Master's Thesis Engineering Technology

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Feasibility of artificial synapses using thin film photovoltaic materials and architectures

Pieter Paulissen

Master of Electronics and ICT Engineering

Situation and problem

1

Currently, the von Neumann architecture is used to perform machine learning algorithms, shown in Figure 1. Using this architecture, good results are achieved, but due to the large amount of data transportation between the central processing unit (CPU) and memory unit, the **energy consumption is significantly high**. This is called the bottleneck of the von Neumann architecture.

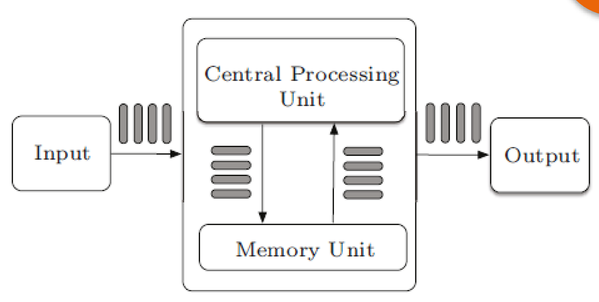


Figure 1: von Neumann architecture[1]

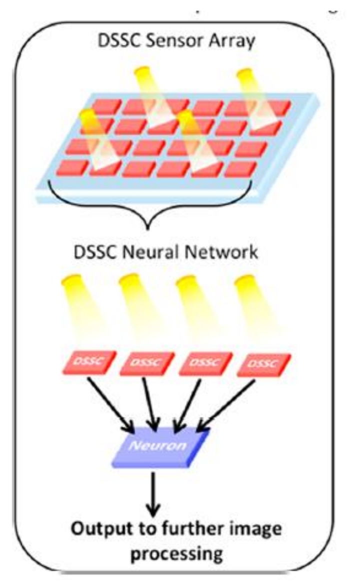


Figure 2: Artificial neural networks using solar cells[2]

One way to avoid the bottleneck of the von Neumann architecture is to create a new architecture. An **artificial neural network** with an inorganic thin film solar cell as the basic block is a possibility to create a new architecture. This master's thesis investigates the memory effect of an **inorganic thin film solar cell** as the basic block. **Optoelectronic artificial synapse** is a more valuable title for a basic block in an artificial neural network. The synaptic behavior is expected to occur in the i-ZnO.

Methods and materials

3

The setup to investigate the behavior of optoelectronic artificial synapses consists of:

- Keithley model 6430 source meter,
- G2V solar simulator,
- characterization tool,
- black box.

Figure 5: Keithley model 6430 source meter[3]

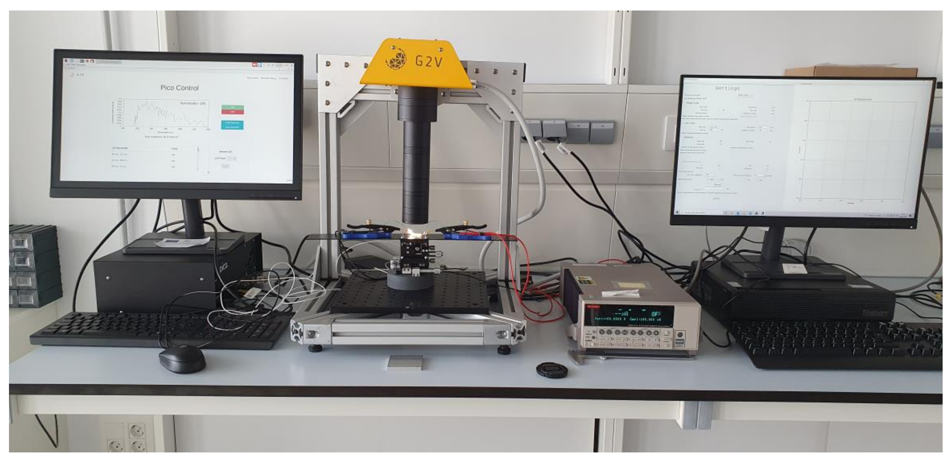


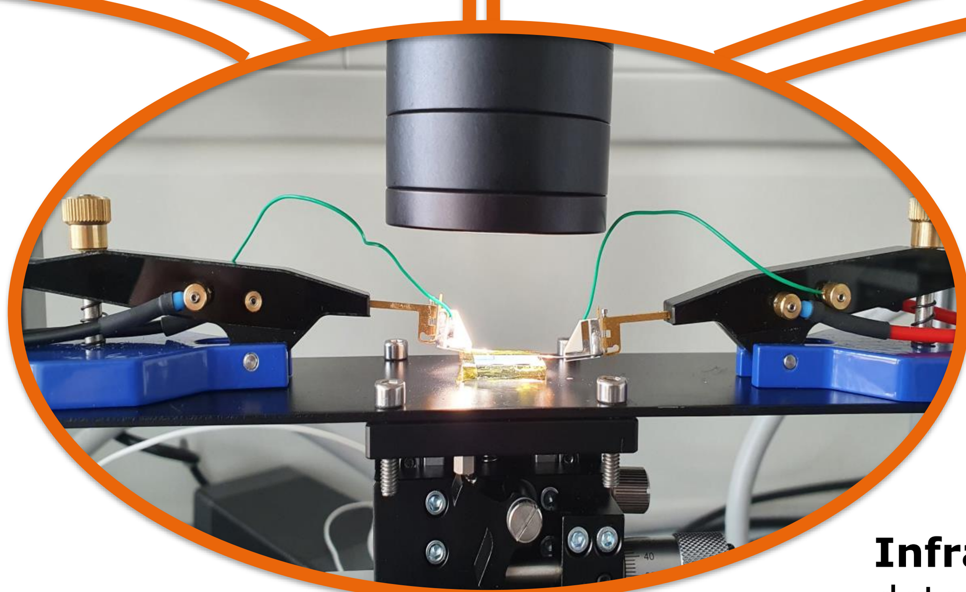
Figure 6: Test setup

The focus is **Long term plasticity (LTP)** and is studied by changing the following parameters:

- the wavelengths,
- the illumination time,
- the bias voltage.

The memory effect of two different inorganic thin film solar cells is being studied:

- copper indium gallium selenide solar cell (**CIGS**) with 0%, 5%, 10% or 15% oxygen content in the i-ZnO,
- copper zinc tin sulfide solar cell (**CZTS**) with 5% oxygen content in the i-ZnO.



Characterization tool

2

To investigate the memory effect of an optoelectronic artificial synapse, it is essential to have a **fast and time-dependent analysis tool**. Because the available analysis tools in the lab did not fulfill these requirements, a new tool had to be created. Figure 3 shows the graphic interface of the analysis tool.

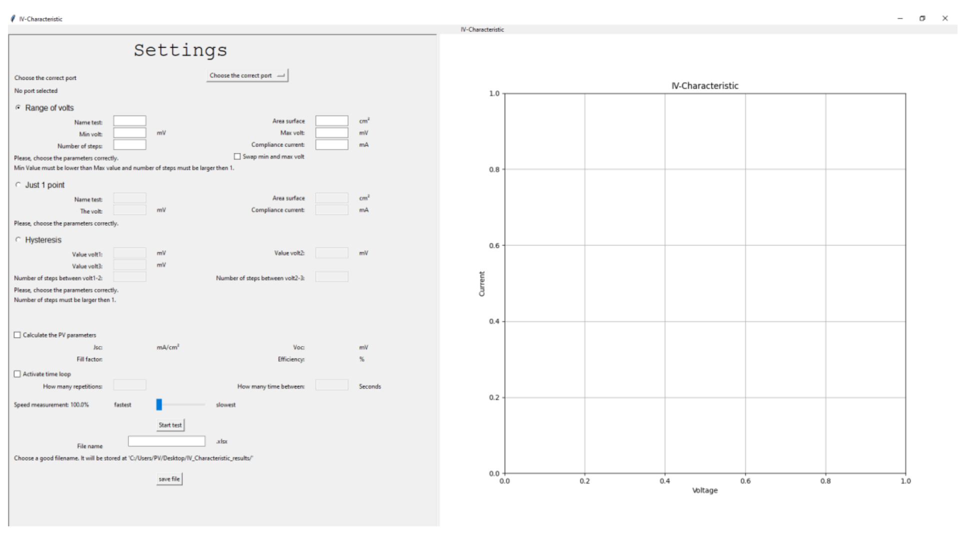


Figure 3: New analysis tool written in python

This analysis tool can measure three different activities:

- an IV-curve,
- the current at a specific voltage,
- a hysteresis.

When measuring an IV-curve, some extra options are possible:

- changing the speed of the measurement;
- calculating the pv-parameters (Short circuit current, open circuit voltage, fillfactor and efficiency);
- creating a time loop to repeat the measurements,

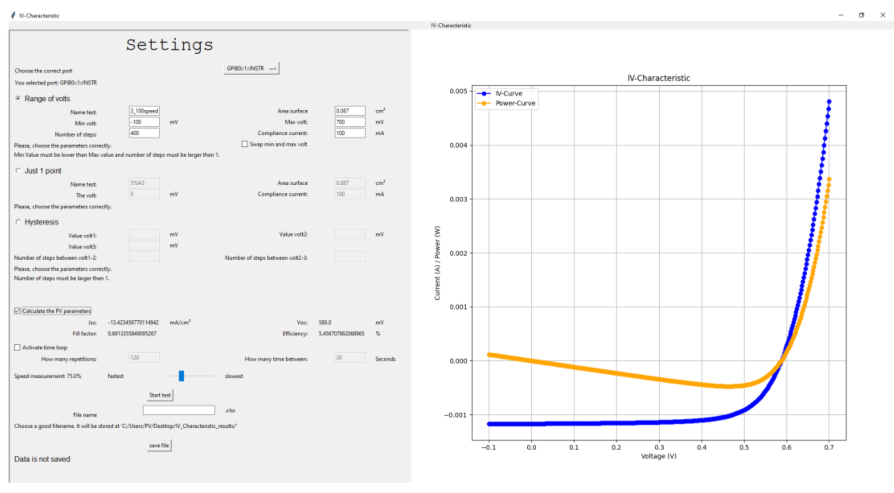


Figure 4: IV-curve (blue) and power curve (yellow) and the results of the pv-parameter

Activating a **time loop** is the only extra option for measuring at a specific voltage, but it is by far the **most important** option to investigate the behavior of an optoelectronic artificial synapse.

Results and conclusions

4

The illumination time has a significant influence at the discharge time as shown in Figure 7.

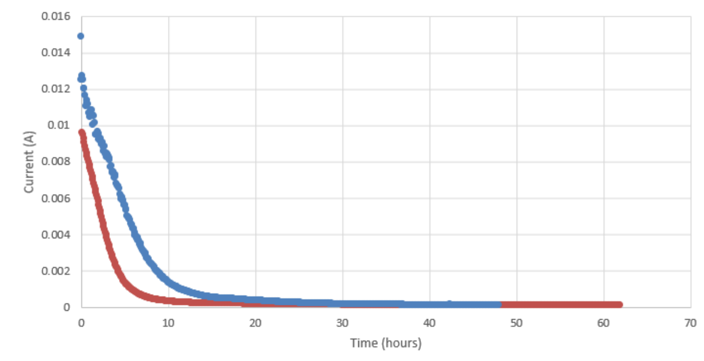


Figure 7: (Red) empty process at 700 mV after 15 minutes of light illumination – (Blue) empty process at 700 mV after 90 minutes of light illumination

Infrared light (1403 nm – 1556 nm) can be used to detect if a cell is charged or discharged and to fasten the discharged process (synaptic depression).

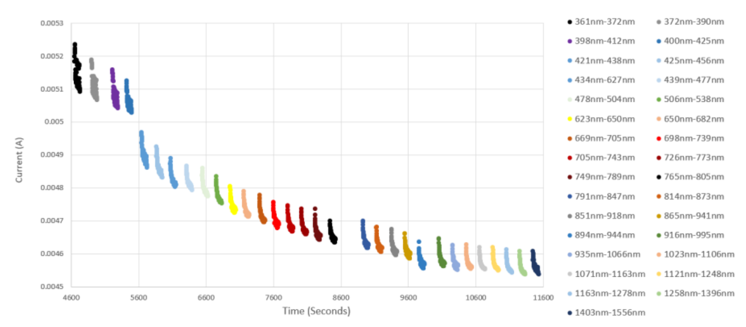


Figure 8: The effect of different wavelengths on a charge device at 700 mV

Figure 8 shows the effect of all the different wavelengths on a charged device at a **bias voltage of 700 mV**. A limited number of wavelengths have the same effect as an **RC-circuit** by turning the light on and off. Only these wavelengths are useable in creating an analog memory.

Figure 9 (up) shows a RC circuit integrator and the output behavior . The behavior at wavelengths 400 nm – 425 nm at CIGS 5%-O cell, as can been seen in Figure 9 (down),corresponds to the behavior at the output of the RC integrator.

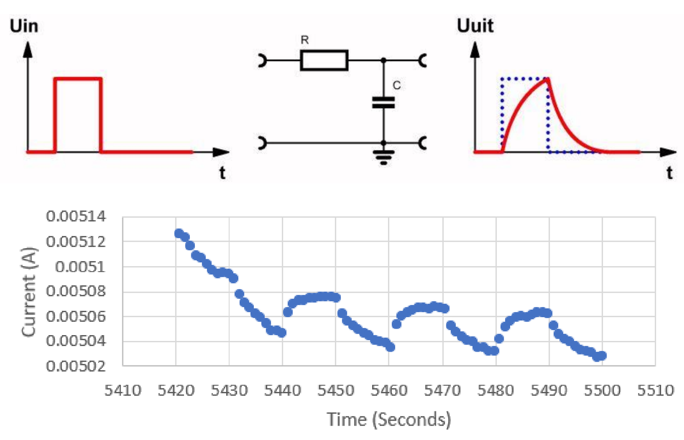


Figure 9: (Up) RC circuit integrator[4] (Down) The effect of wavelengths 400 nm – 425 nm at 700 mV at the CIGS 5%-O cell

CIGS 0%-O, 5%-O and 10%-O cells show memory effect at different wavelengths, under light illumination and in the dark. The exact phenomena and metastabilities involved in the synaptic plasticity are the next step to investigate and understand better.

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[1] Y.-G. Bao and S. Wang, 'Labeled von Neumann Architecture for Software-Defined Cloud', J.Comput. Sci. Technol., vol. 32, no. 2, pp.219–223, Mar. 2017, doi: 10.1007/s11390-017-1716-0.
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[4] 'Elektronica-hobby blog van Jos Verstraten (525 artikelen): Theorie-13: RC-kringen', Elektronica-hobby blog van Jos Verstraten (525 artikelen). https://verstraten-elektronica.blogspot.com/p/rc-kringen.html (accessed May 17, 2022).

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