Real-Time Studies of Resistive Switching Mechanisms

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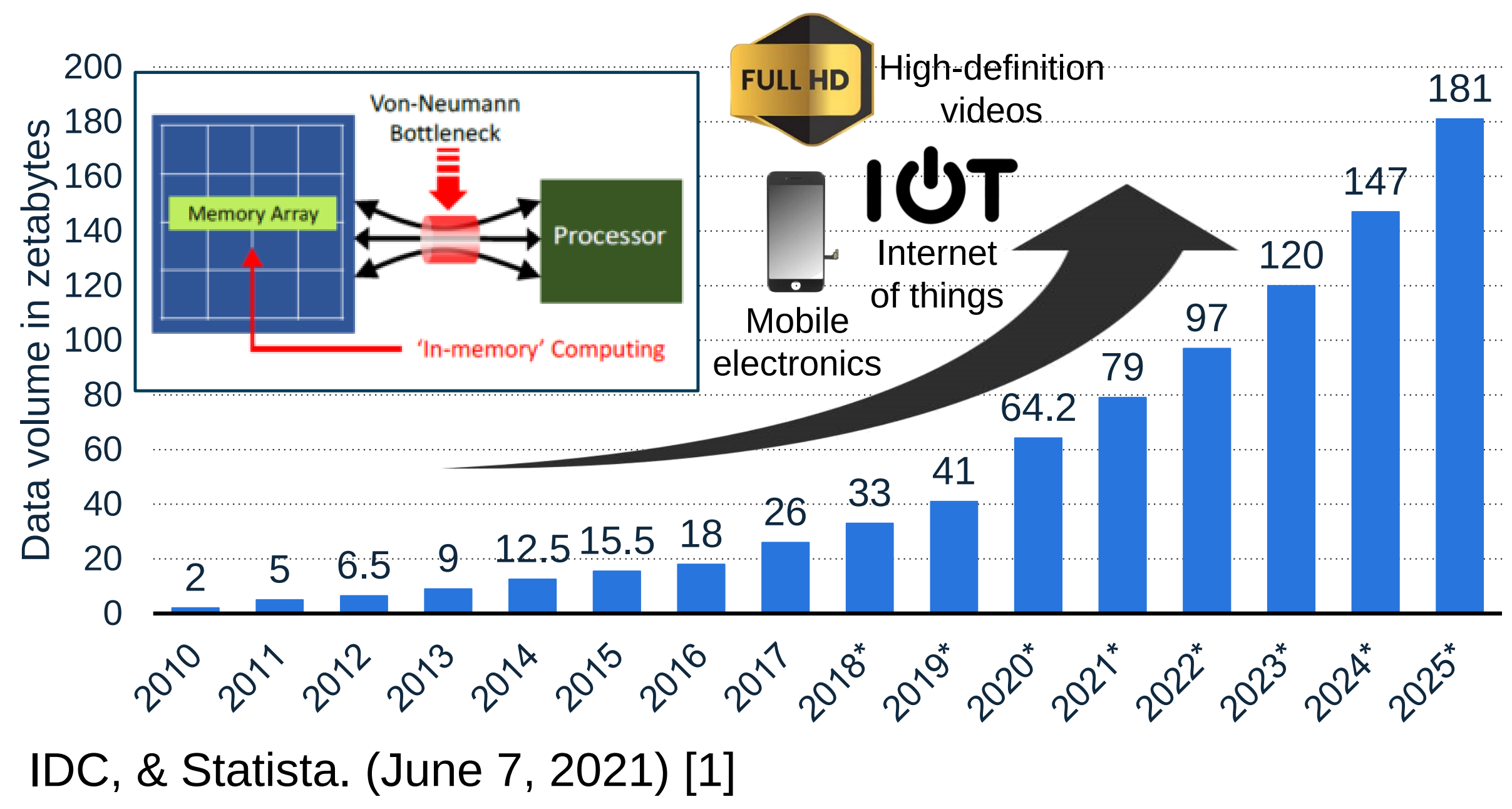
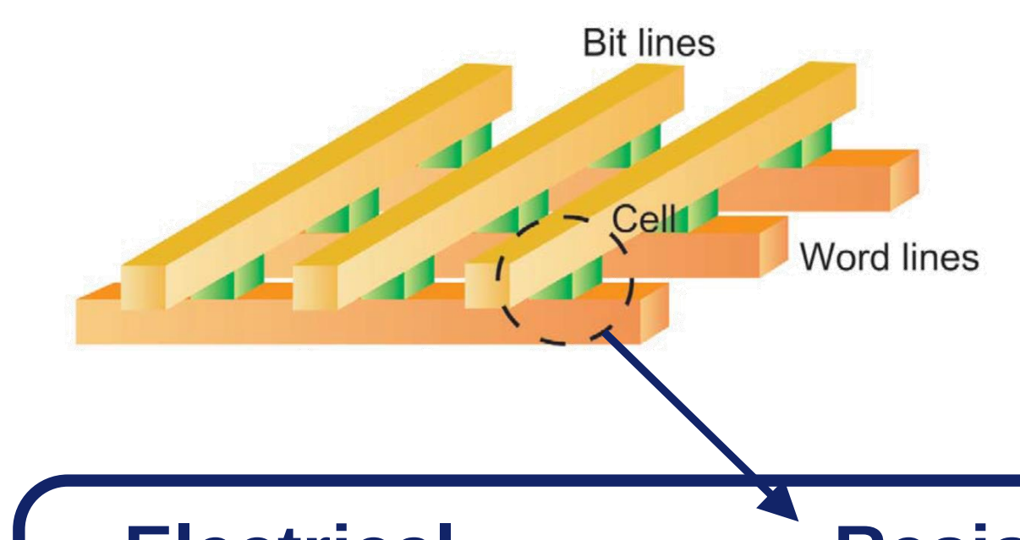
Exponential increase in the demand for data storage and processing



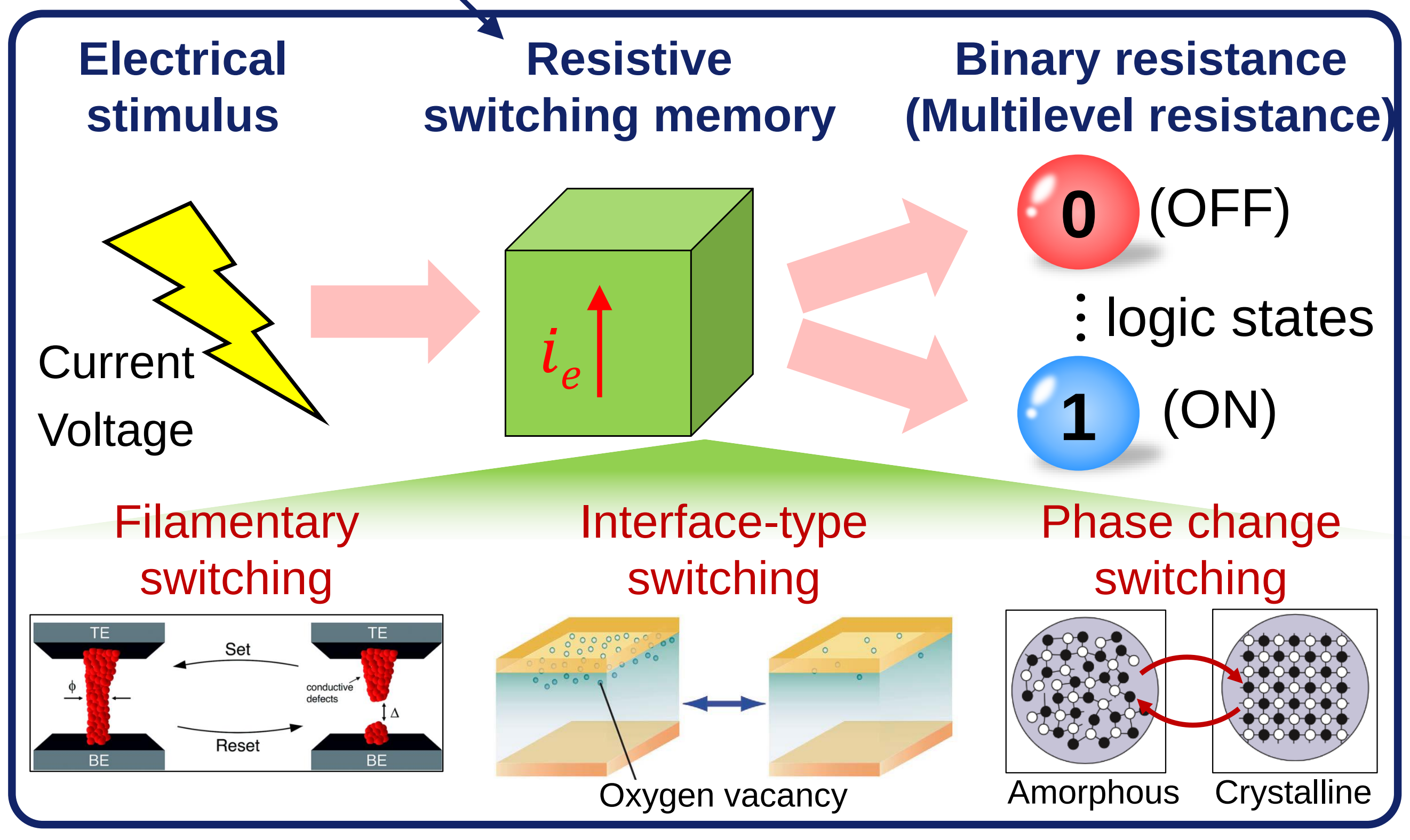
IDC, & Statista. (June 7, 2021) [1]

- Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2020, with forecasts from 2021 to 2025 (in zettabytes).
- Changes in computing architecture and hardware are therefore urgently needed to meet the increased demands for data storage and processing.

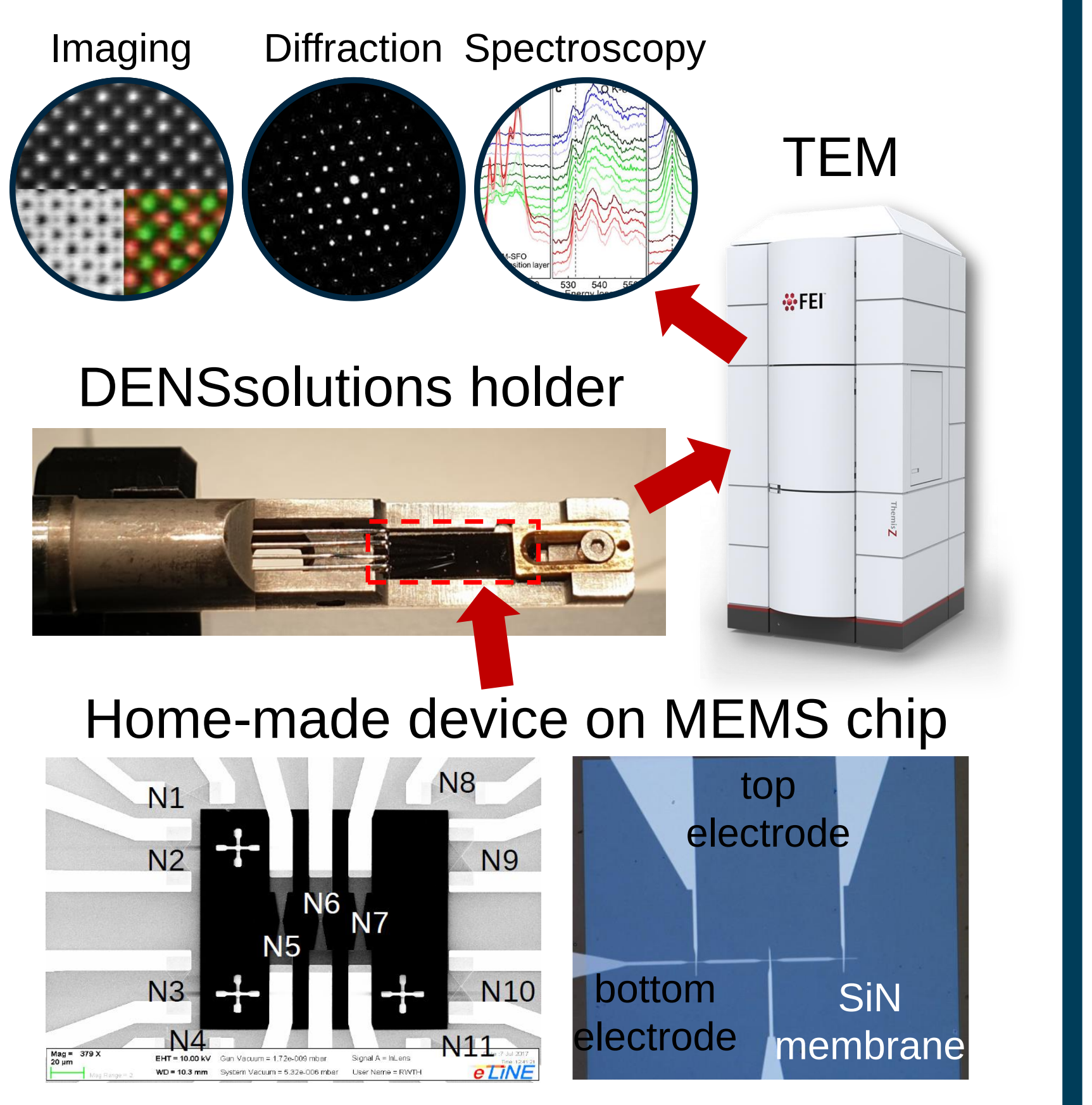
A promising solution: Resistive switching memory



- Non-volatile memory
- Simple cell structure
- Fast switching time
- Low power (voltage) operation
- Large on/off ratio [2–4]



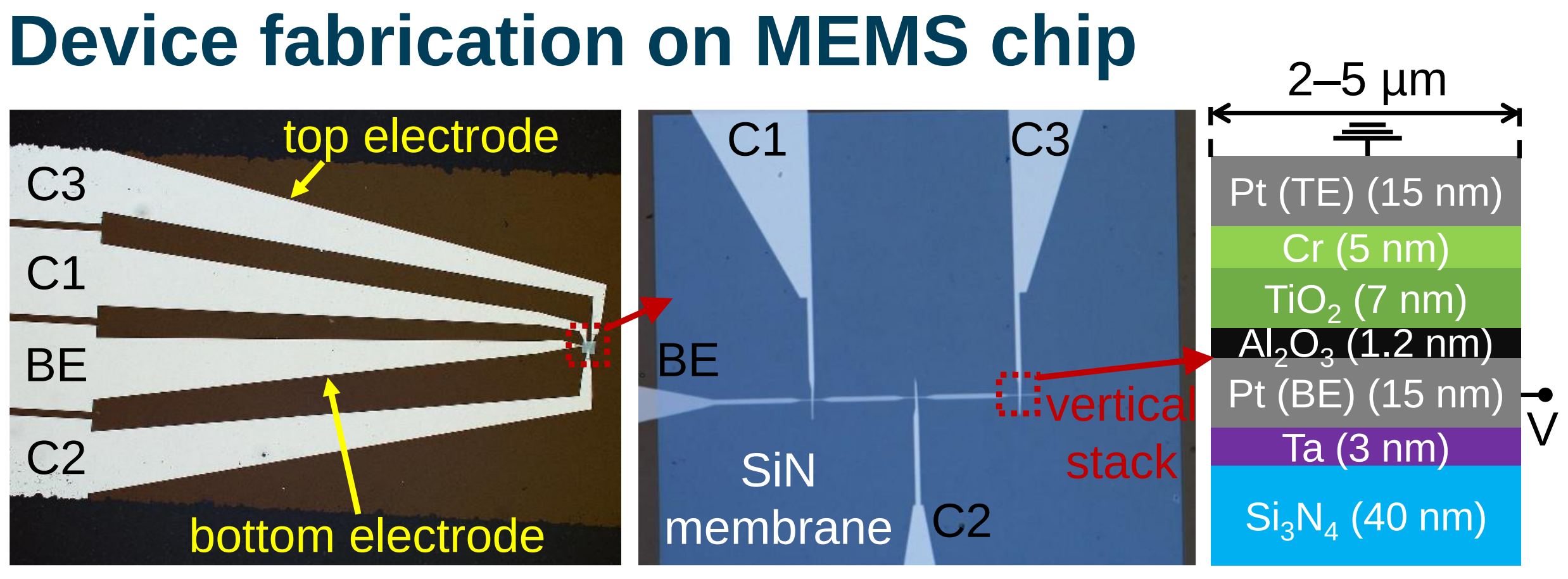
Real-time biasing experiments in the TEM



- In situ biasing setup in the TEM is a great tool to unravel resistive switching mechanisms in different material systems.

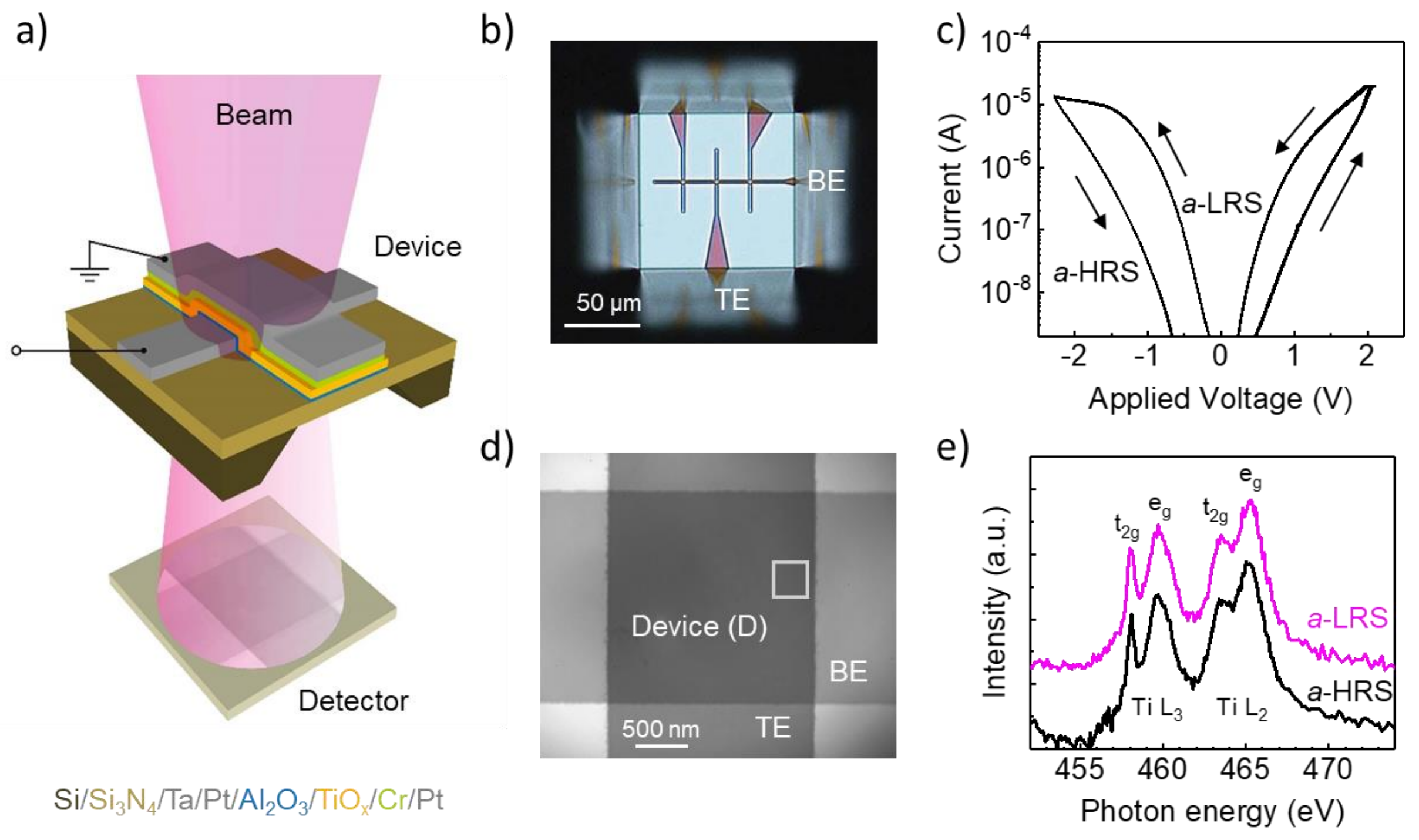
Filamentary and interface-type switching (Valence change material, VCM)

Device fabrication on MEMS chip



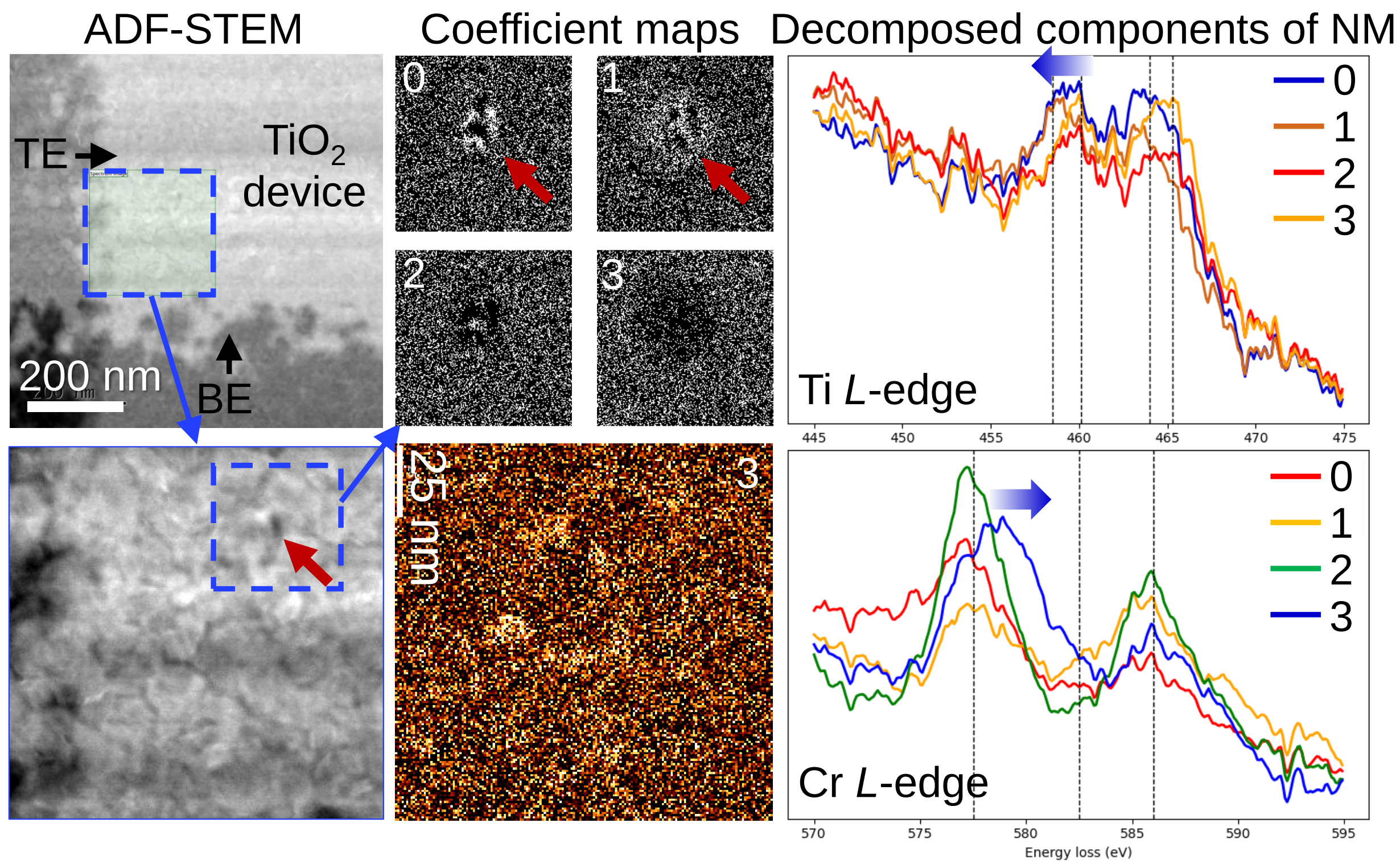
- Micro-crossbar device on Si_3N_4 membrane
- Metal oxide layers grown by ALD
- TiO_2 switching layer

Area-mode switching studied by TXM in real-time



- No clear difference in the spectra between the HRS and LRS of the device
- No structural change of TiO_2 and strong Joule heating

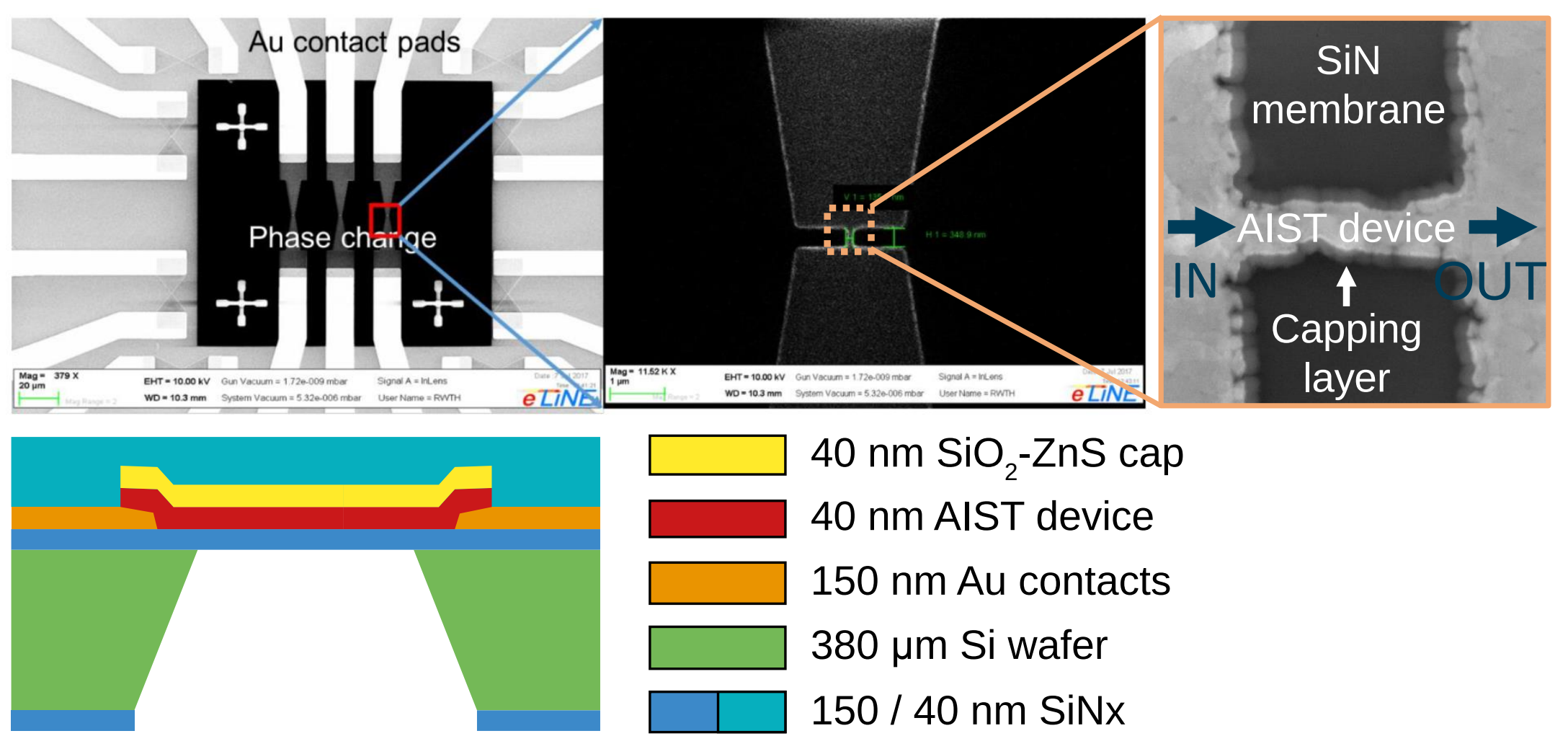
Local investigation of conducting filament by STEM-EELS



- Filamentary switching at higher voltage and compliance current in the same device
- Non-negative matrix factorization (NMF) performed to extract feature spectra
- Local formation of conducting filament (reduction of Ti and oxidation of Cr) [5]

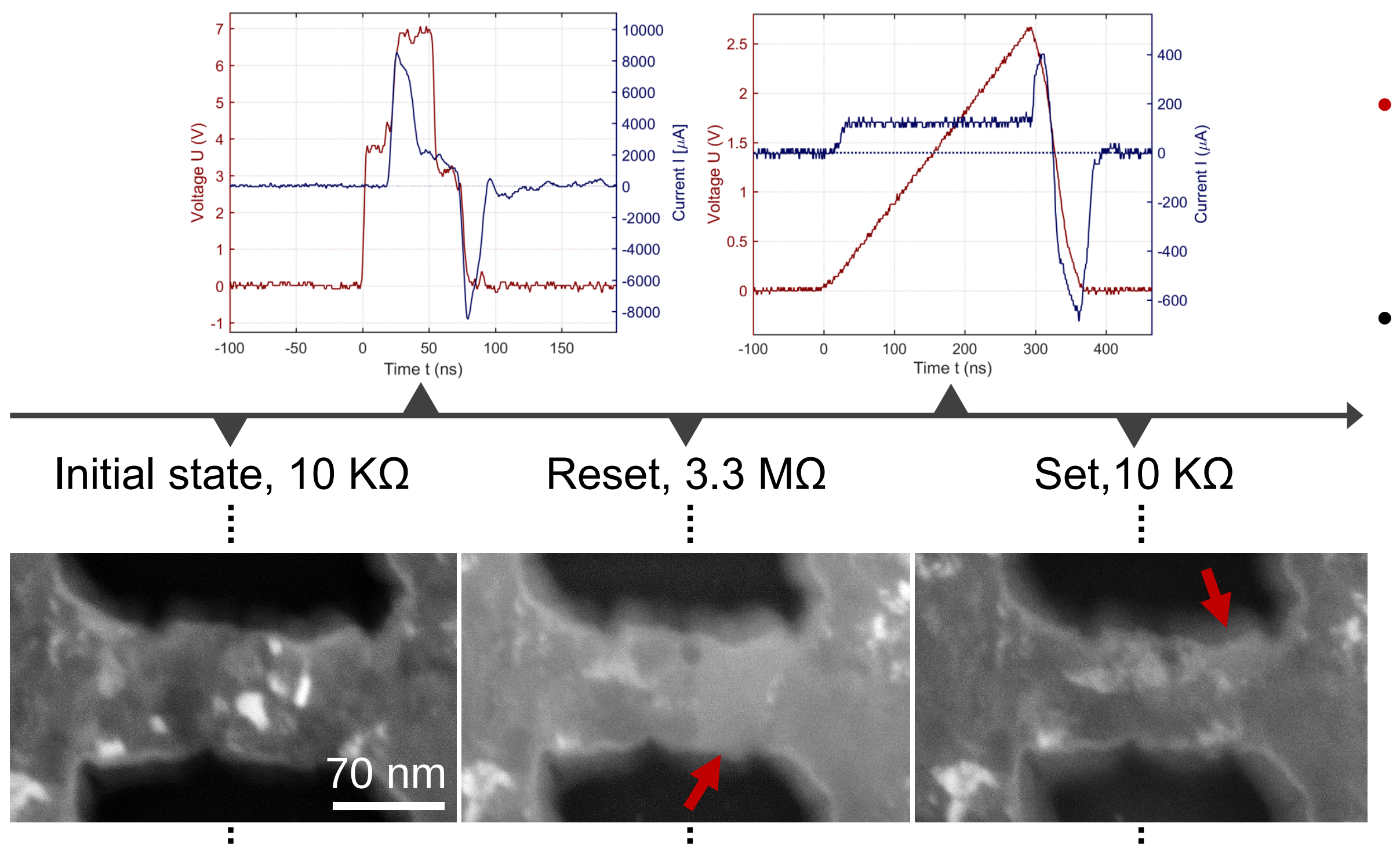
Phase change switching (Phase change material, PCM)

Device fabrication on MEMS chip



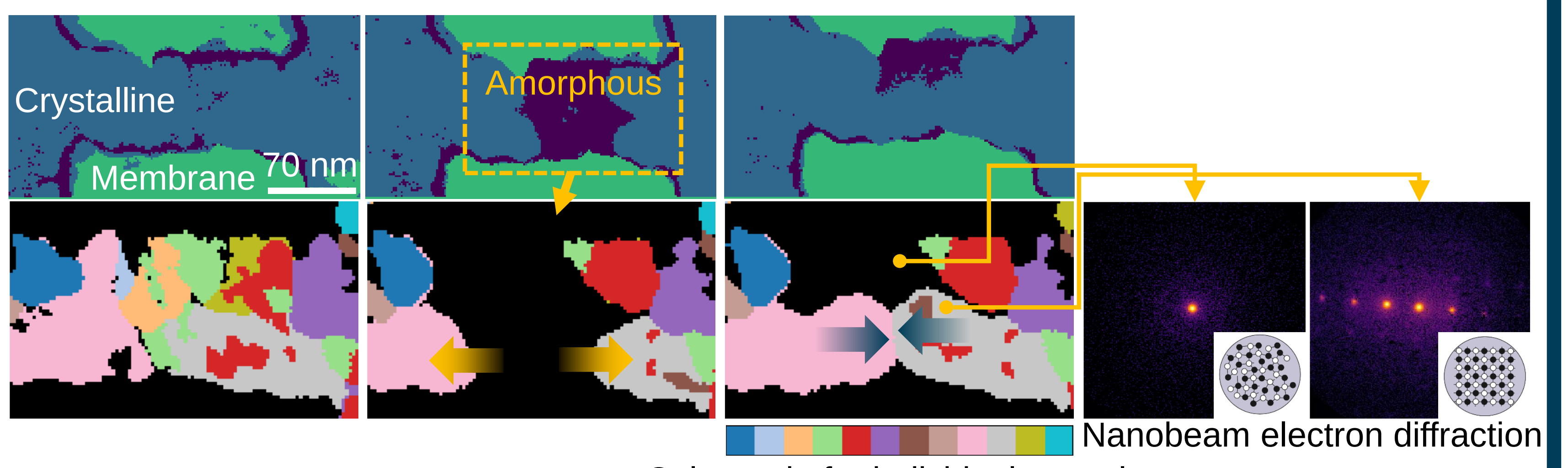
- Ag-In-Sb-Te (AIST) cells (bridge structure) on Si_3N_4 membrane
- Capping layer for the heat dissipation
- AIST switching layer

Resistive switching of AIST observed by STEM imaging



- Contrast changes at the bridge observed by HAADF-STEM
- Need to confirm whether contrast changes originate from the transition between amorphous and crystalline phases of AIST or not

Identification of amorphous and crystal by 4D-STEM



Nanobeam electron diffraction

Color code for individual crystals

- Differentiation between amorphous and crystalline phases using 4D-STEM
- Rupture and recreation of the conduction path caused by the transition between amorphous and crystalline phases, resulting in the evolution of crystalline grains

Conclusions

- Reliable resistive switching of PCM and VCM was successfully investigated by *in situ* electrical biasing setup with advanced TEM techniques.
- Correlative measurements by TXM and TEM revealed the presence of a conducting filament, which is the origin of the filamentary switching of VCM device.
- 4D-STEM with a nanobeam electron diffraction enabled tracking the annihilation and recreation of conduction path (*e.g.* evolution of crystalline grains) of AIST during resistive switching.

References

[1] IDC, & Statista. (June 7, 2021).
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[3] M. Lanza *et al.*, *Science*, **376,** 1066 (2022).
[4] W. Banerjee *et al.*, *Small*, **18,** 1 (2022).
[5] S. Aussen *et al.*, *Adv. Electron. Mater.* **9,** 2300520 (2023)

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