Study on 2D Material Based RRAM and Remote Sensing Applications

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SHINE — Summer High School Intensive in Next-Generation Engineering

Introduction

2D materials have recently been a hot research topic due to their unique properties, which makes them suitable for a variety of applications, from synaptic devices to resistive memory, solar panels, and pressure sensing. In Prof. Han Wang's lab, we are studying the properties and applications of 2D materials like graphene, tin selenide, and black phosphorus. Graphene is only one atomic layer thick and has high carrier mobility, making it a promising candidate for device contacts, flexible and foldable sensors and more. Thin layered tin selenide has also received increasing interest for research due to its properties. In our lab we have combined these materials together to try to achieve an electronic device that has outstanding performance compared to current devices.

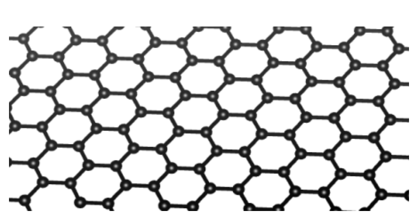

Fig 1.1 Crystal structure of monolayer graphene

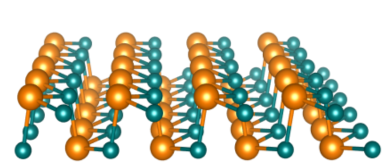

Fig 1.2 Crystal structure of SnSe (Tin selenide) layer

Research Motivations

- In recent years, electronic circuits based on von Neumann paradigm have reached their efficiency limits. Current memory cannot keep pace with the speed of processors. This is why neuromorphic devices that communicate with each other, have local memory, and distribute the computing load may be a promising solution. The graphene/SnSe device shows promising performance, as resistive memory switching which can be applied into synaptic device applications in future research.
- Accurate remote sensing is highly desired in areas such as remote surgery and remote explosives diffusion. Due to their properties, 2D materials are a great option.

2D RRAM Device Characterizations

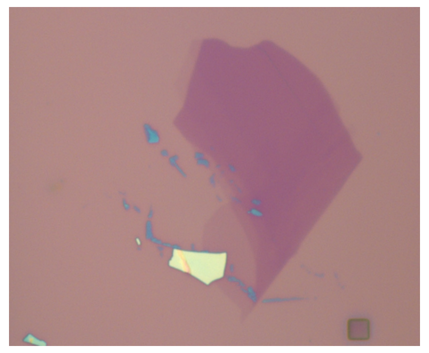

Fig 2.1 SnSe/graphene heterostructure

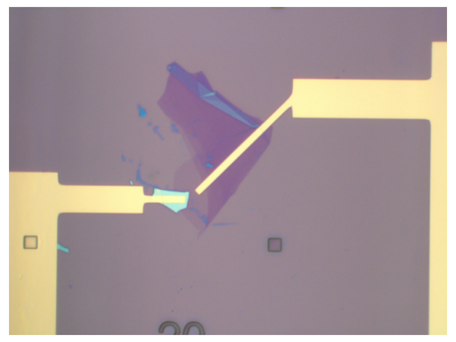

Fig 2.2 Contacts evaporated onto the device

Devices are shown in Fig. 2.1 and Fig.2.2. The size of the monolayer graphene is around 20 x 20 μm^2. The schematic of the device is shown in Fig. 2.3. The monolayer graphene connects to source contact. The 100nm layer of SnSe connects to drain contacts. The SiO_2 layer is 300nm thick.

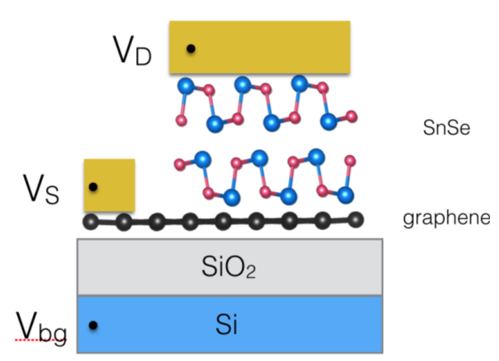

Fig 2.3

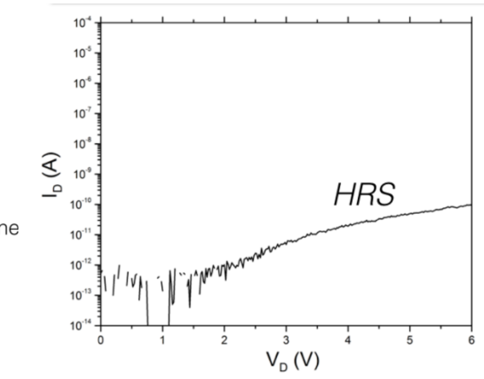

Fig 2.4

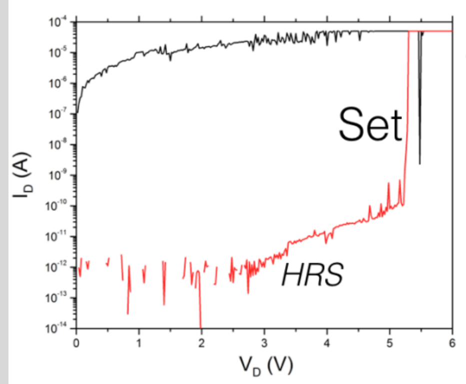

Fig 2.5

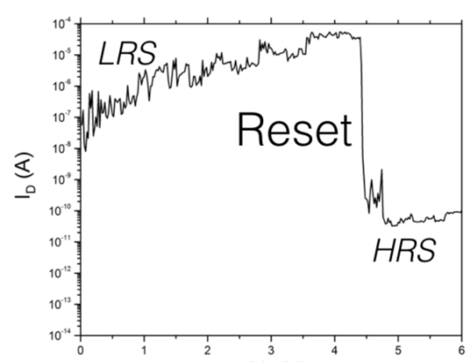

Fig 2.6

The device behaviors are shown in Fig. 2.4, 2.5 and 2.6. The device can be switched between HRS and LRS repeatedly. The on/off ratio is more than 5 orders of magnitude between HRS and LRS. This allows for the easy distinction between these two states. The off state current is around 10^{-14}A, which is key to high energy efficiency. During tests, the devices' state was changed over a 100 times and it is still working well. In the future, we plan to apply this into memory technology into synaptic device applications.

Building Robotic Hand for Remote Sensing Applications

Another potential use of graphene and other 2D materials is as a highly flexible, thin pressure sensor that could be used in robotic tasks such as remote surgery. I built and programmed a robotic hand using servo motors and a microcontroller. I programmed the microcontroller in both C and Maestro Scripting, the first of which ran on an attached computer and communicated commands directly through the wired connection, and the second, which ran locally on the device. The program allows the hand to close by rotating, while attached to string embedded in the hand. This creates tension in the string which forces the hand to close.

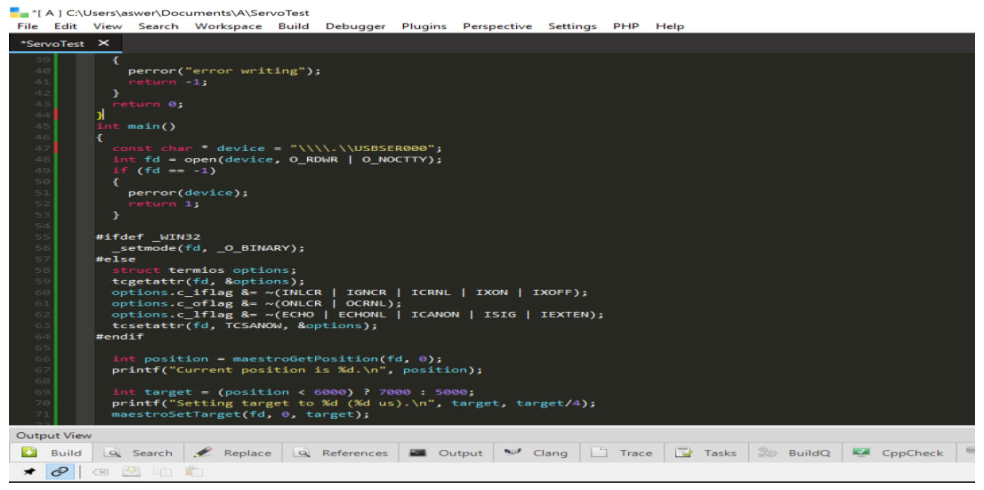

Fig 3.1 Code for a program that controls the servos, programmed in C

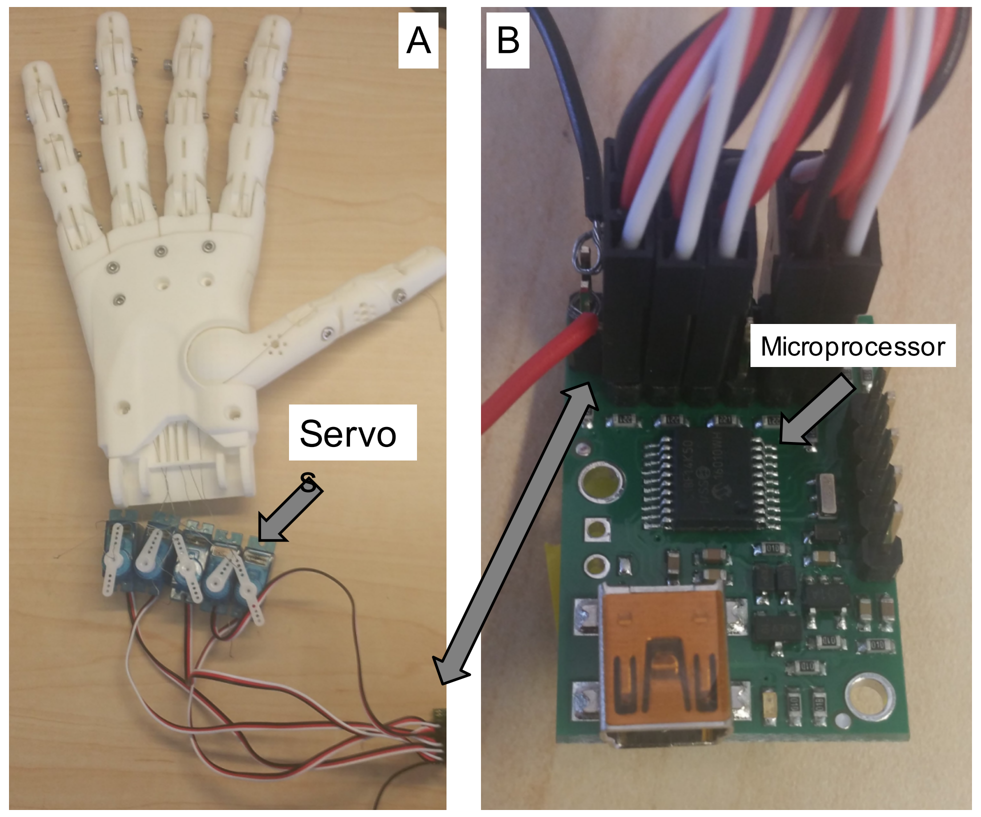

Fig 3.2A A robotic hand using servos, and a programmed microcontroller. Fig 3.2B Zoomed in servo microcontroller connected to servos, and battery.

How This Relates to my STEM Coursework

The SHINE program gave me a better understanding of using programming and electrical engineering principles in order to solve actual problems. Furthermore, I learned in detail how chemistry, physics and electrical engineering all intersect in the real world, such as in semiconductor research.

Skills Learned and Future Plans

This research has given me a more comprehensive understanding of the work that goes into college-level research and the scientific process used in research labs. SHINE has allowed me to explore one of the many areas of electrical engineering and gave me a better sense of its various fields. As a result, I plan to further explore these different areas and subsets of computer science. Furthermore, I plan to apply what I have learned in future research, and at my FIRST robotics team at my school.

Throughout the summer research process, I also learned:

- The programming language C
- Matlab
- HP BASIC (A specialized form of BASIC)

Acknowledgements

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