

Filamentary TaO_x digital memristors made by Ta oxidation for fuzzy-logic applications

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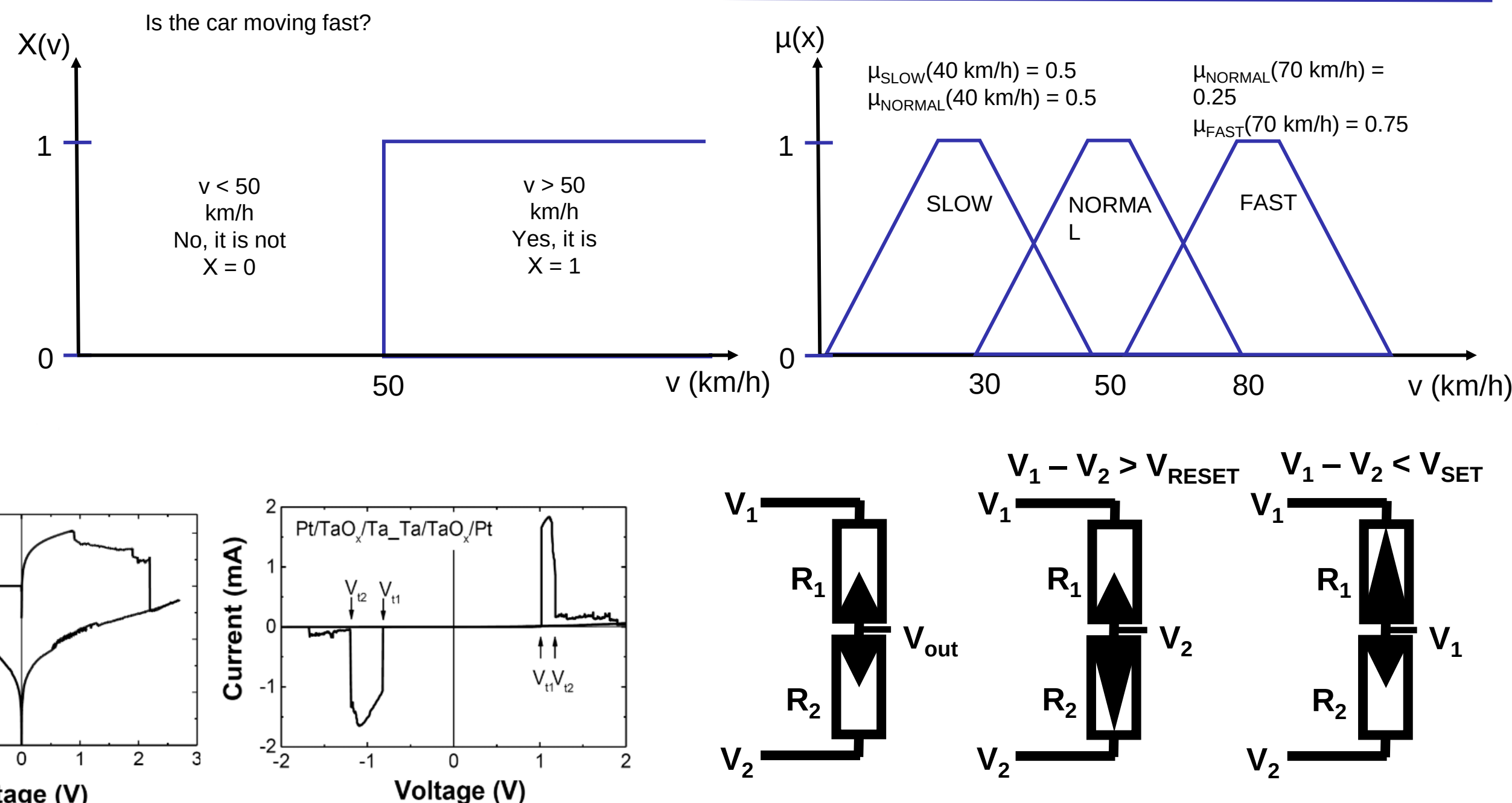
Introduction

Fuzzy logic extends the classical Boolean logic by allowing values to range from 0 to 1 continuously. This enables systems to handle uncertainty, ambiguity, and partial truths. This architecture combines logical inference with graded membership functions, improving:

Robustness – handling of noisy or imprecise input data

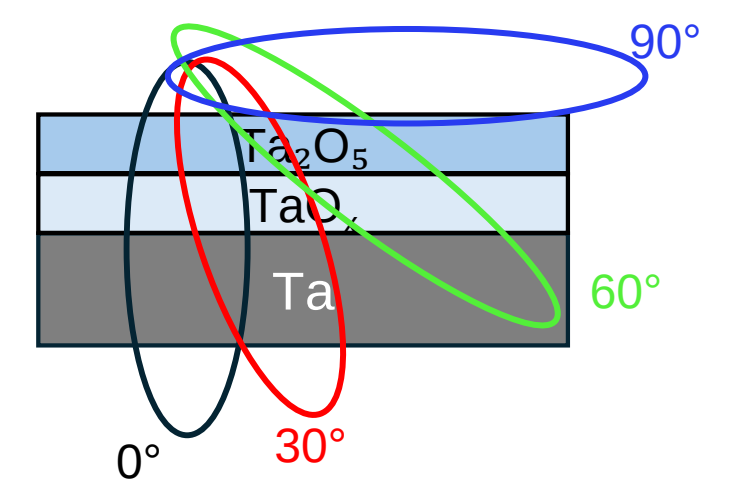
Adaptability – nonlinear or complex relationships are difficult to model with crisp logic

Interpretability – the structure can be aligned with human reasoning

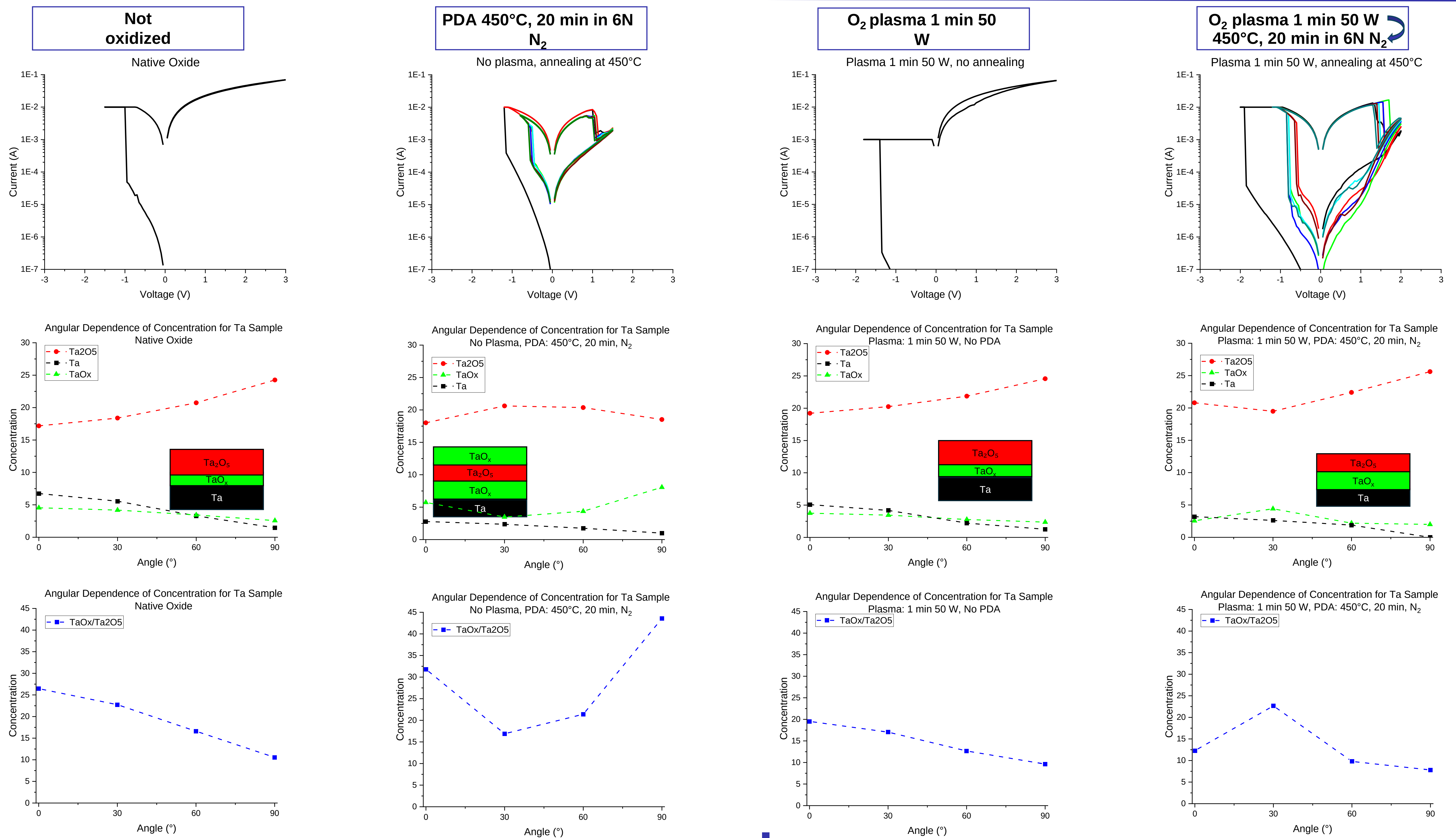


XPS Measurement

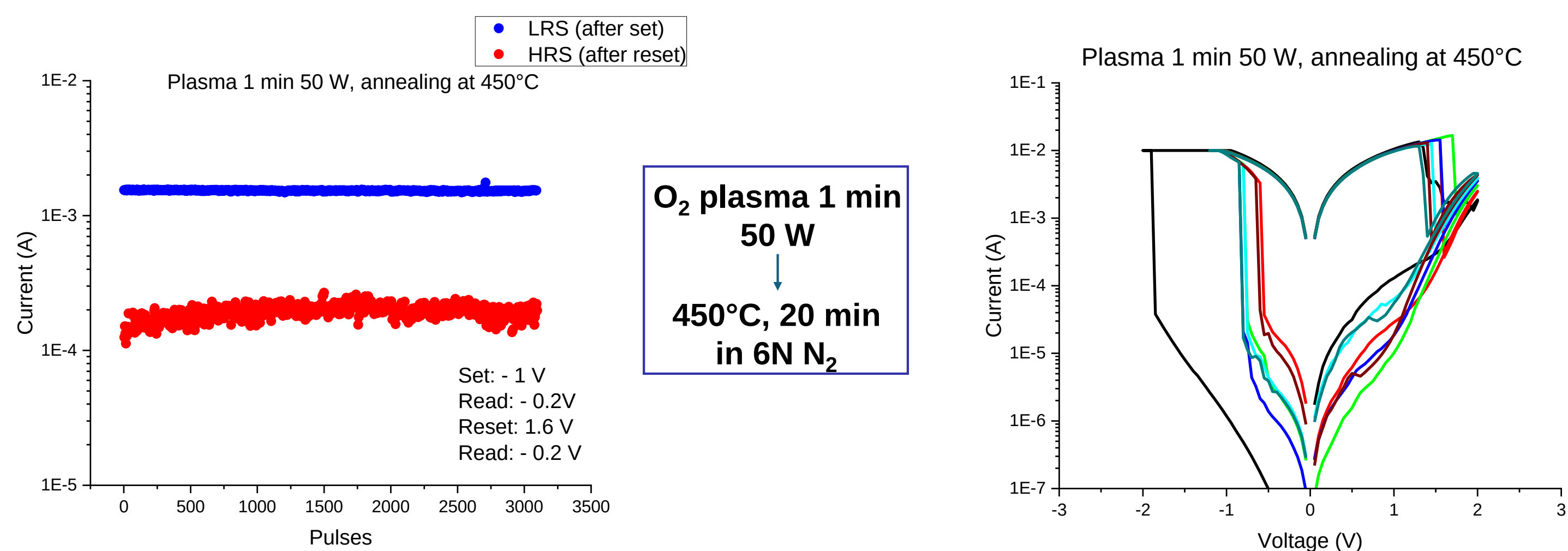
- Electrons in atoms have specific binding energies depending on the element and chemical environment
- In XPS (X-ray photoelectron spectroscopy), X-rays eject photoelectrons from the material, their kinetic energy is measured to calculate the characteristic binding energy, this allows identification of elements
- Chemical shifts in binding energy reveals oxidation states and bonding environments
- The X-rays are emitted at different angles to analyse different parts of the sample



Results of the XPS Measurements and I-V Characteristics



TaO_x Memristor for Fuzzy-logic

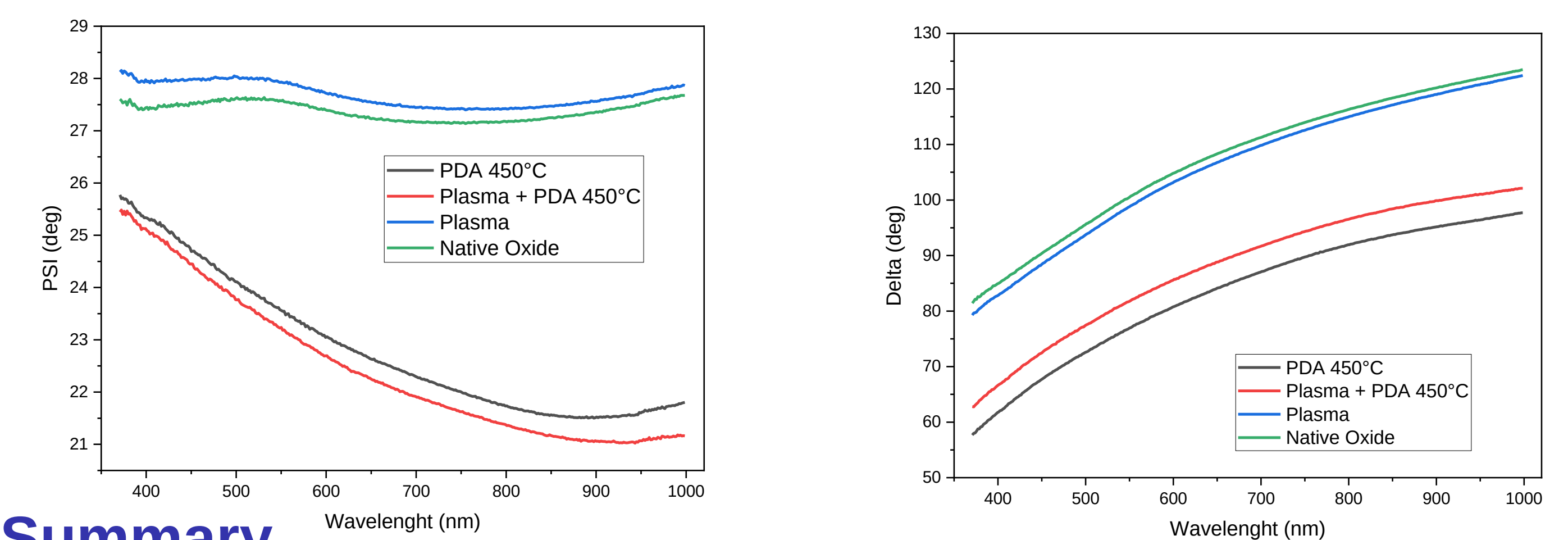


- The sample with the **best yield and endurance** was the one oxidated with **plasma** and then **annealed**
- For **fuzzy logic applications** we need filamentary memristors with an abrupt SET/RESET which can be obtained by creating a good spatial oxygen gradient
- In the native oxide there are already two layers: Ta₂O₅ (insulating), TaO_x (oxygen-deficient, conductive)
- A better defined interface for oxygen vacancy formation and migration is needed, thus the **oxidation** is an essential process

Acknowledgements

This work was supported by the IPCEI project Memristor technology R&D for industry, ITMS code 09I05-03-V01-00003, and by the m-ERA.net projects Atosens & PhotoPrint.

Ellipsometry



Summary

By changing the oxidation conditions, we were able to create different structures in the dielectric layer:

- the sample with **no oxidation** did have a thin TaO_x layer in comparison to the Ta₂O₅, there were not enough vacancies, the sample was not able to RESET
- the oxidation with **only PDA** created a thicker TaO_x layer, the I-V characteristic was stable, but the yield was low
- the oxidation with **plasma** and no PDA created a thicker Ta₂O₅ layer which is more insulating – no RESET was present
- the oxidation with **plasma** created a thicker Ta₂O₅ layer, the **annealing** a thicker TaO_x layer, I-V characteristic was stable

References

- Breuer, T., Nielsen, L., Roesgen, B. *et al.* Realization of Minimum and Maximum Gate Function in Ta₂O₅-based Memristive Devices. *Sci Rep* 6, 23967 (2016).
- Frohlich, J., Kundrata, I., Blaho, M., *et al.* Hafnium oxide and tantalum oxide based resistive switching structures for realization of minimum and maximum functions. *JAP* 124, 152109 (2018).