InP Synaptic Device for Neuromorphic Computing

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Introduction

The brain is arguably the most powerful organ in our bodies. Everyday, researchers and scientists come closer and closer to replicating it. They work to approach this goal by analyzing neural networks and how to make them more efficient. With Professor Kapadia and my PhD Mentor Jun Tao, I used something called Cross_Sim simulator to evaluate the performance of Indium Phosphide Field Effect Transistors (FETs), which can mimic synaptic behaviors. We chose to use this compound due to its sheer mobility and high energy efficiency. Through the process, we received sample data, and after running the data, we plotted accurate graphs on a software called Igor. We have been observing the pattern recognition accuracy and its trends to analyze the performance trend for different FET synaptic devices.

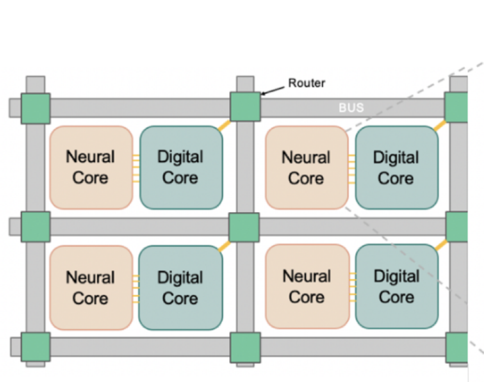

Fig 1. Neural Architecture

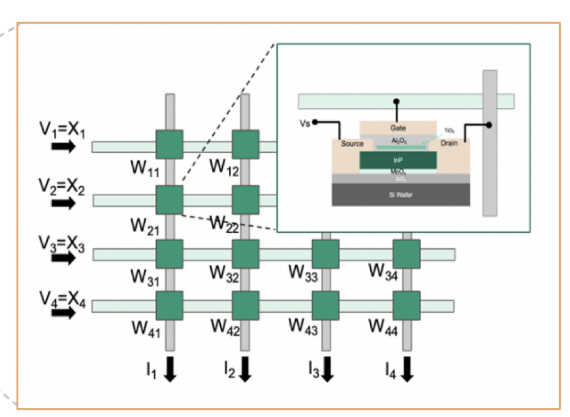

Fig 2. Close-up of the Crossbar

What I Learned Through This Research

Our research was centered around crossbar simulators and data models of accuracy. With this, our plan was to find a way to use software to make data plotting much more efficient. To make myself more familiar with this research, I began to use published research journals, including Nature, Nature Materials, and ACS Nano as references. Throughout the experiment, I observed how essentially, this is constituted of a trial-and-error mentality. As we know it, there are billions of equations in existence, and some are more efficient than the others. Although it is quite impossible for all of these equations to be tested, I learned that some of the equations, like the exponent and logarithm functions, work much swifter than others, like multiplication and roots. With these equations, I could see how there are variodata trends in the data graphs. Besides this, the research also taught me how patient we must be while running data!

Models/FET performance simulated by Cross Sim

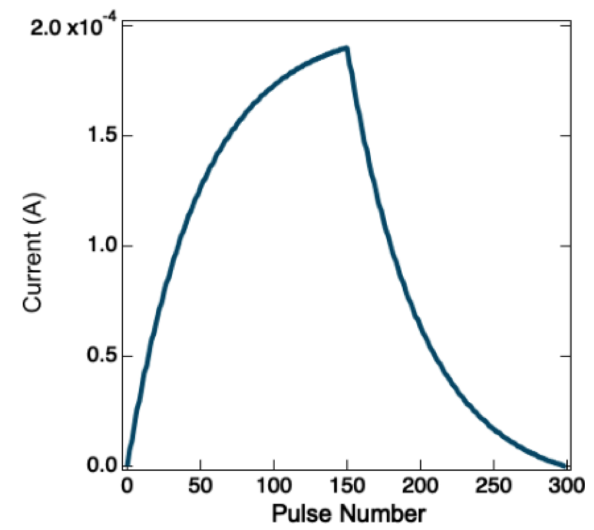

Fig 3. Typical stochastic performance of FET under gate voltage pulses

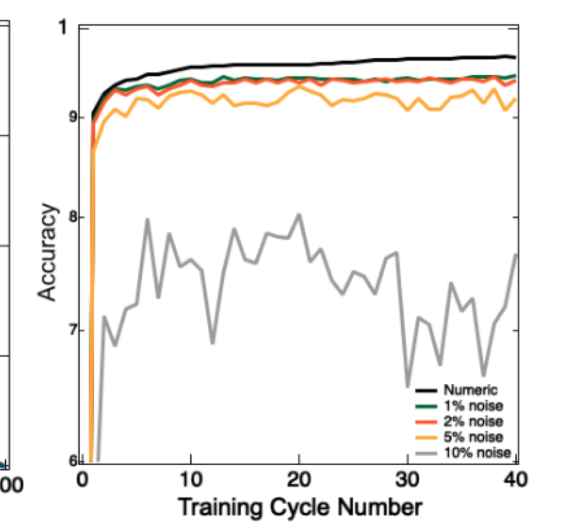

Fig 4. Small image recognition accuracy for different noise level input

Figure 3: This is a zoomed in version of the graph created by MATLAB software. While the left side represents the "set", the right side represents "reset". There are multiple rounds of these, forming a detailed model. This graph specifically was processed from the exponential function.

Figure 4: This graph was modeled through Cross-Sim, and represents the different accuracy levels at different noise levels. As the noise level for the set and reset graphs increases, the accuracy decreases.

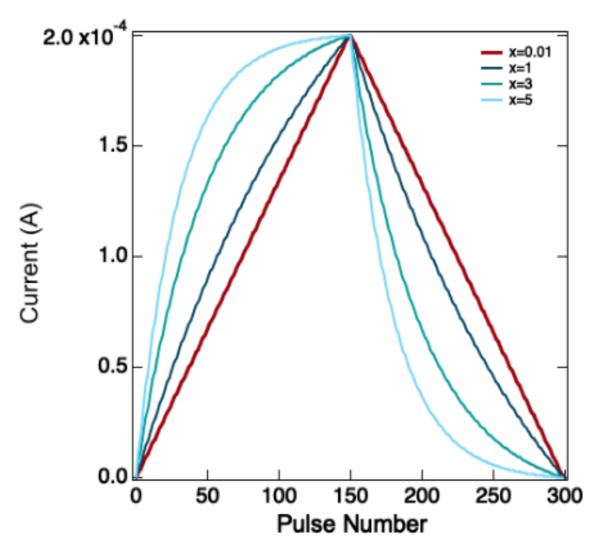

Fig 5. Typical stochastic performance of FET simulated by **exp((x-b)/a) * c**

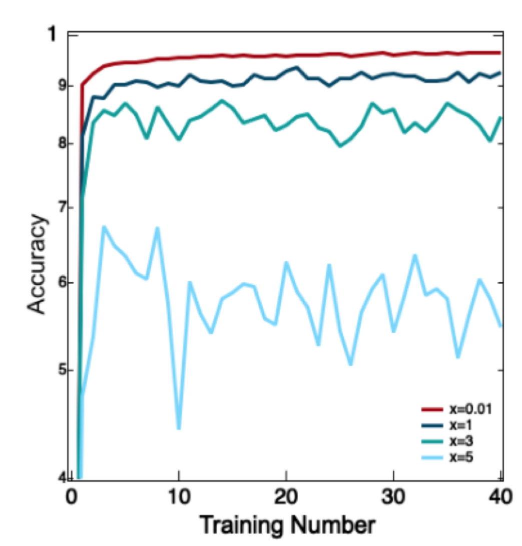

Fig 6. Small image recognition accuracy for different linearity input

Figure 5: Just like the model in Figure 3, this shows how the graph decreases linearity as ***a*** is increased. The red curve has the highest linearity, while the sky blue curve has the highest ***a***, but the lowest linearity.

Figure 6: This model is very similar to Figure 4. This is because the same function was used in both graphs (the exponential function), but there were different parameters. Once again, it is proved that the higher the ***a***, the lower the linearity, which leads to lower accuracy.

While Figure 5 is the input curve, Figure 6 shows the output accuracy. As displayed, higher linearity leads to higher accuracy.

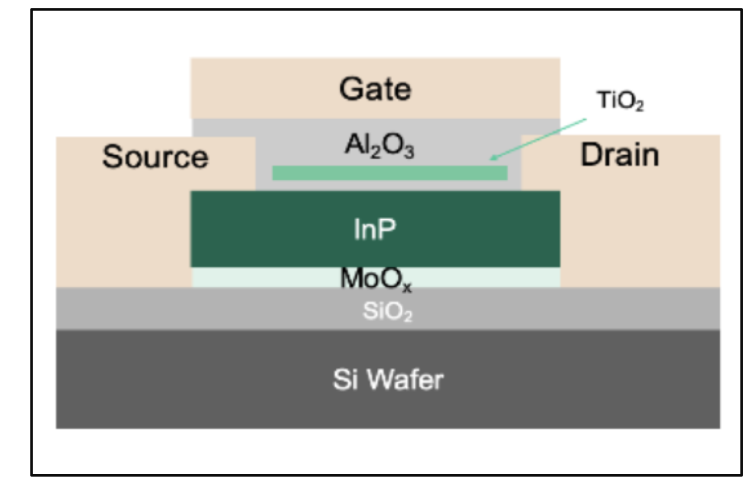

Fig 7. Schematic of InP synaptic device

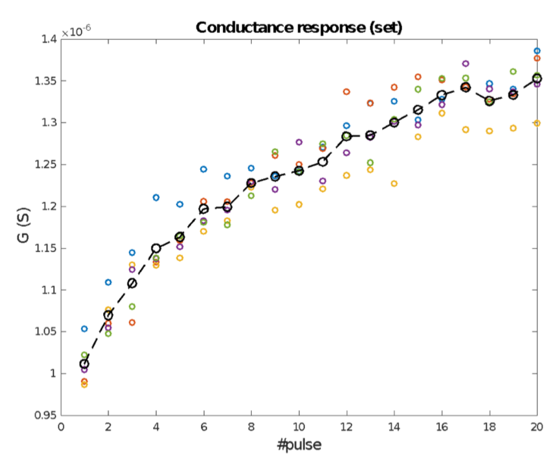

Fig 8. Channel Conductance under -8V gate pulse for Set

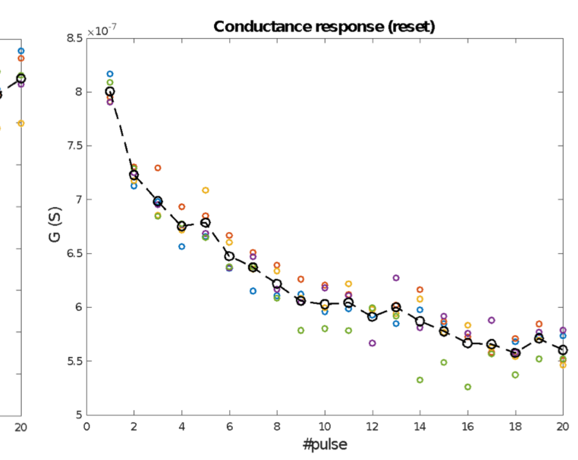

Fig 9. Channel Conductance under 7.5V gate pulse for Reset

In Figure 7, the components of a field effect transistor are shown. The drain, source, and gate are the three terminals that are present in all FETs. The gate voltage changes the conductivity of channel by modulating the electric field, which then allows the gate to have control of the current between the source and the drain. These are all shown in the picture above. Also, there is a faint green layer that is present. This is Titanium Oxide, and it acts as a floating gate, as it traps electrons. There is a maximum capacity of electrons that TiO_2 can hold.

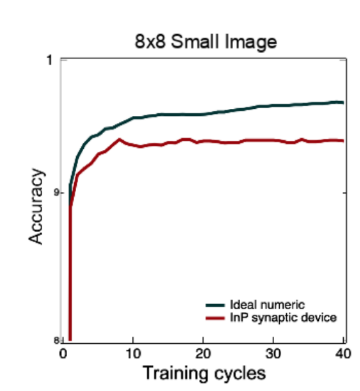

Fig 10. Small image accuracy

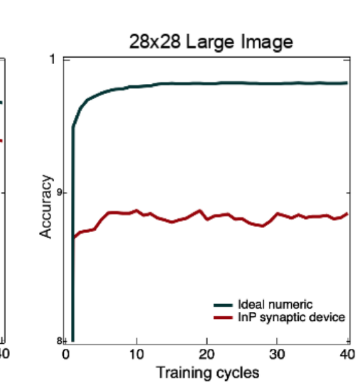

Fig 11. Large image accuracy

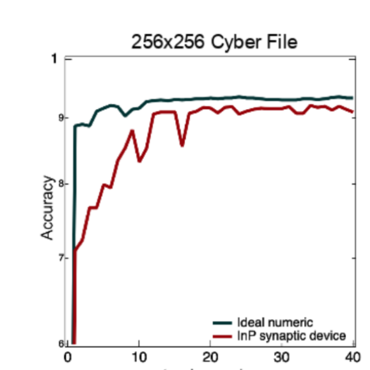

Fig 12. Cyber file accuracy

These three graphs show the curve trend of the accuracy of Indium Phosphide FETs. There are three different graphs for three different categories: small image, large image, and cyber file. As displayed, the three different categories have different performances. While the small image and the cyber file have similar performance, it is noticeable that the large image does not have great performance. To achieve better accuracy for the large image, it would be best to have a device with a lower noise level, and higher linearity.

Figure 13 : Probing Station
PC: Abhinav Buddhavaram

Next Steps for You OR Advice for Future SHINE Students

Throughout my time at this program, I have thoroughly learned how to utilize different computer software programs for making accurate data models. I am sure that all of these skills will be extremely applicable and useful in my future job. Also, I have learned many new Physics concepts that will help me in my future STEM Courses in college.

Tips for Future SHINE Students

1. Most of the research is quite captivating and pertinent, so make sure to always be attentive to what your PI/PhD Mentor is saying.
2. Make sure to network with the your peers, as this is a program from which many different and very intelligent high schoolers stem.
3. This is a very rare opportunity, so be sure to ask questions not only to your PhD Mentor and PI, but also to all of the people at SHINE.
4. Also, make sure to always stay in contact with your Professor, PhD Mentor, the SHINE officers, and all of the SHINE students!

Acknowledgements

I would like to acknowledge the help of Professor Rehan Kapadia and my PhD mentor, Jun Tao. I would also like to thank Dr. Katie Mills, Dr. Megan Herrold, and all of the other dedicated SHINE officers for organizing special meetings, allowing me to network with my peers!