Simulating an InP Synaptic Device for Fast Neuromorphic Computing

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Introduction

In the last few decades, computers have advanced considerably, and can now perform millions or even billions of simple mathematical operations every second. However, they aren't designed to recognize patterns, unlike the human brain. As a result, neural networks have been developed to allow computers to recognize patterns and categorize data. However, on conventional computers, neural networks are very slow and inefficient. As a result, researchers are looking to create computing devices that are faster and more efficient at processing neural networks. Professor Kapadia's lab is trying to create computing devices that mimic synaptic behavior, allowing them to quickly run neural networks. One of the projects in Professor Kapadia's lab is the development of Indium Phosphide transistors that have a tunable conductivity. The tunable conductivity allows the transistors to behave like the synapses in the brain, or the neurons in neural networks. By creating a device designed to behave like the synapses in our brains, Professor Kapadia's lab is hoping to make neural networks much more accessible.

Objective & Impact of Professor's Research

A powerful and efficient neuromorphic computing device would allow for neural networks to be used in many more applications. For example, a dedicated neuromorphic computing device on a smartphone could allow for extremely fast image recognition, or allow the smartphone to learn a user's behavior over time and use that to improve the user experience. They could also be used in larger applications to speed up the running and training of neural networks. A powerful neuromorphic computing device would not only make running neural networks faster, but also make them available to more devices.
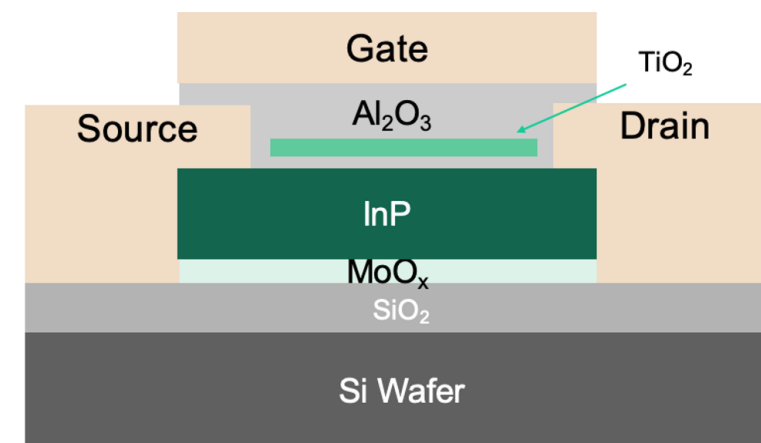
The InP Synaptic Device

Fig 1. Schematic of InP Synaptic Device. PC: Jun Tao

The InP Synaptic Device is essentially a transistor using an Indium Phosphide nanowire. Applying voltage pulses to the gate results in the trapping of electrons in the Al_2O_3 and TiO_2, changing the conductance of the InP.

Simulating with CrossSim

CrossSim is an open source simulator developed by Sandia National Laboratories to model Resistive Random Access Memory (RRAM) crossbars for neuromorphic computing. The InP Synaptic Device has an adjustable conductivity, so CrossSim can be applied to it. Below is a way the device could be used in a crossbar: the source is connected to ground, and the gate is used for programming conductance. The current flowing to the drain when a voltage is applied depends on the conductance.
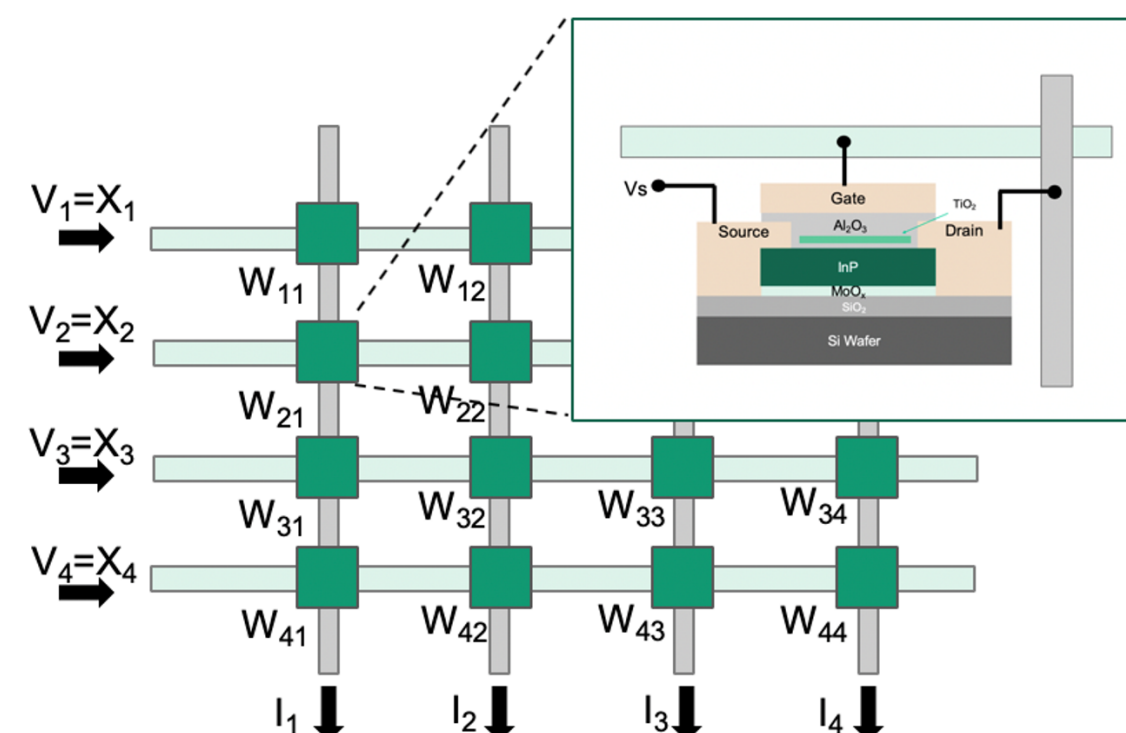

Fig 2. Basic structure of an InP Synaptic Device crossbar. PC: Jun Tao
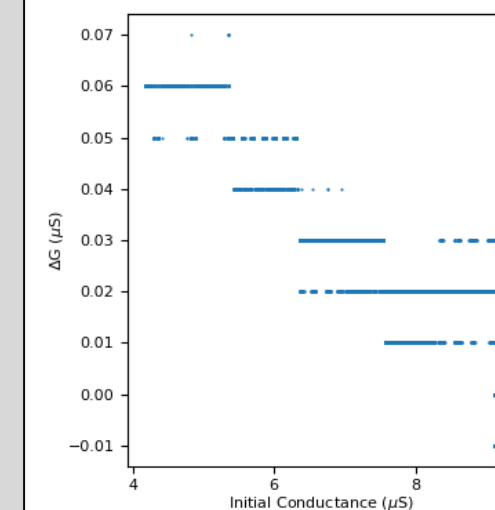
Generating a Lookup Table

Fig 3. Scatter plot of data points for how much a voltage pulse increases the conductance. PC: Tyler Weigand on CrossSim
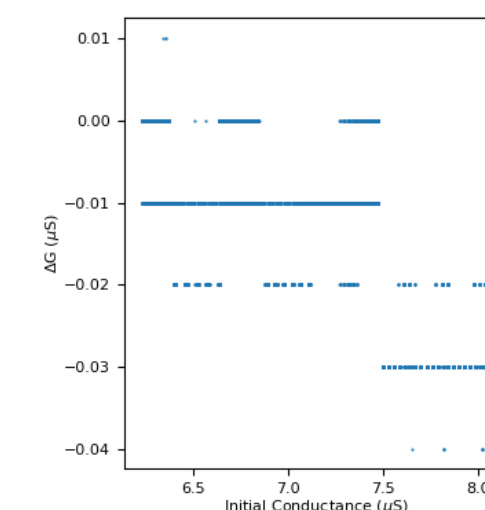
Fig 4. Scatter plot of data points for how much a voltage pulse decreases the conductance. PC: Tyler Weigand on CrossSim

The above scatter plots indicate measured data of how much voltage pulses changed the conductance. As can be seen, the amount by which the conductance changes varies, and so we need to simulate this variance. Using CrossSim, we can generate lookup tables from the data to tell us the probabilities for conductance change for a given conductance.
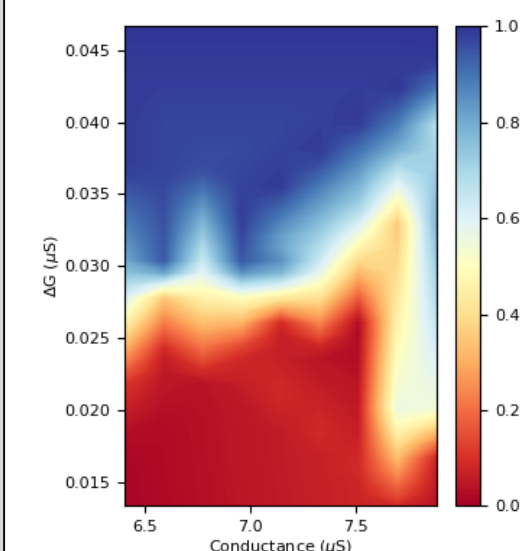

Fig 5. Cumulative Distribution Function of how much a voltage pulse increases the conductance. PC: Tyler Weigand on CrossSim
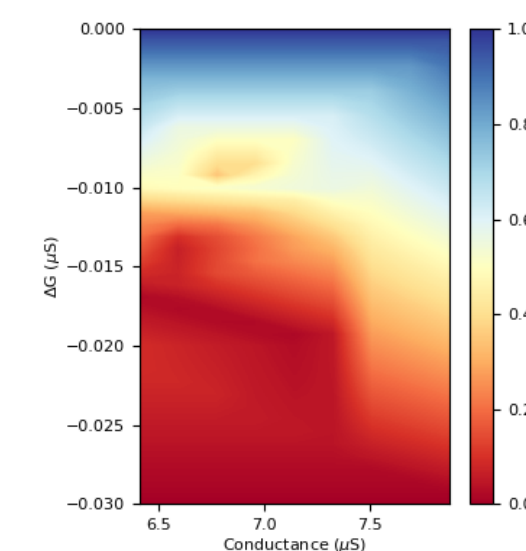
Fig 6. Cumulative Distribution Function of how much a voltage pulse decreases the conductance. PC: Tyler Weigand on CrossSim

Figures 5 and 6 demonstrate the properties of the InP transistor. The synaptic device's conductance responds differently to pulses depending on its conductance, and there is also noise involved. Because CrossSim allows us to simulate these properties, we can use it to determine how good an actual crossbar using InP Synaptic Devices would perform without building a physical device.
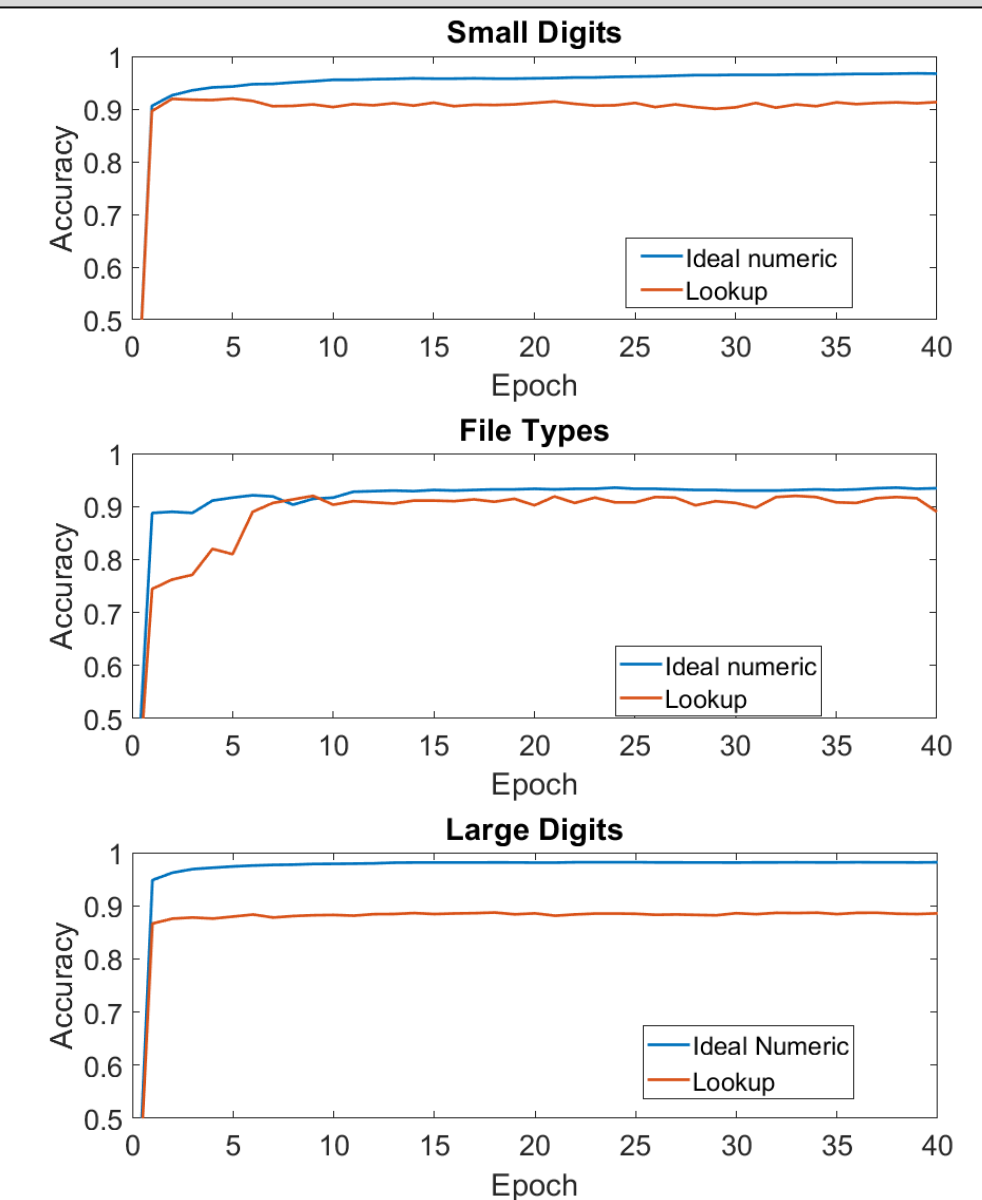
Results

Fig 7-9. Training performance comparisons of a crossbar using the simulated properties of the InP Synaptic Device compared to the performance of an ideal crossbar. PC: Tyler Weigand

From the data, we can see that the simulated InP Synaptic Device crossbar can reach relatively high accuracies after 40 epochs, but is not quite as good as an ideal crossbar, most likely due to variations in conductance programming. As a result, it could be suitable for applications that require a very fast neural network, but that don't need extremely high accuracy.

Acknowledgements