

In-sensor computing thermometer using analog memristor crossbar array

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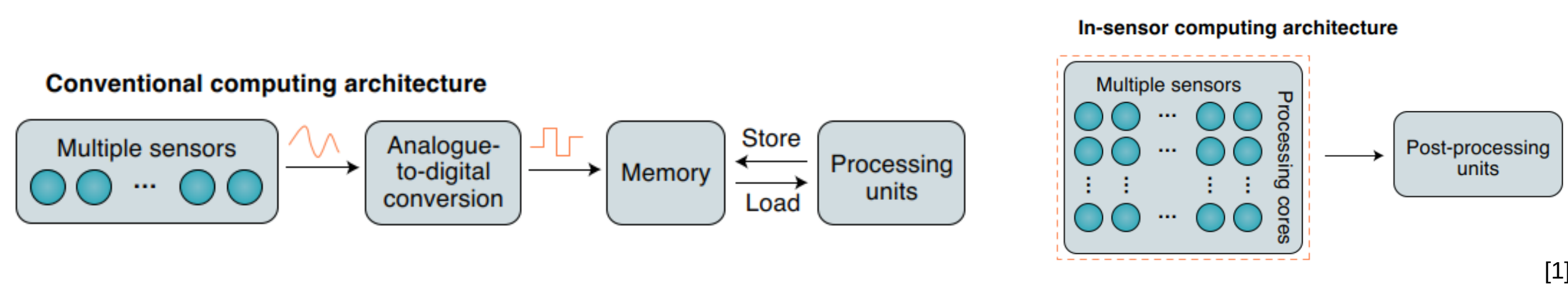
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Introduction

In-sensor computing is an emerging paradigm in which data is not only captured by a sensor but also processed directly within it. This sensor architecture helps to reduce the transfer of raw data between the sensor, memory, and processing unit. By combining sensing and computation, this approach improves:

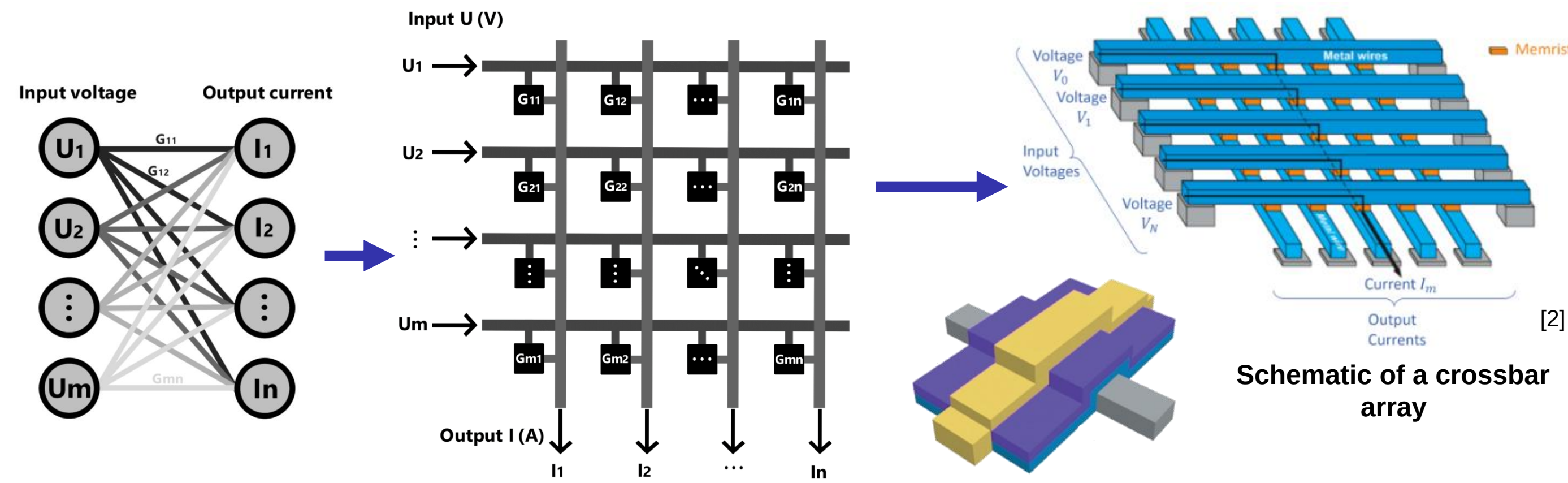
- Efficiency** - Reduces the massive data transfer from sensor, thereby saving energy
- Speed** - Enables real-time processing close to the data source
- Parallelism** - Parallel processing of data provides further improvements in efficiency

Our approach uses a crossbar array of sensors, enabling neural network-like behaviour. In this work we explored our Ni/HfO₂/TiO₂/TiN analog memristor crossbar arrays for application as a programmable smart temperature sensor.

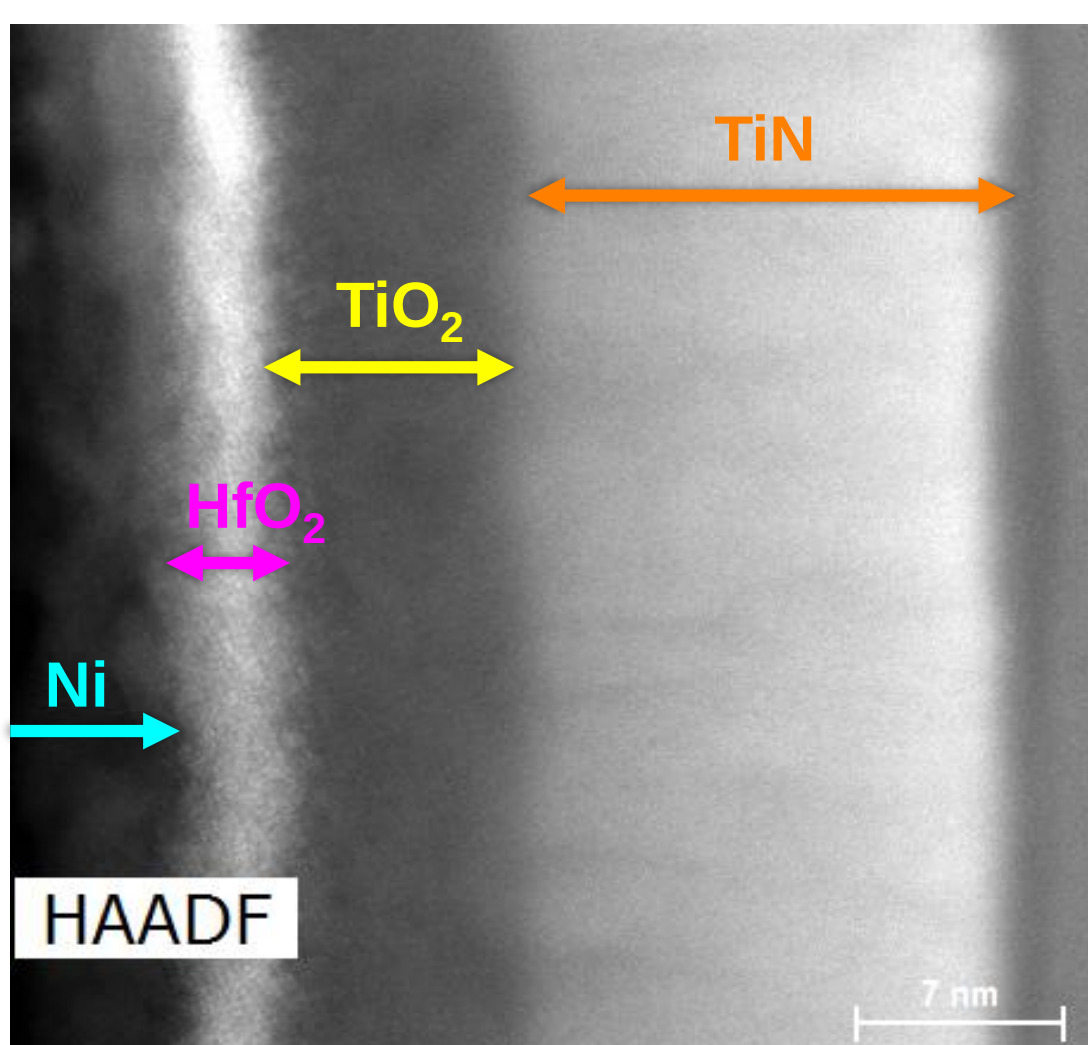


Memristor crossbar arrays – hardware ANN

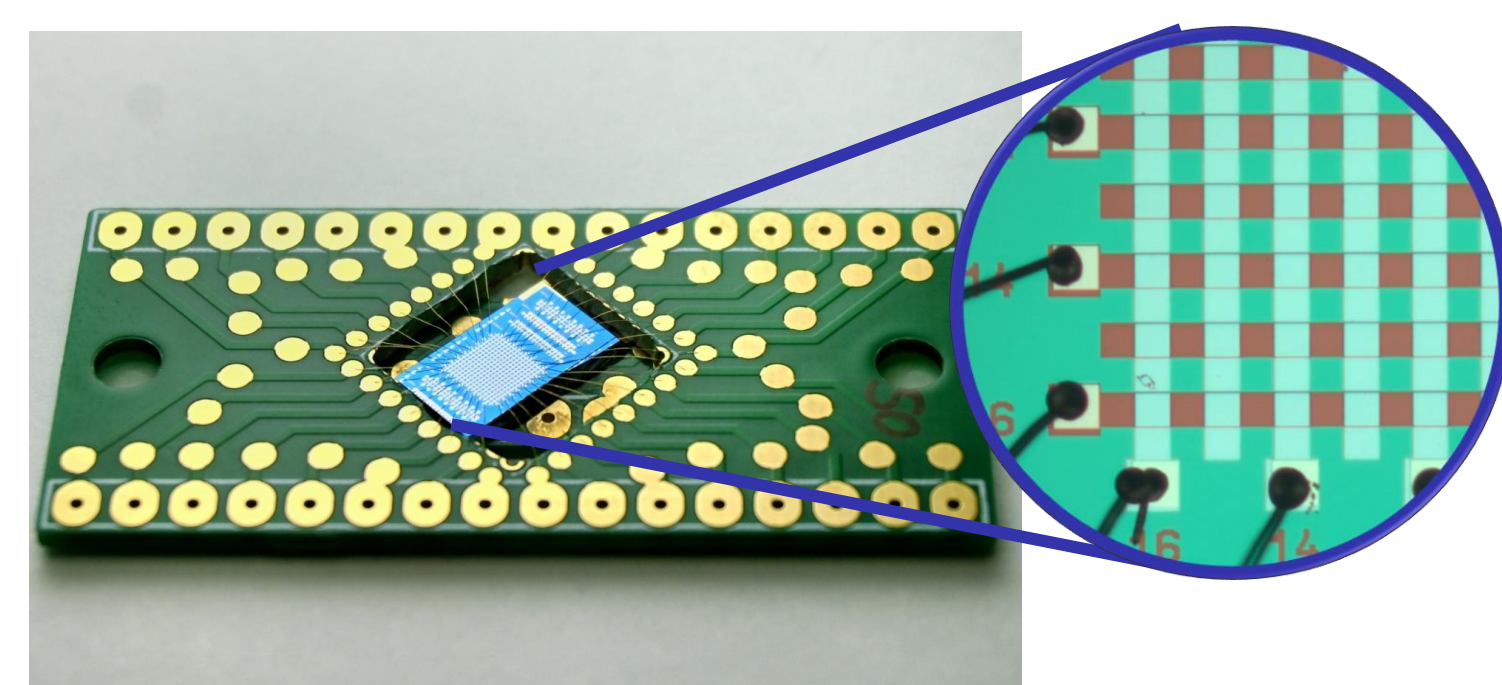
The concept of In-sensor computing originates from neural networks that simulate how the human brain works. By applying Ohm's and Kirchhoff's laws in a crossbar structure, we can replicate the same signal-processing logic as in a neural network.



When using hard-coded temperature sensors, a selector is necessary for the prevention of sneak-path currents. In this case they are not necessary due to the non-linearity of the memristor used for temperature sensing.



HR-TEM cross-section image of the analog memristor stack

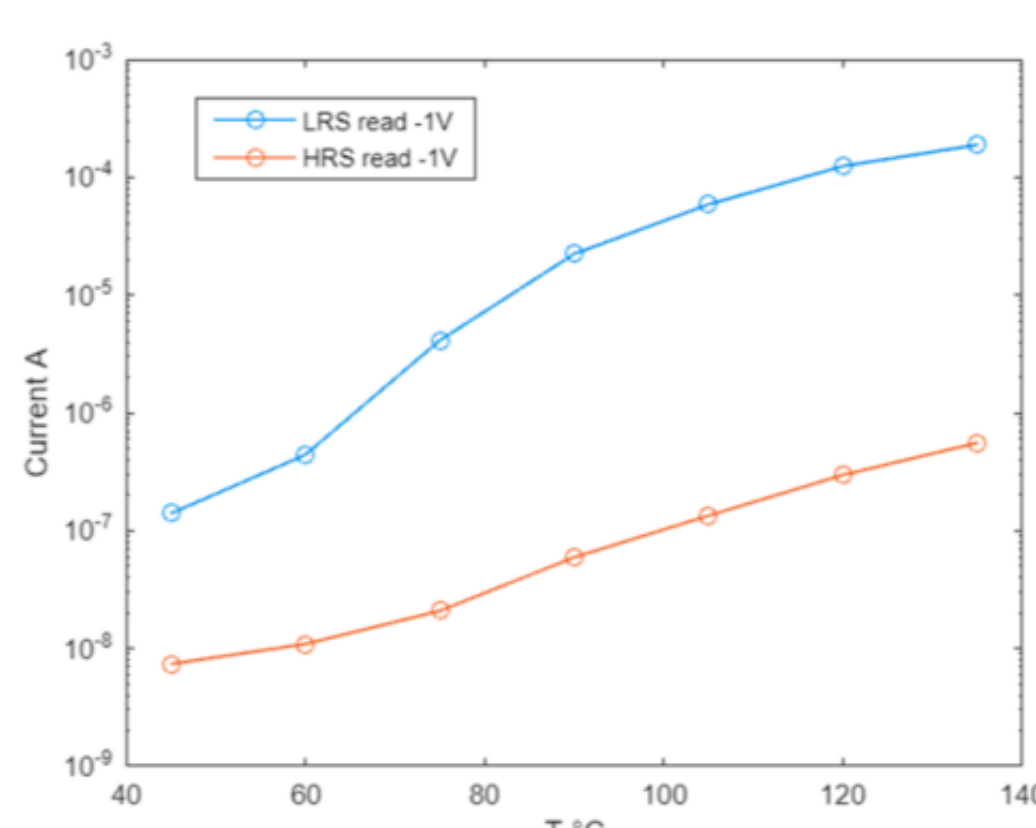


Crossbar array on carrier board

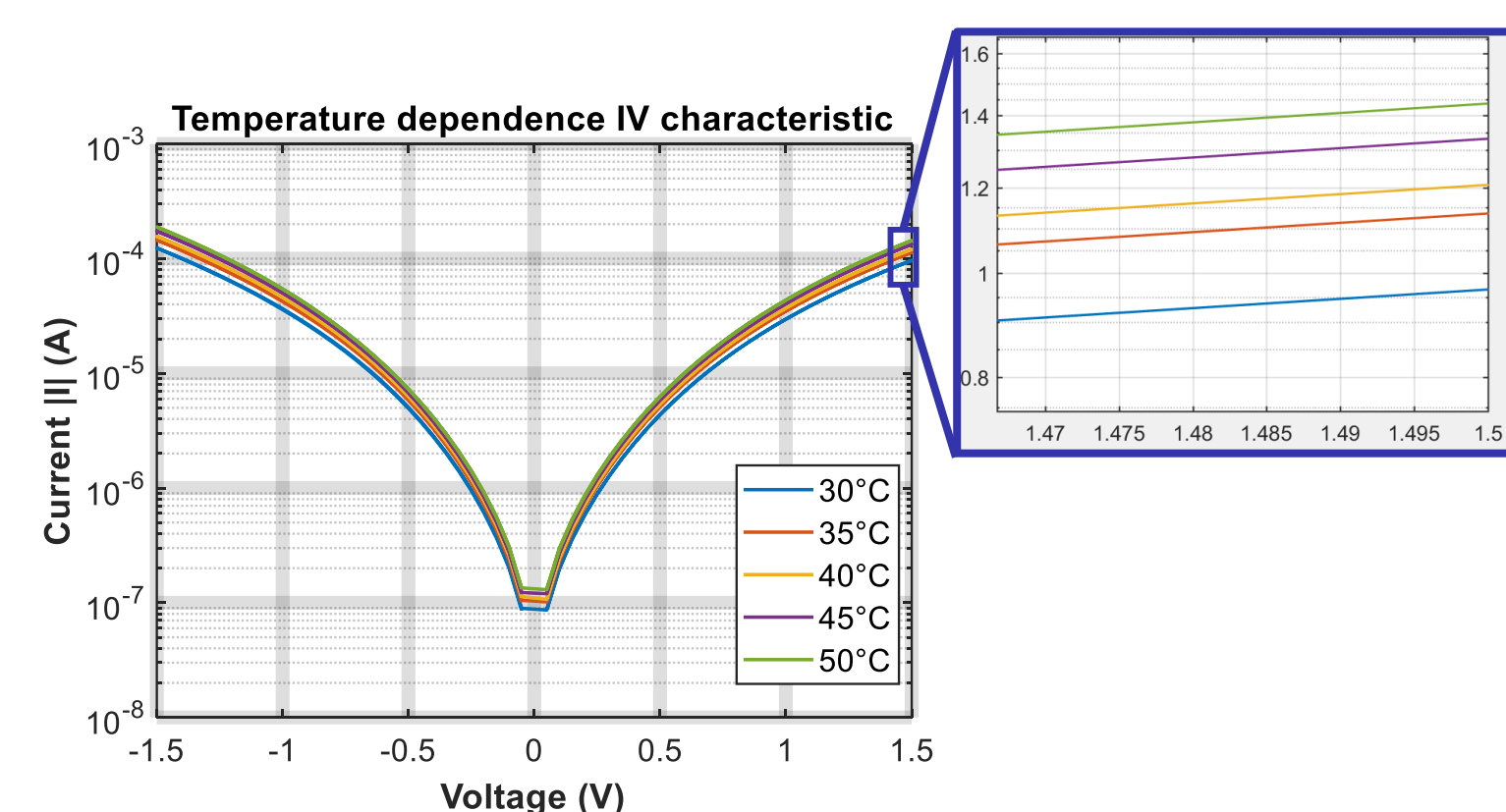
The analog memristor crossbar array was fabricated using physical vapour deposition (PVD) electrodes, with the two oxide layers deposited by atomic layer deposition (ALD), enabling sufficient reproducibility and nanoscale control.

The devices are being used for research in the field of in-sensor computing. For more information about these arrays see poster from Matej Horský - MEM25-131.

Motivation



Initial temperature dependency measurements



IV read characteristic of memristor, shows different resistance levels based on temperature it was measured at

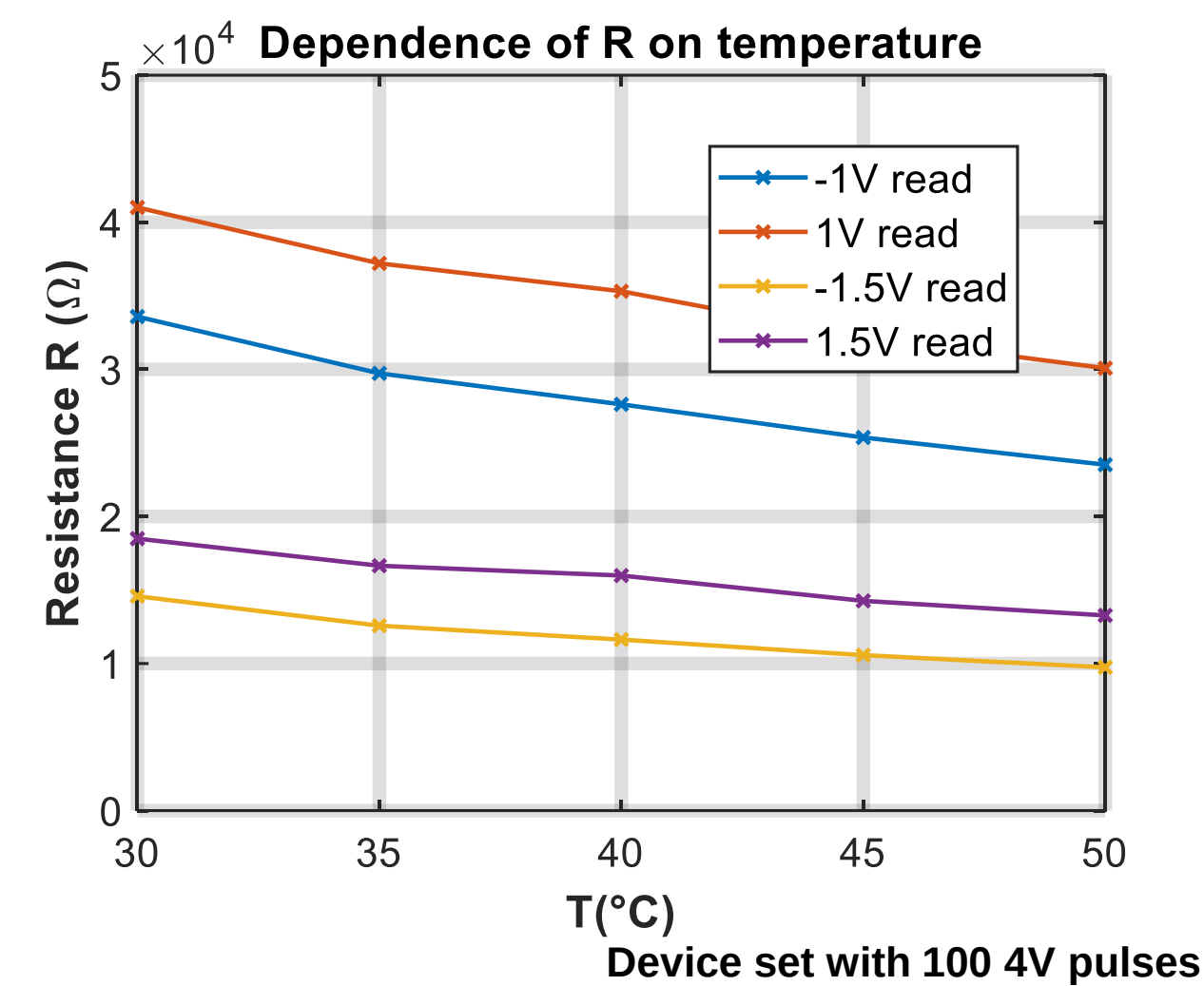
Initial temperature measurement shown significant temperature dependency of programming temperature on the memristor state. This fact lead us to believe they can be used in temperature sensors. By exploiting the array structure in sensor computing can be achieved.

References

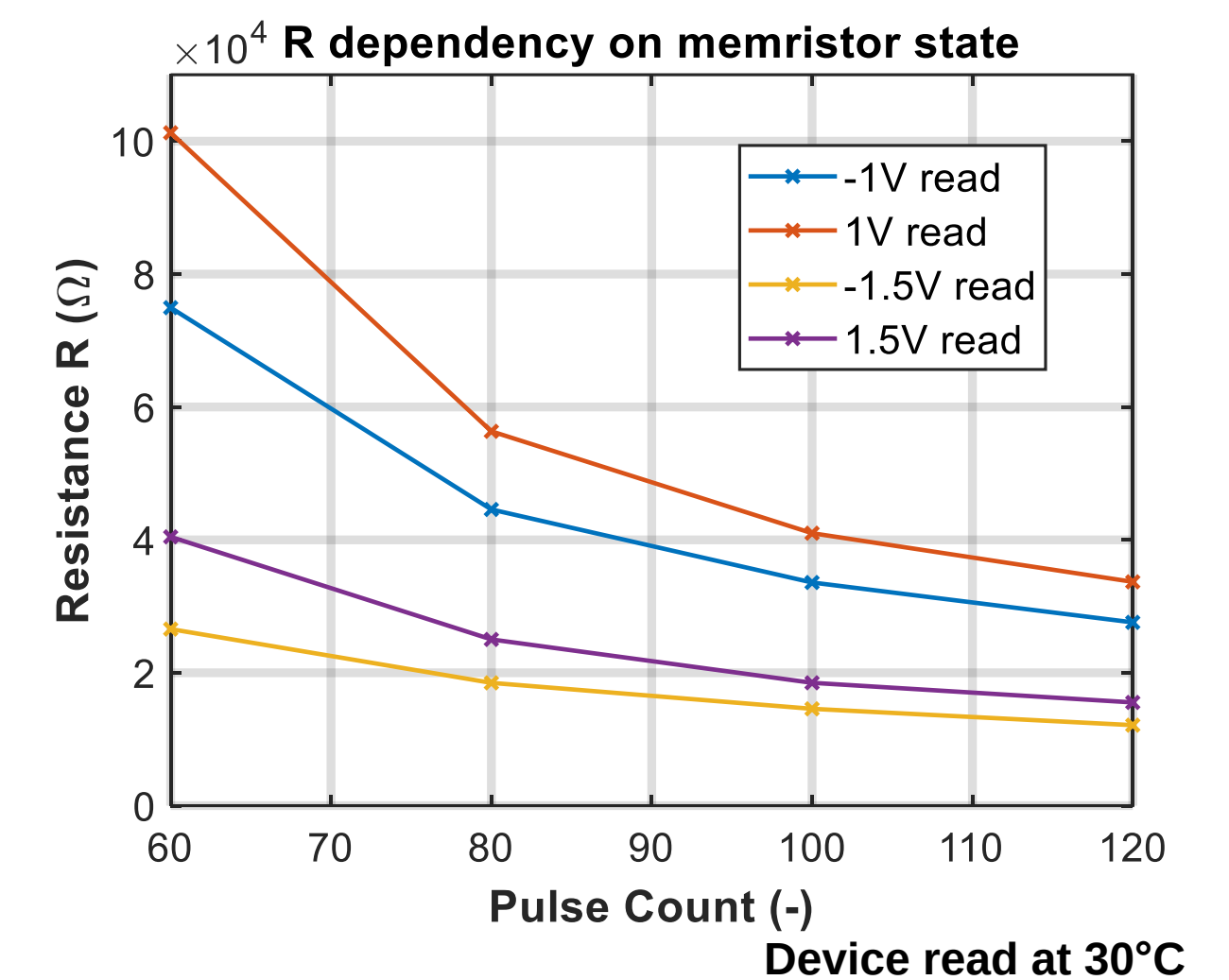
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Temperature characterization

- Sensors were measured from 30 °C to 50 °C
- Devices set with 4 different memristor states were measured
- Devices were set at elevated room temperature of 30 °C

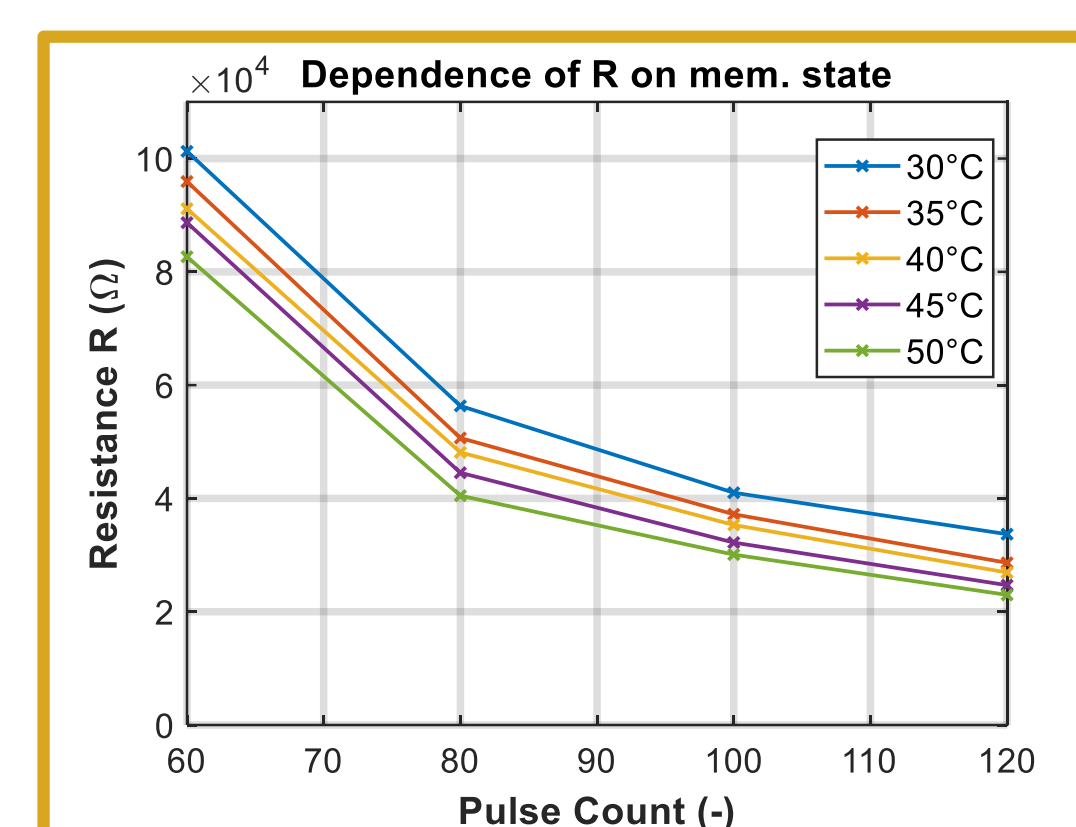
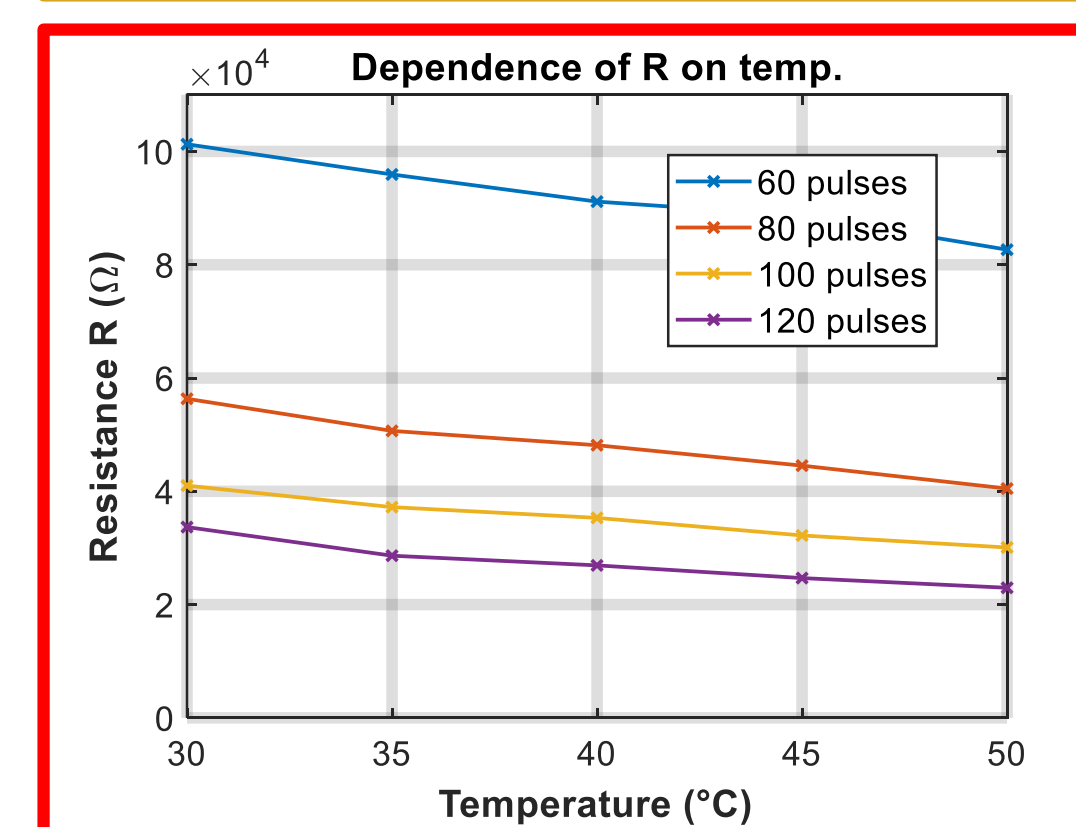


Device set with 100 4V pulses

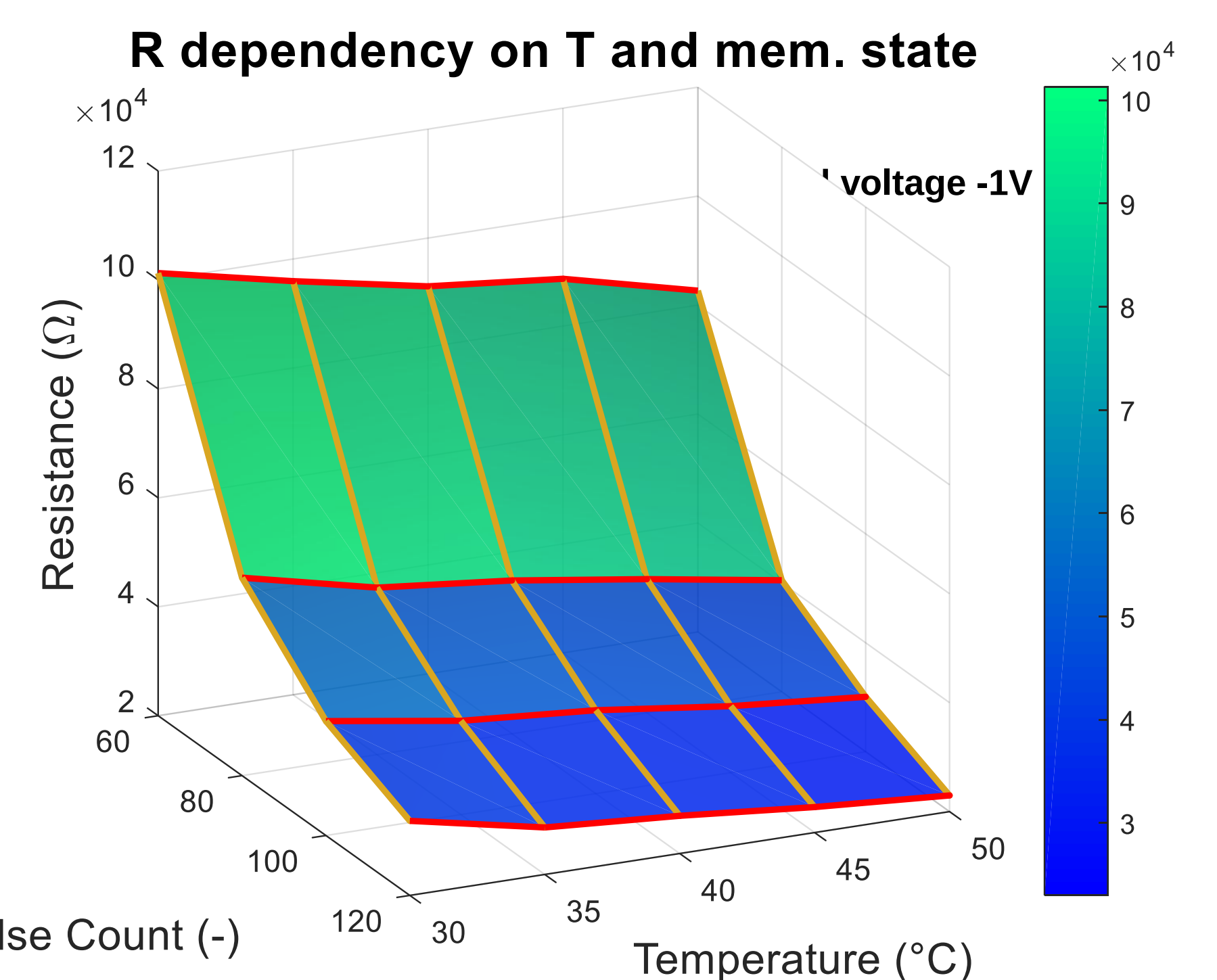


Device read at 30°C

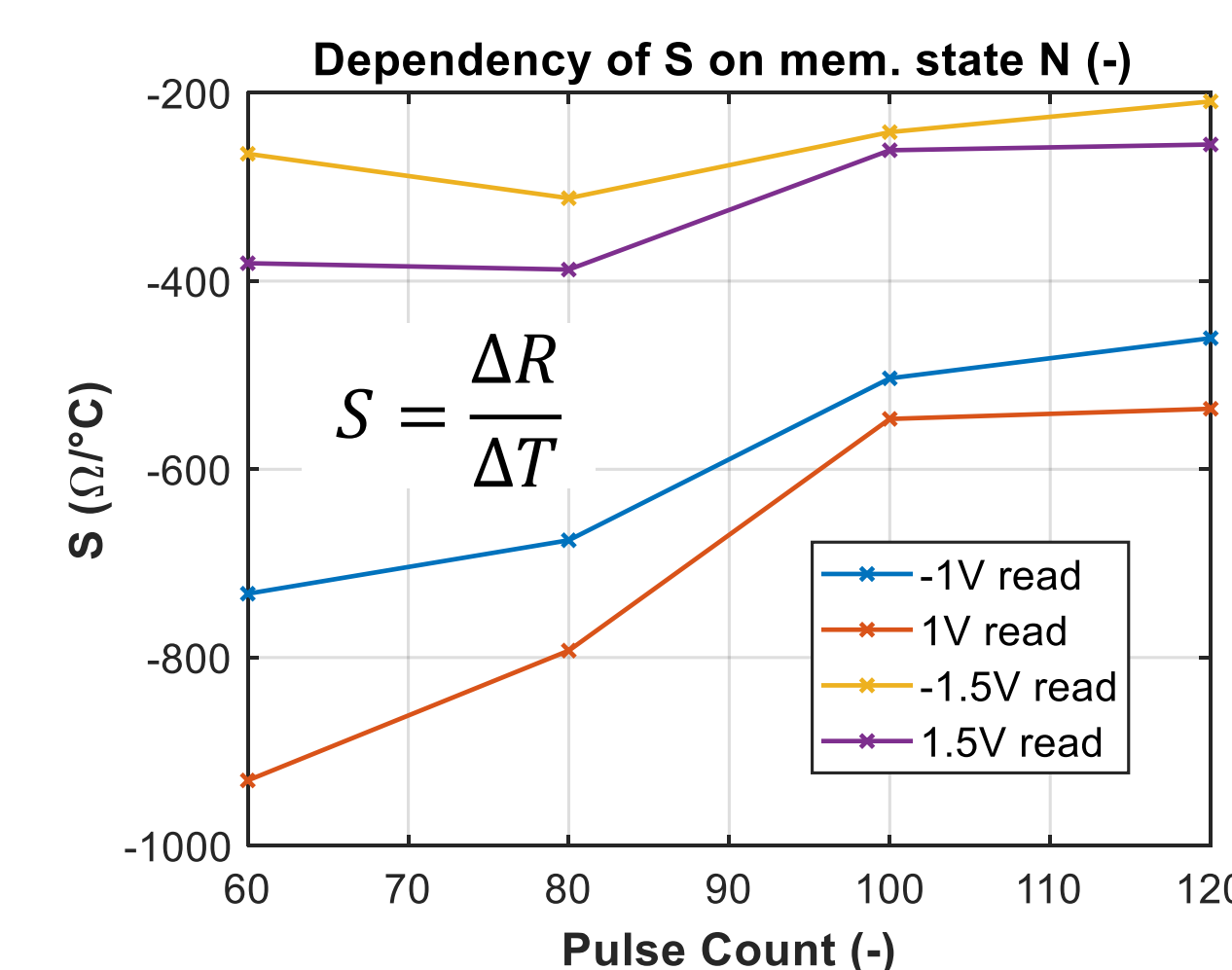
- 4 different voltages were used for reading the resistance



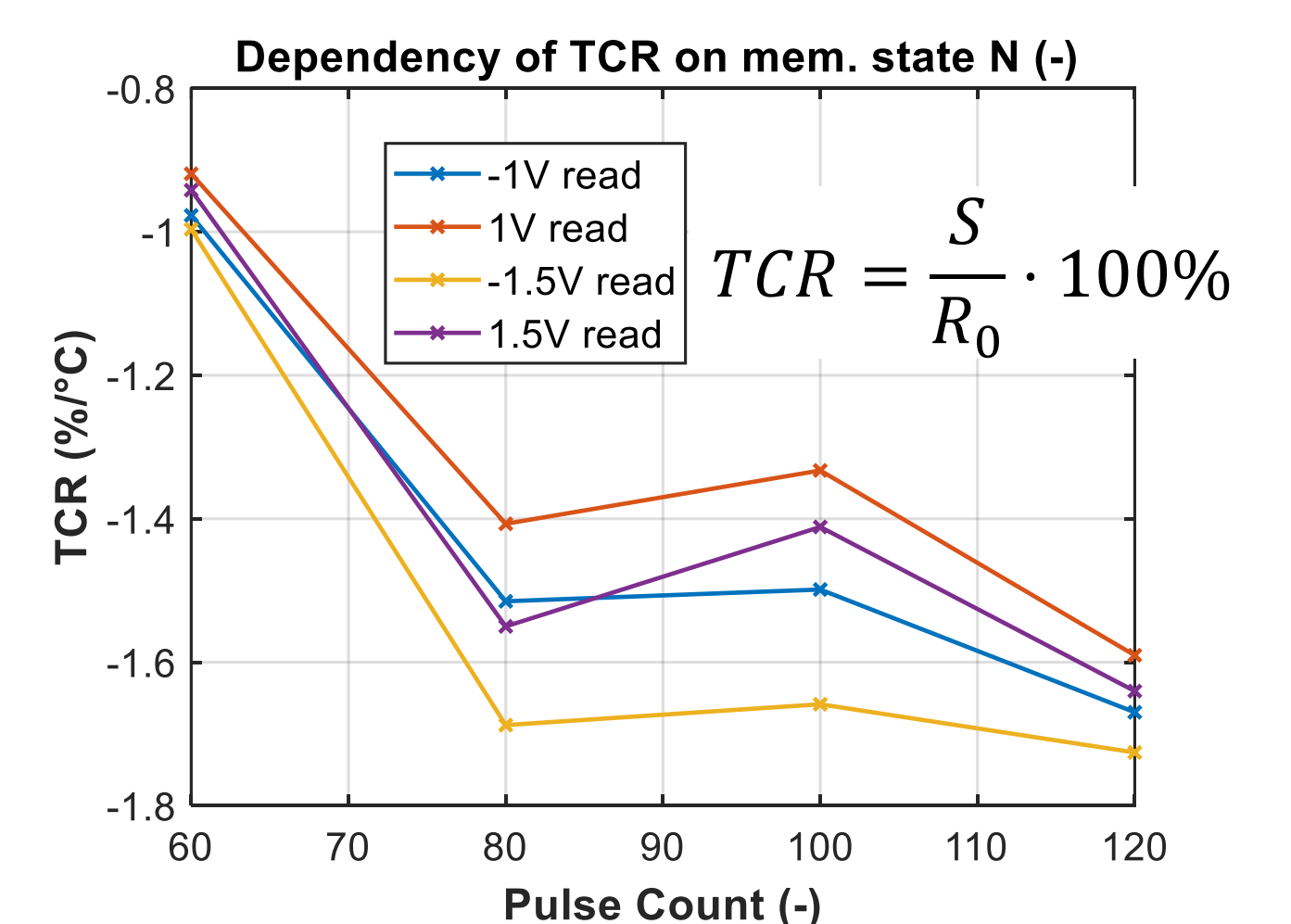
Projected views of the R-T-N surface



- The R-T characteristics shown a significant temperature dependency just from reading the memristor state (not only when programmed)



Dependency of S on mem. state N (-)

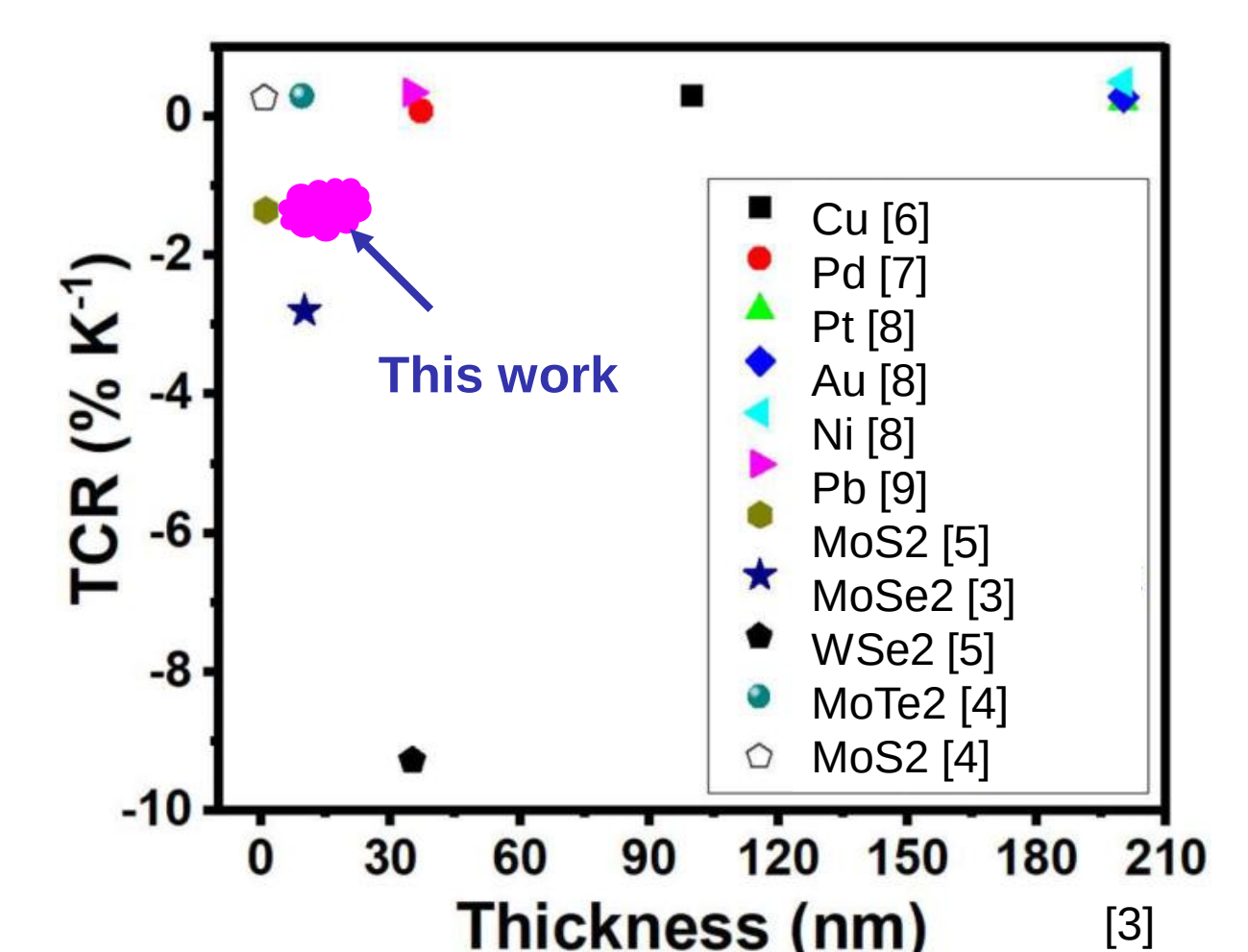


Dependency of TCR on mem. state N (-)

- The dependence of sensitivity on the memristor state is demonstrated, showing that varying levels of sensitivity can be achieved as a function of the number of programming pulses applied.

Comparison of TCR to known materials

- When comparing the thermal coefficient of resistance to other materials our memristor array has shown significantly higher values to materials regularly used for thermal sensors
- Only exotic 2D MOS devices show higher values, which are more complex



Summary and key points

- A crossbar array is a hardware implementation of the weighted connections in a neural network.
- The input of the crossbar is a voltage vector and the output is the current vector.
- Instead of fixed weights, each weight is represented as a sensitivity function
- By changing the voltage and number of pulses used to program the memristor, different temperature sensitivities can be achieved.

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