Beyond Moore's Law: Neuromorphic Computing

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USC Viterbi School of Engineering

SHINE Summer High School Intensive in Next-Generation Engineering

Introduction

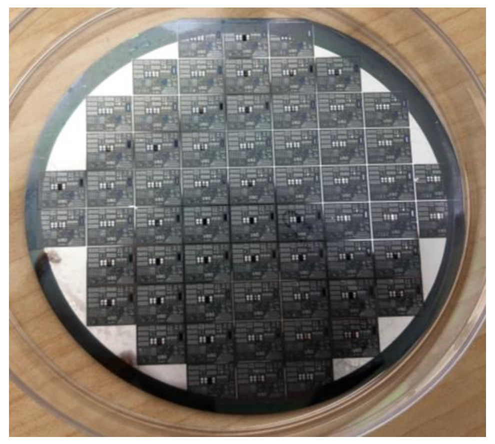

Figure 1: A dense lab-made sample of computer chips PC: Brian Chu

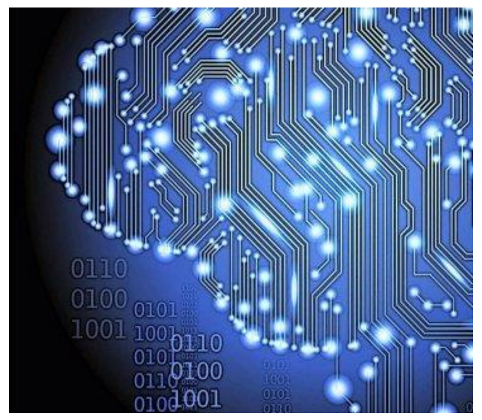

Figure 2: Neuromorphic computation-integrating neuroscience with EE <https://bit.ly/2JB4d7Y>

Today, computer chips possess billions of transistors, but the exponential growth in the number of transistors predicted by Moore's Law will eventually come to a end due to the physical size limits of their components. To solve this issue, Professor Wang's team and I are seeking new types of devices and materials to replace current silicon transistors. We are studying transistors based on emerging 2D materials and designing neuromorphic devices (memristors) that can emulate neuronal functions.

From Traditional Transistors to Memristors

Traditional Transistors

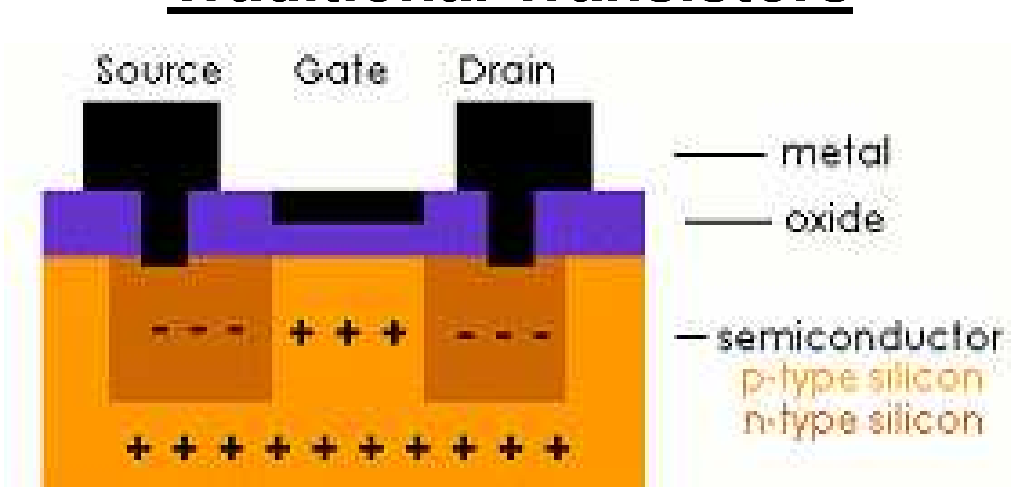

Figure 3: The structure of a traditional silicon transistor <https://bit.ly/2LudfWk>

A transistor is a silicon-based device that either amplifies an electric current or can be switched on/off, storing information in the form of 0's and 1's. It is primarily composed of an negatively charged source and drain that store electrons and a positively charged gate that accepts them. However, the electrons cannot flow from the source to the drain unless we apply a positive gate voltage to switch it on. Our objective in this lab is to replace the silicon with a more conductive and power-efficient material to simplify the fabrication process of transistors.

Graphene Transistors

Figure 5

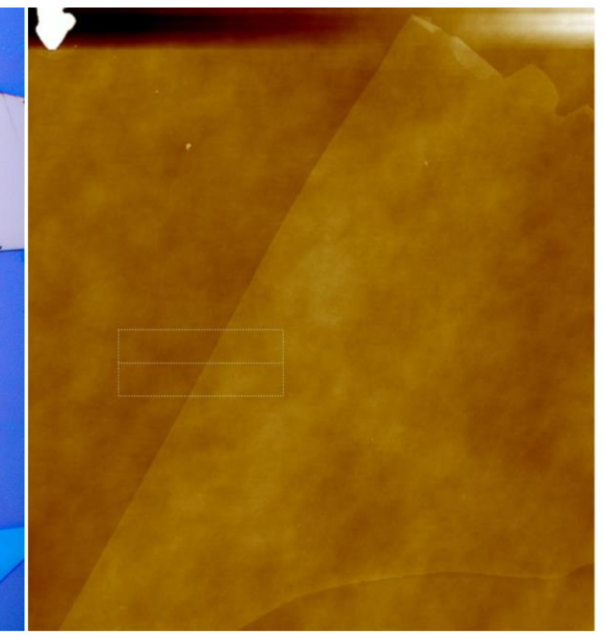

Figure 6

Figure 5: I discovered the graphene flake above using a Zeiss microscope and determined its length to be approximately 20 um.

Figure 6: I utilized an AFM machine to measure the thickness of this sample, which was about 3 nm (about 8 monolayers of graphene) PC: Brian Chu

Graphene is a 2D carbon allotrope that meets all of our requirements for transistor fabrication and performance. Most notably, it has high electron mobility, which allows transistors to be turned on/off in nanoseconds. This ability to quickly switch states could drastically increase the processing power of transistors, and because graphene-based transistors are much smaller than conventional ones, they also consume less electricity.

Memristor & Pulse Generator

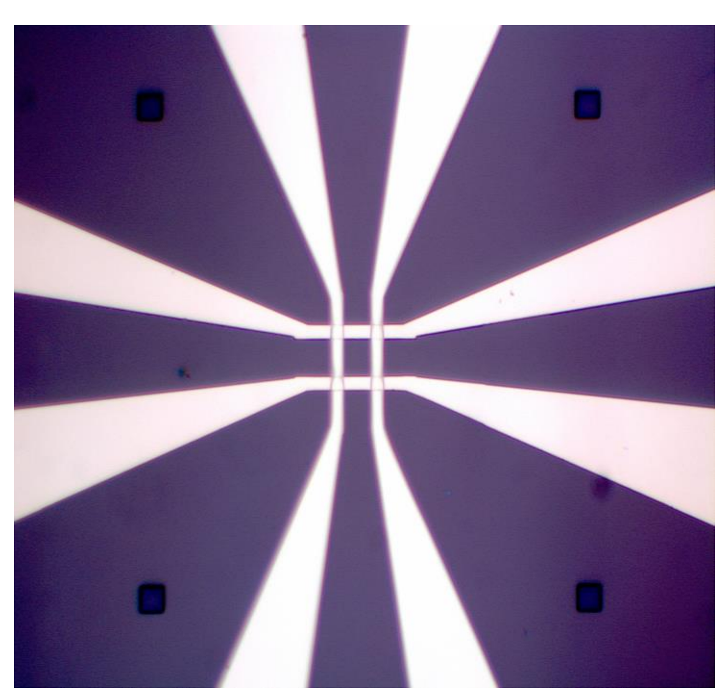

Figure 7: This is a picture of a 2x2 memristor crossbar taken under a microscope. Notice the 4 intersection points in the center: each crossbar is joined to a large metal electrode where a probe can be placed to apply a voltage across the crossbar. PC: Brian Chu

A memristor is another device capable of improving upon the performance of current transistors, for it performs calculations and memory storage simultaneously as compared to traditional devices. This ability is possible because a memristor can easily transition from a high to low resistance state by the application of a certain voltage pulse, allowing the memristor to output data as 0's and 1's. The more memristors in a crossbar, the more information can be processed and stored with less power consumption.

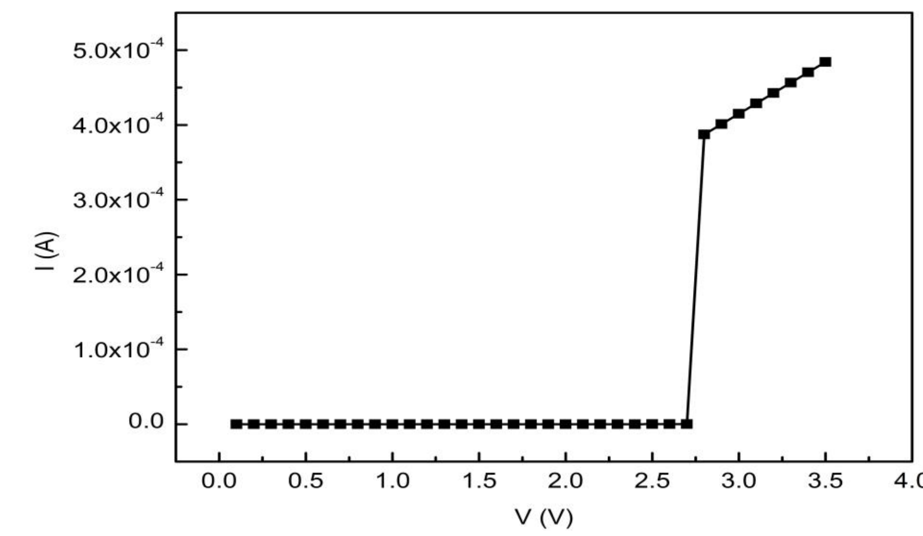

Figure 8: An IV curve plotting voltage inputs against current outputs for the memristor; to calculate the resistance, we take the reciprocal of the slope, or V/I. The flat line from 0-2.75V represents a state of high resistance; once the voltage reaches the threshold of 2.75V, the memristor switches to a low resistance state and turns on. PC: Hefei Liu

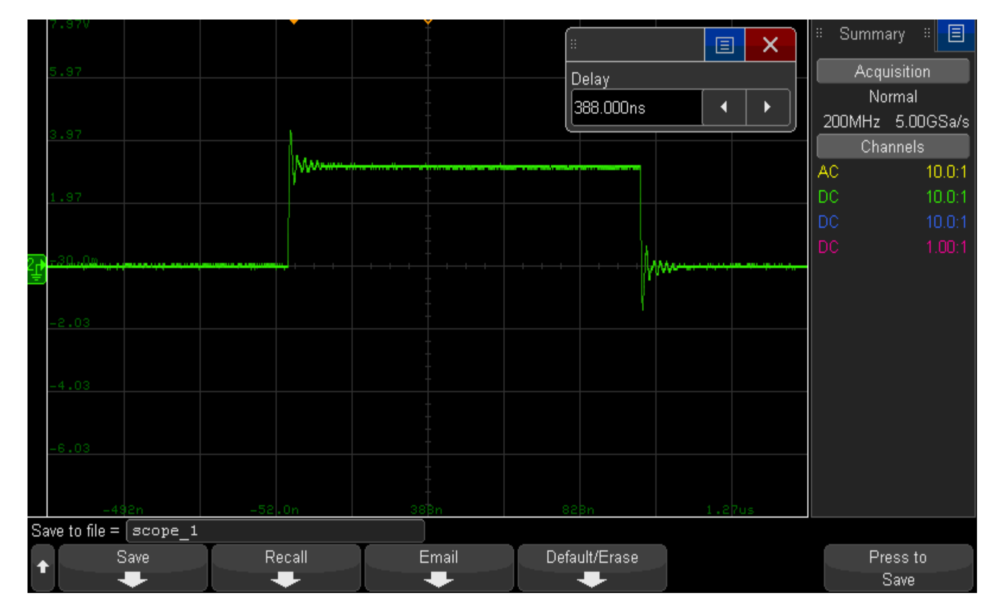

Figure 9: A pulse that I generated using a Quartus II FPGA program that can control the memristor's state by applying/stopping the voltage input at specific intervals. The program is crucial as it prevents the memristor voltage from becoming too strong and causing the device to stop functioning. PC: Brian Chu

Skills Learned

- Fabrication process for transistors
- Finding and measuring graphene flakes
- Using a probe station to test the current of a finished transistor
- Designing a Quartus II FPGA program
- MATLAB and AutoCAD programs
- Simple circuitry and Ohm's Law

Figure 10: The USC and EE Department logos etched onto a lab-made computer chip. PC: Brian Chu

Next Steps & Advice for Future SHINE Students

From my SHINE experience, I have obtained a vast pool of knowledge in not only EE, but also in neuroscience and chemistry. In addition, the background I have gained in circuitry and Ohm's Law will definitely aid me in my school's Honors Physics class. I hope to bring some the skills I have obtained, such as using AutoCAD, back to my school's robotics team and to hopefully inspire others to explore the fields of EE and CS. Because of SHINE, I have gained a greater appreciation of the electrical engineering and neuroscience fields, and I hope to pursue either one in higher education.

Tips for future SHINE students:

1. Be patient with your studies, as an understanding of anything complex requires lots of time and diligence to grasp.
2. Reach out for help whenever you can! Everybody here is extremely supportive and will help you achieve the most of your SHINE experience.
3. Keep a weekly journal of any lectures and thoughts regarding your experience here!

Acknowledgements

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