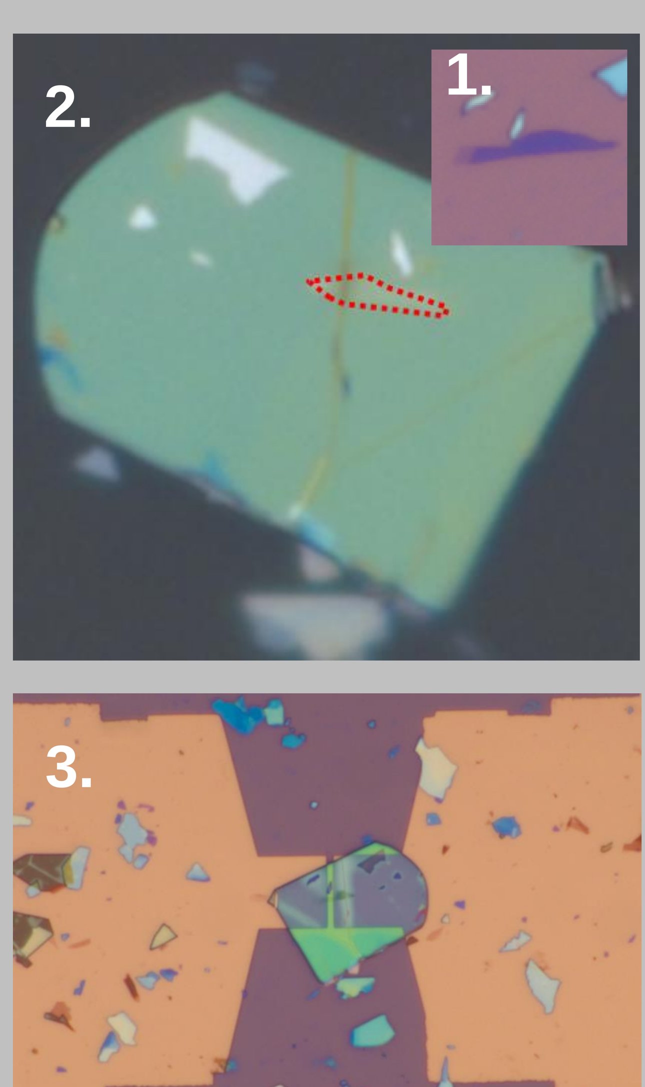


Fig. 1: MoS_2 crystal structure

Objectives

A. Measure the effects of time on an I_d-V_g transfer curve. Is the curve shifted or changed when there is a pause in time?
B. Study the effects of temperature on transfer curves, from room temperature to 500 K. Compare monolayer and multilayer MoS_2.

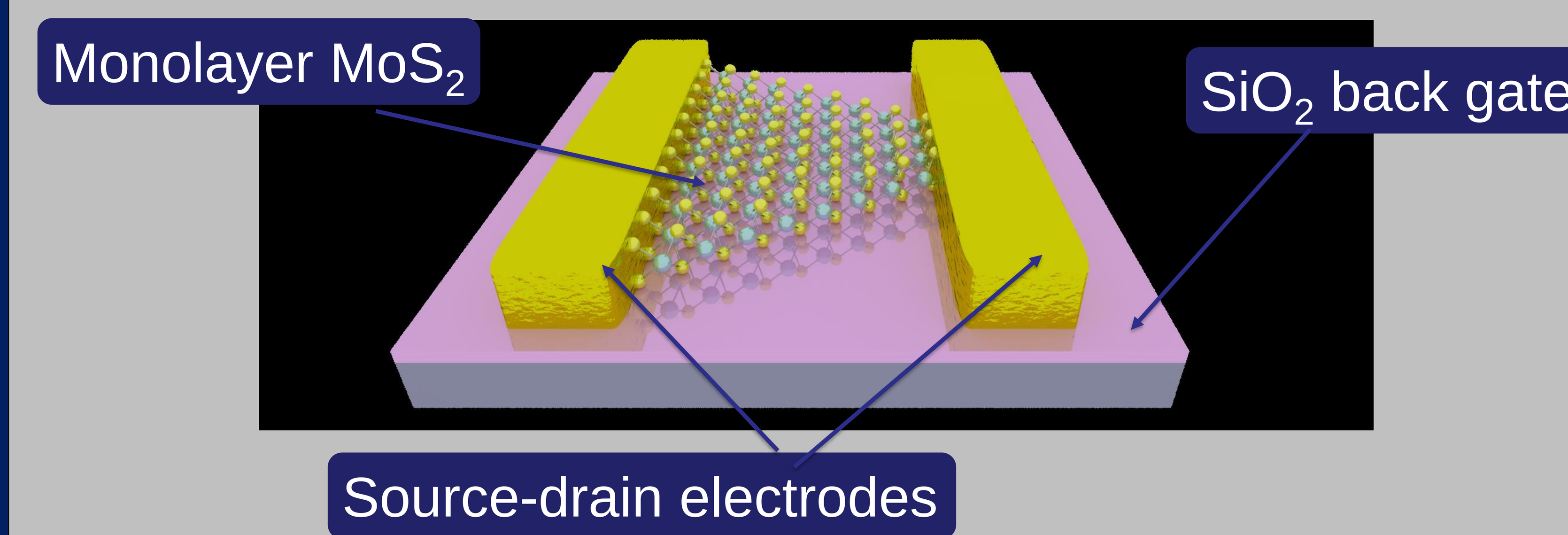
Methods



Sample-making Process

1. Monolayer MoS_2 (5 μm)
2. MoS_2 on h-BN on PPC
3. h-BN on MoS_2 on electrode

CVD Sample Structure



Results

A. Time-Dependence

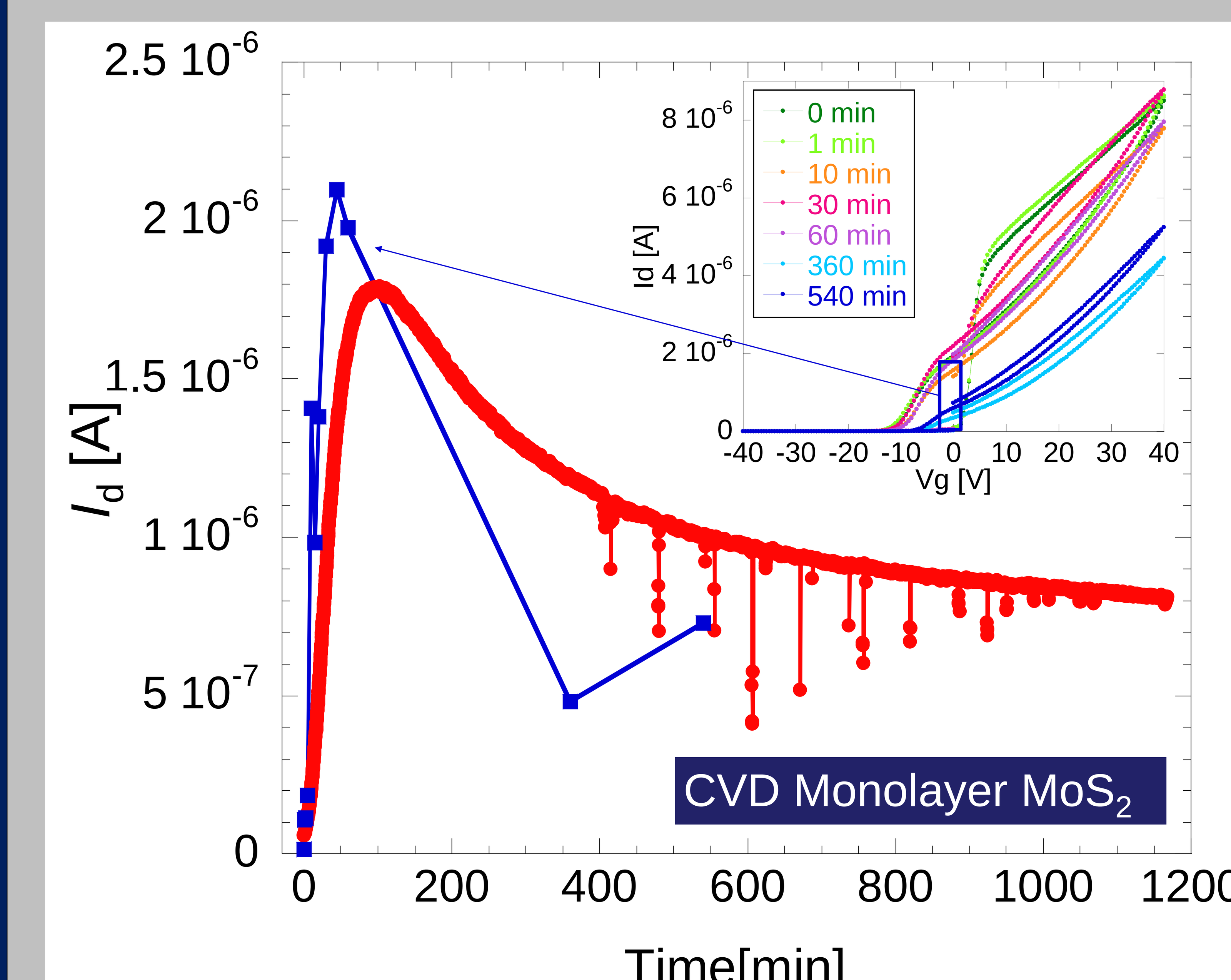


Fig. 2: Varied the waiting time after sweeping; V_g= 0V, V_{SD}= 1V. Red line: continuous time variation. Blue line: swept gate voltage after each time variation. Inset: Measured I_d-V_g at stop time from 0 min to 540 min.

B. Temperature-Dependence

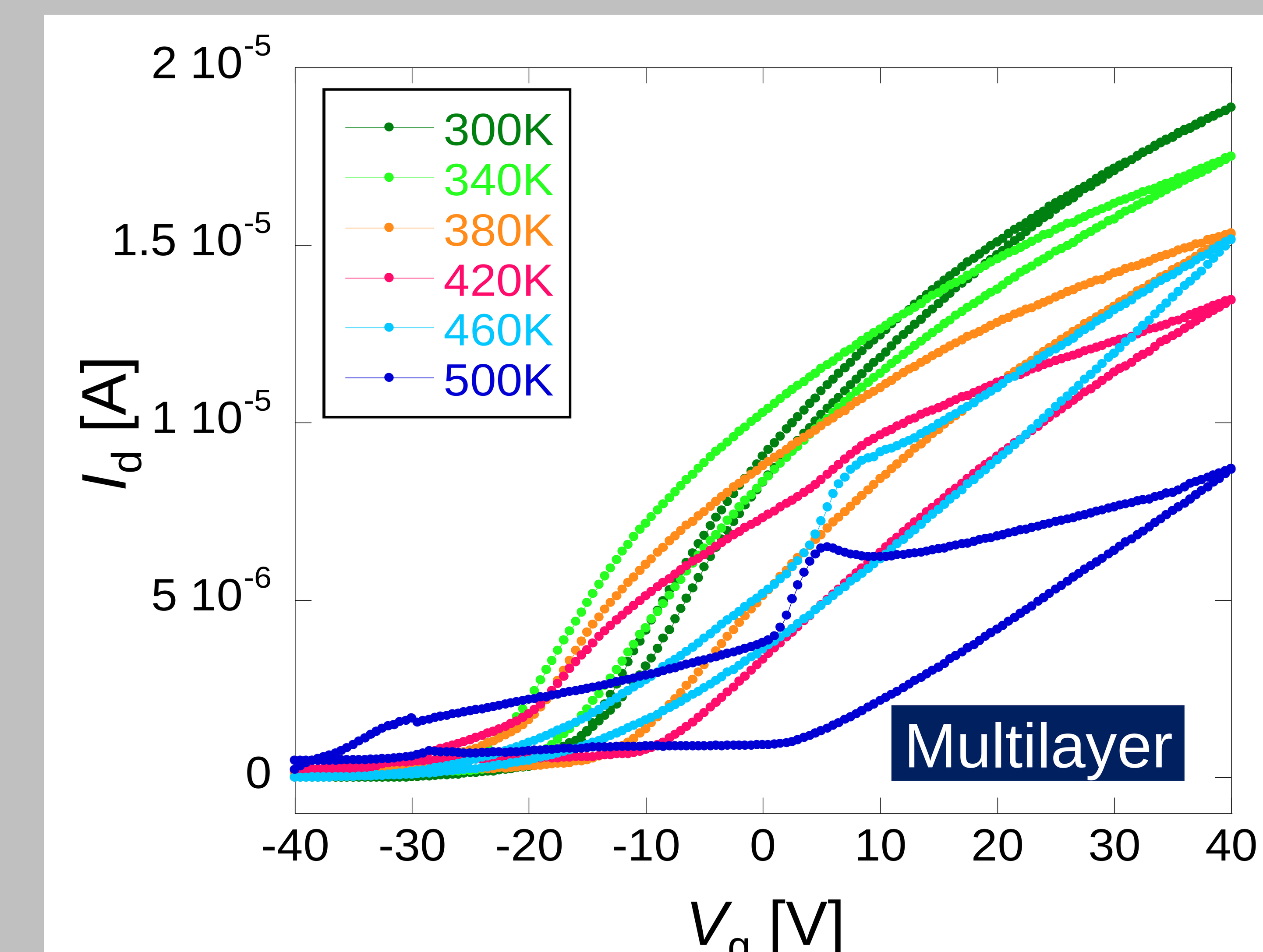


Fig. 3: Varied temperature from 500K to room temperature at V_d= 0.5 V.

Discussion

A. Increasing time between sweeps decreased I_d. Difference between red and blue line is due to pause in gate sweeping.
B. At the highest temperatures studied, hysteresis exhibited a step-like change in I_d. However, monolayer form exhibits more charge screening than multilayer.

Future Work

- Study the characteristics of trilayer MoS_2 FET compared to the monolayer version
- Create a top gate with monolayer MoS_2
- Study n-type characteristics of Cr/Au contacts to MoS_2 by using SGM

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Contact:
Shweta Modi
sm2258@cornell.edu