

ATOMIC LAYER DEPOSITION OF METAL OXIDE NANOLAMINATES EXHIBITING NONLINEAR ELECTRICAL AND MAGNETIC POLARIZATION WITH TUNABLE RESISTIVITY

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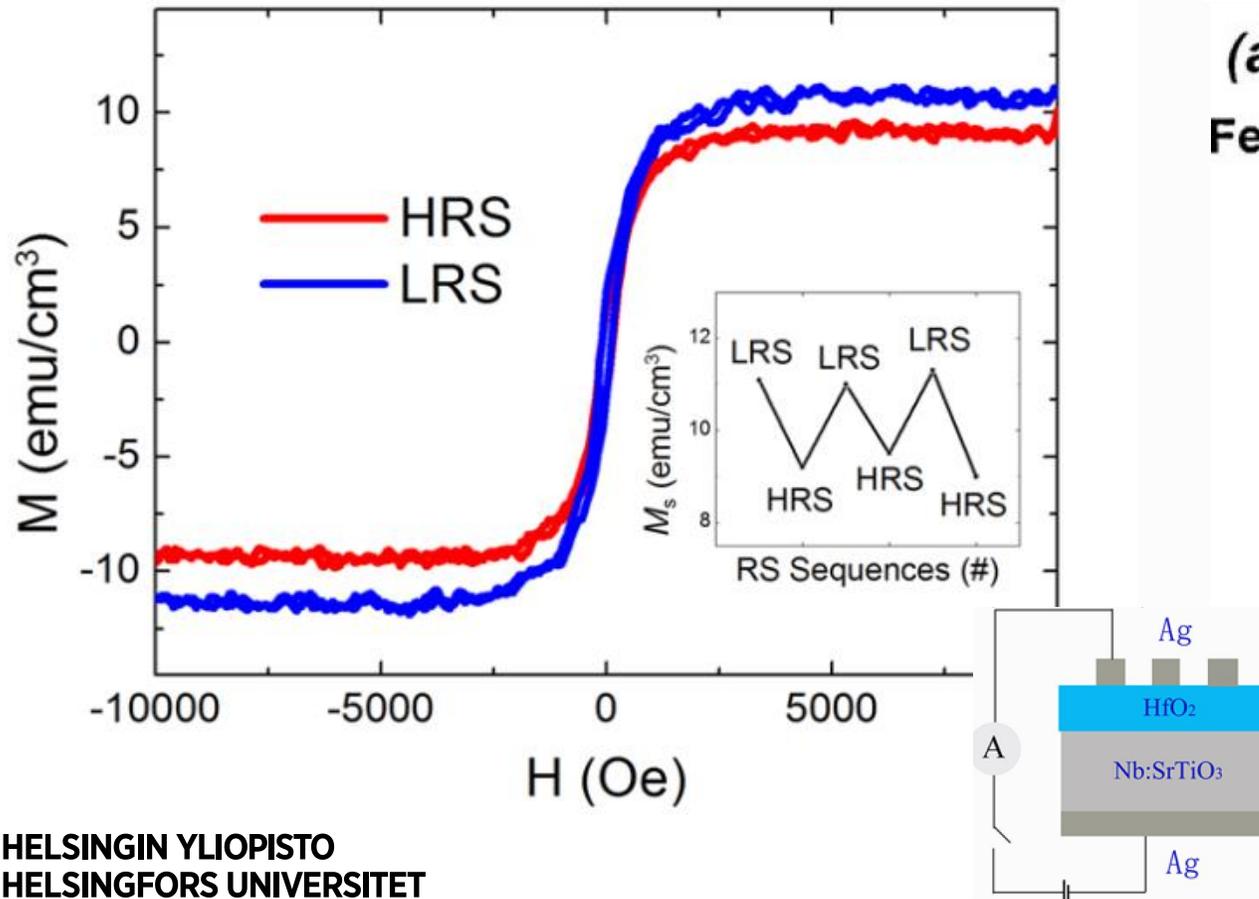
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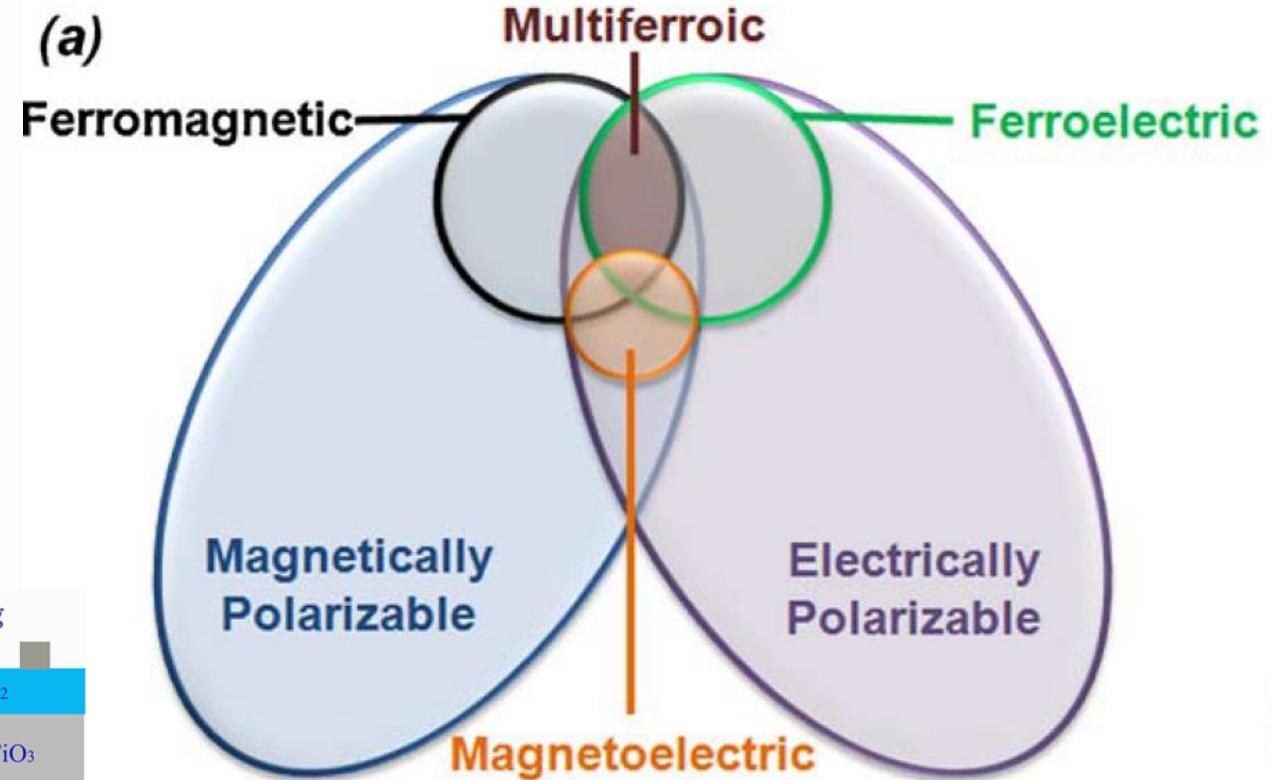


Targeting magnetoelectric + resistive switching materials

S Ren *et al*
J. Phys.: Condens. Matter **28** (2016) 056001



L.W. Martin *et al.*
Materials Science and Engineering R **68** (2010) 89





ALD chemistry in the present series of works

HfO₂ from HfCl₄, H₂O or O₃;

ZrO₂ from ZrCl₄, H₂O or O₃;

Al₂O₃ from AlCl₃ and O₃;

Fe₂O₃ from FeCl₃ and O₃;

SiO₂ from Si₂(NH₂)₆ and O₃;

T_{GROWTH} = 300..350 °C

Reactors: a commercial research-scale flow-type hot-wall F120

[T. Suntola, Thin Solid Films 216 (1992) 84]

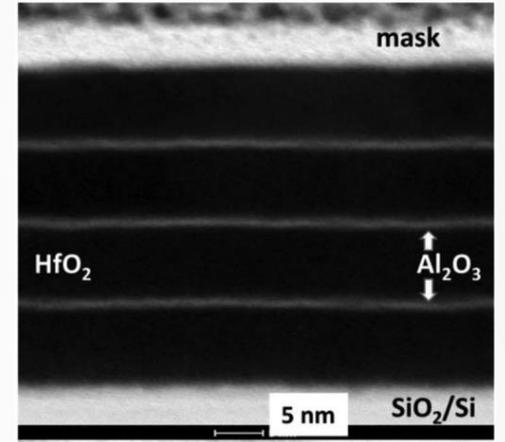
or an in-house made flow-type hot wall reactor

[T. Arroval *et al.* Thin Solid Films 600 (2016) 119]

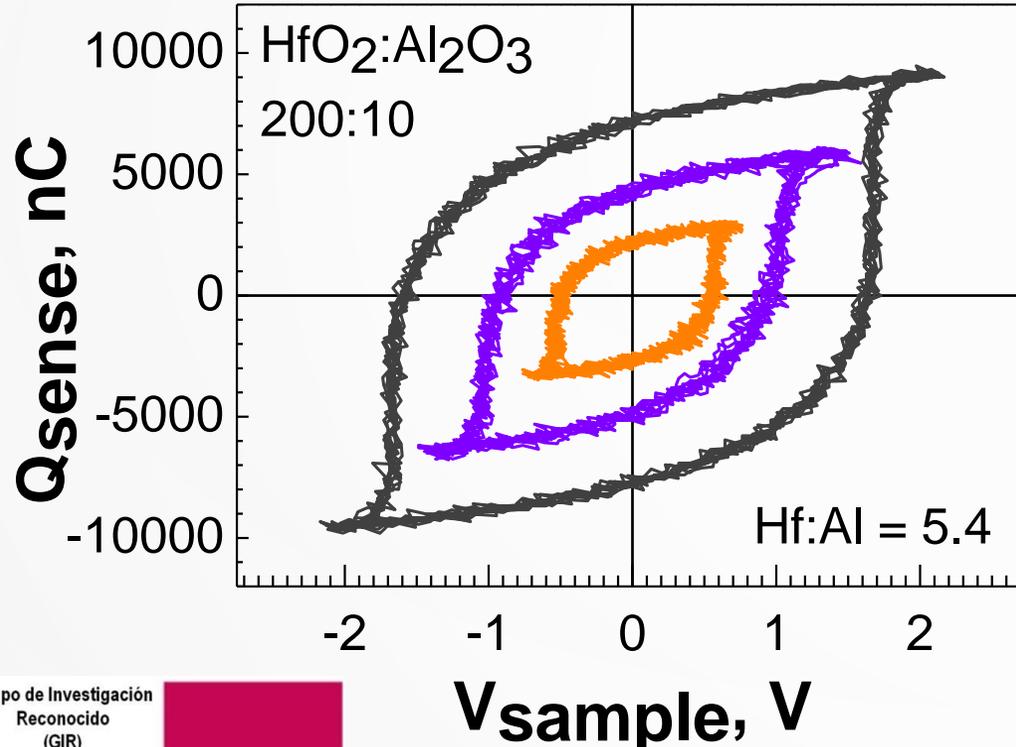


HfO₂-Al₂O₃ nanolaminate

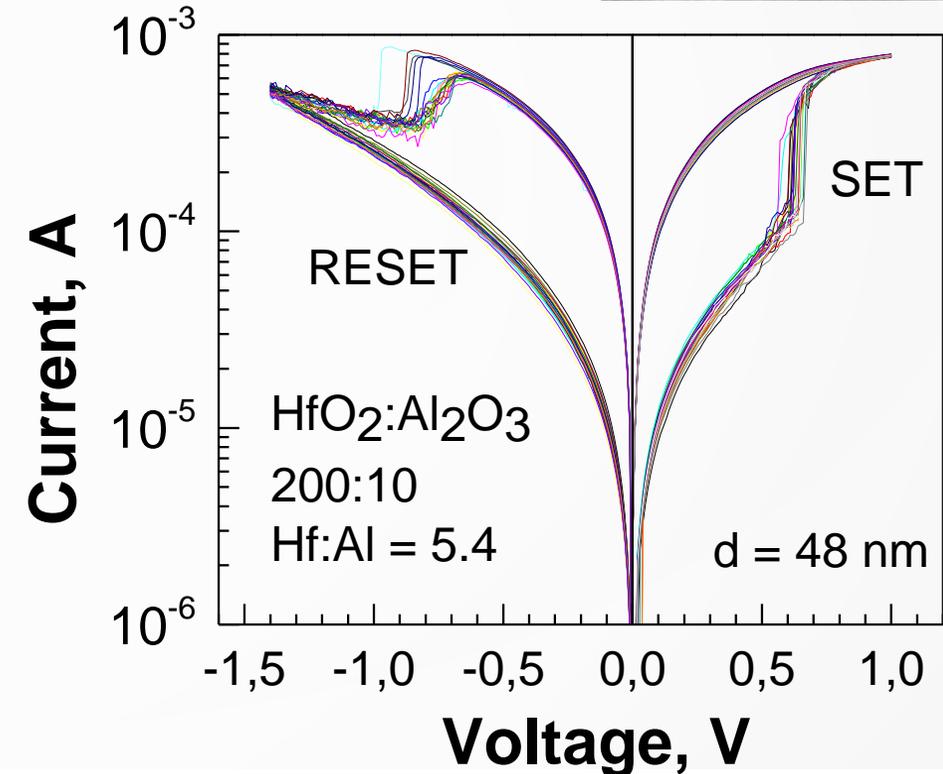
ALD cycle ratio 200:10, 4 x [200 x HfO₂ + 10 x Al₂O₃]



(ferro)electric polarization



resistive switching



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Kukli et al.,

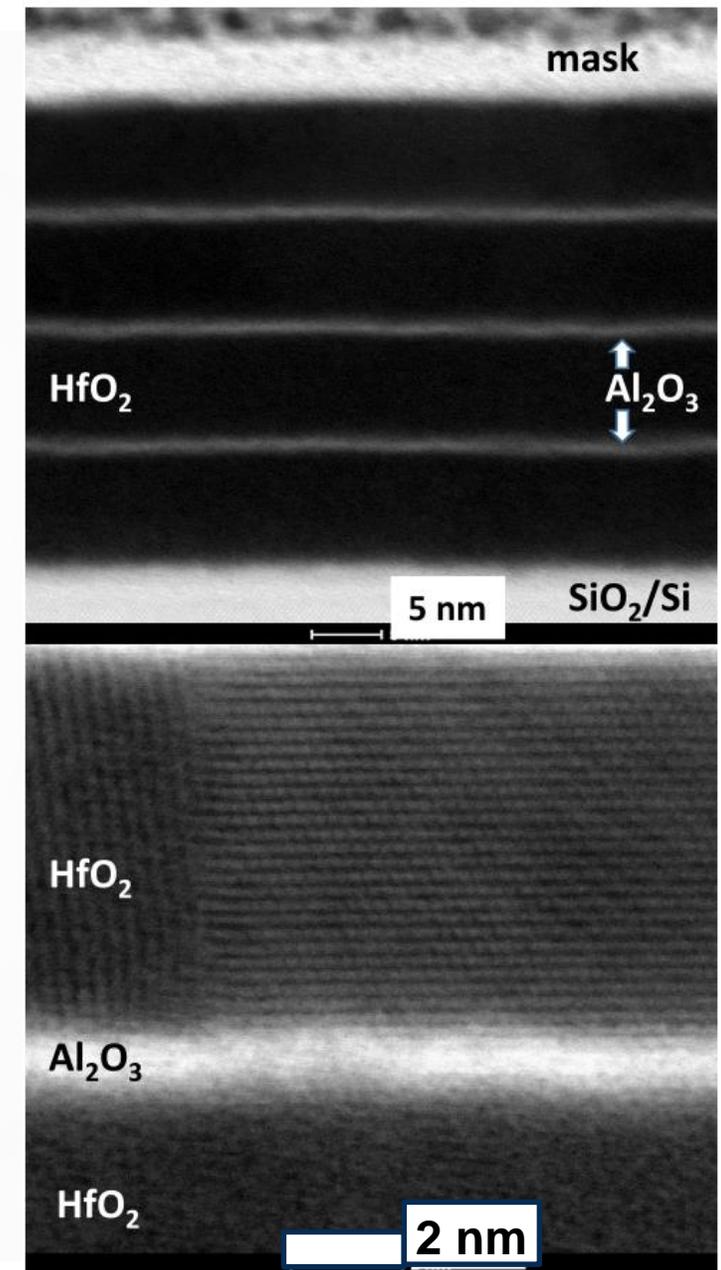
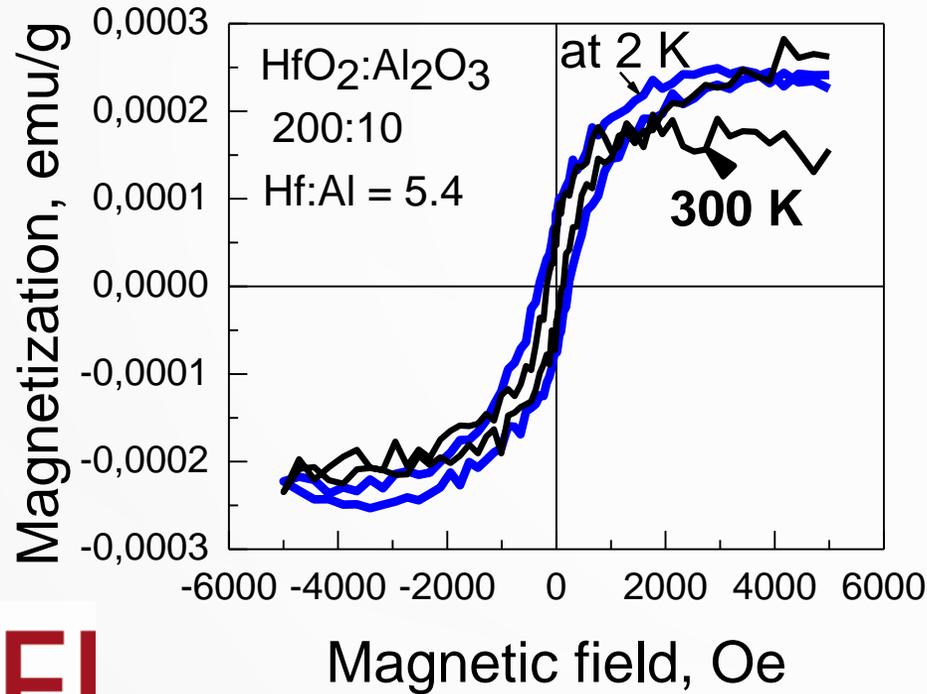
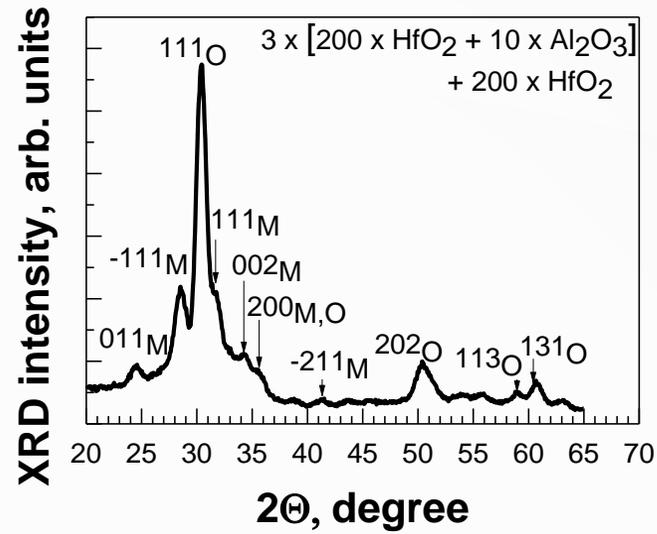
ECS Journal of Solid State Science and Technology, **7** (9) P501-P508 (2018)

17/06/2019

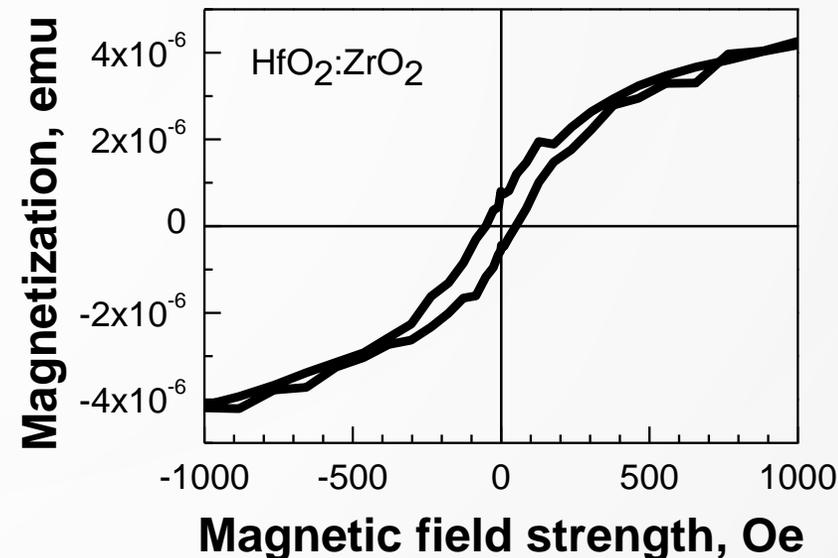
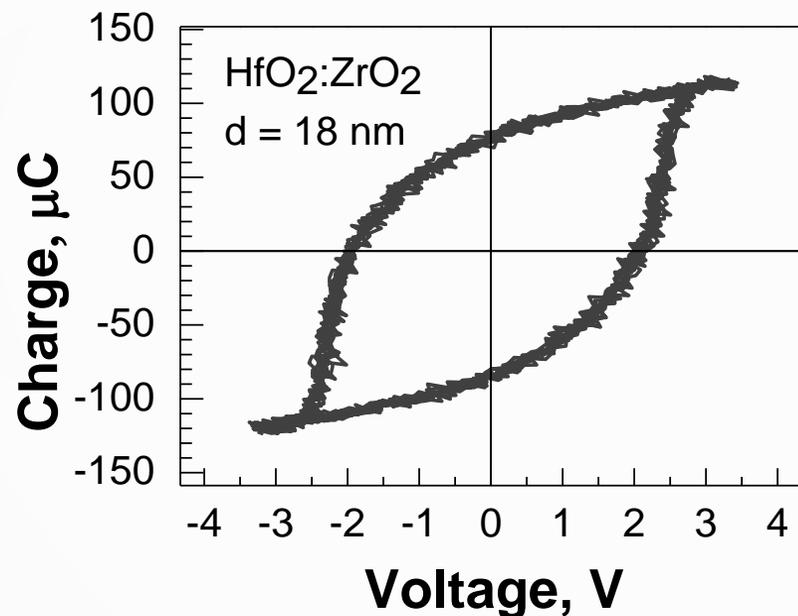
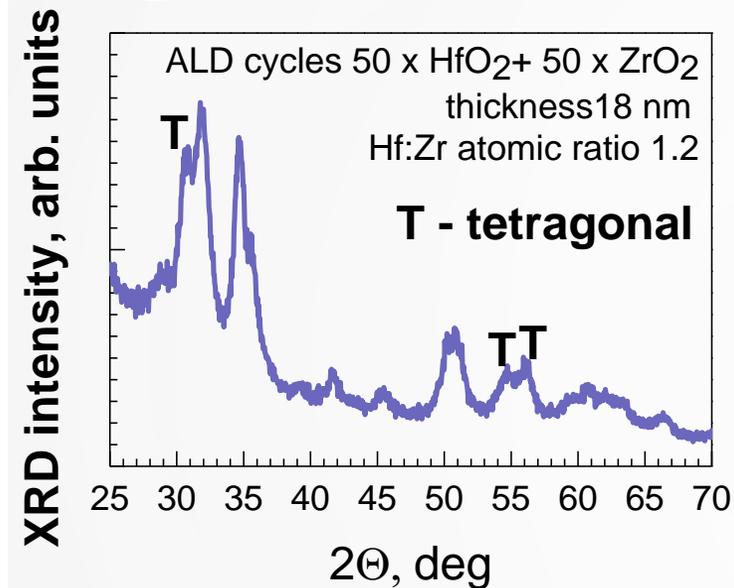


HfO₂-Al₂O₃ nanolaminate

Magnetization

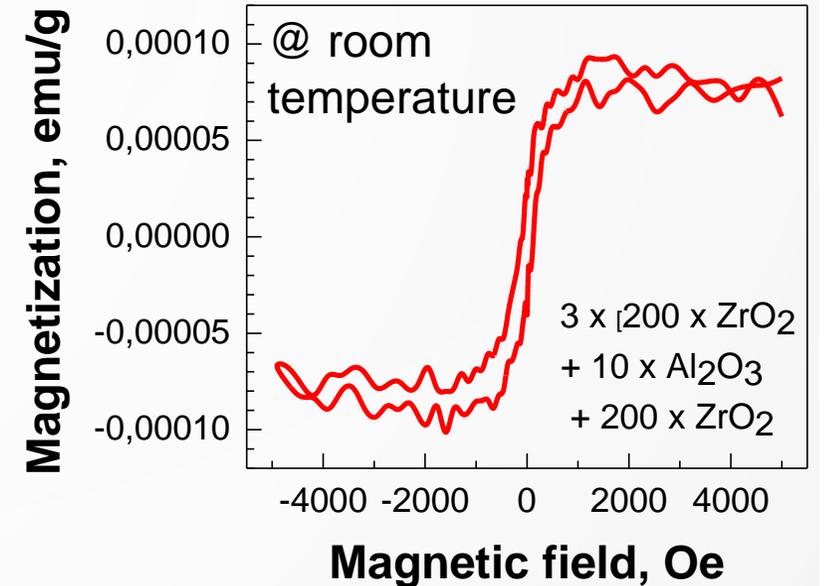
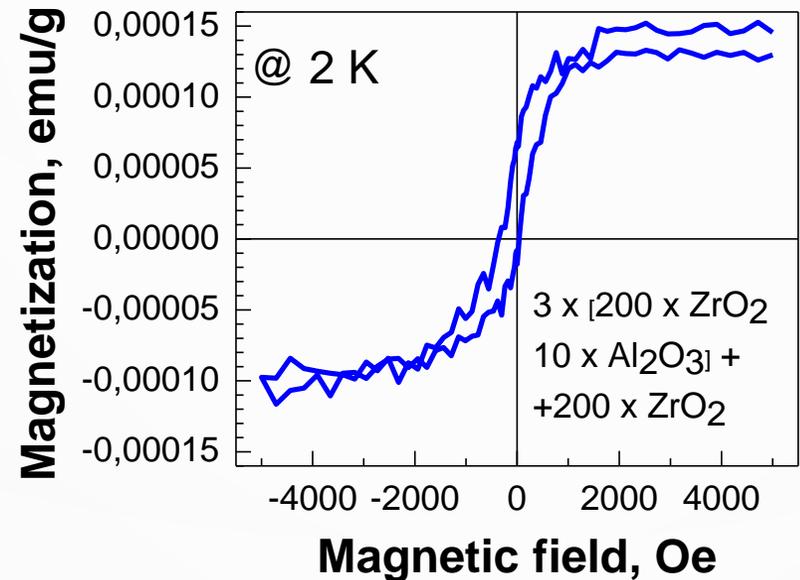
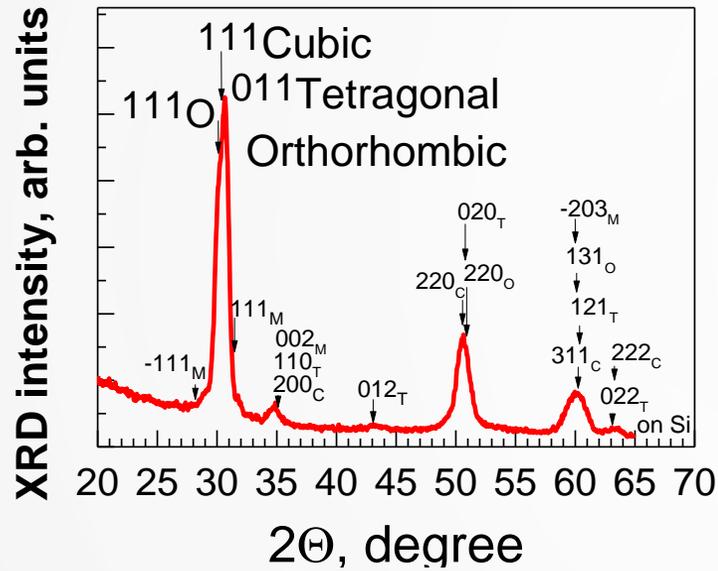
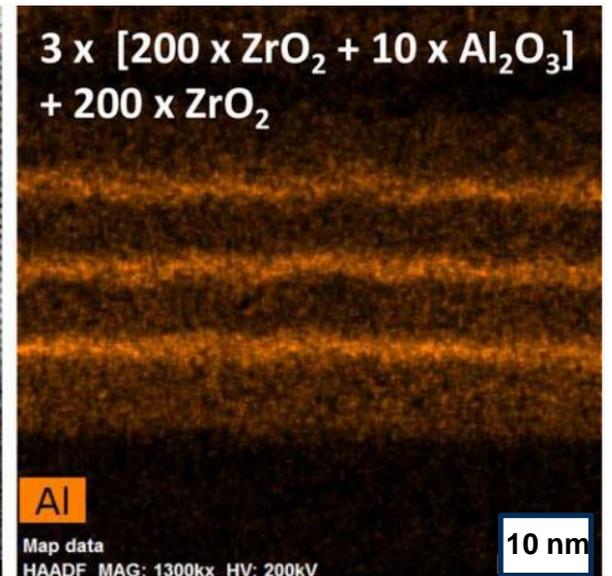
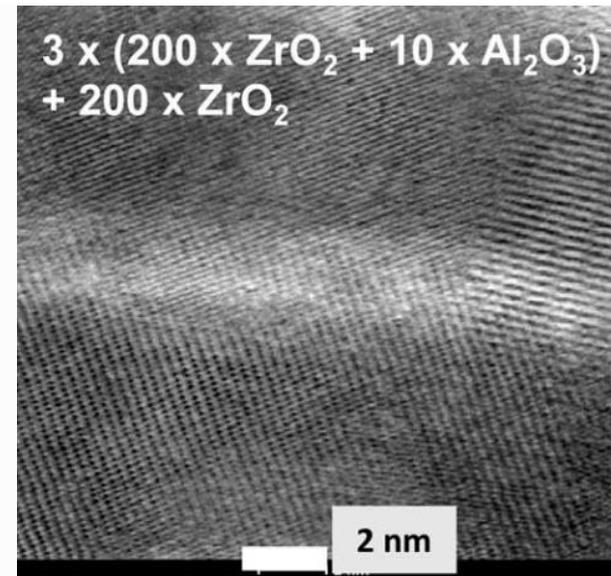


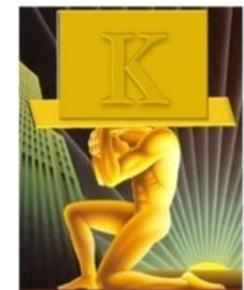
Structure, electrical and magnetic polarization in a $\text{ZrO}_2\text{-HfO}_2$ double layer





ZrO₂-Al₂O₃ nanolaminate

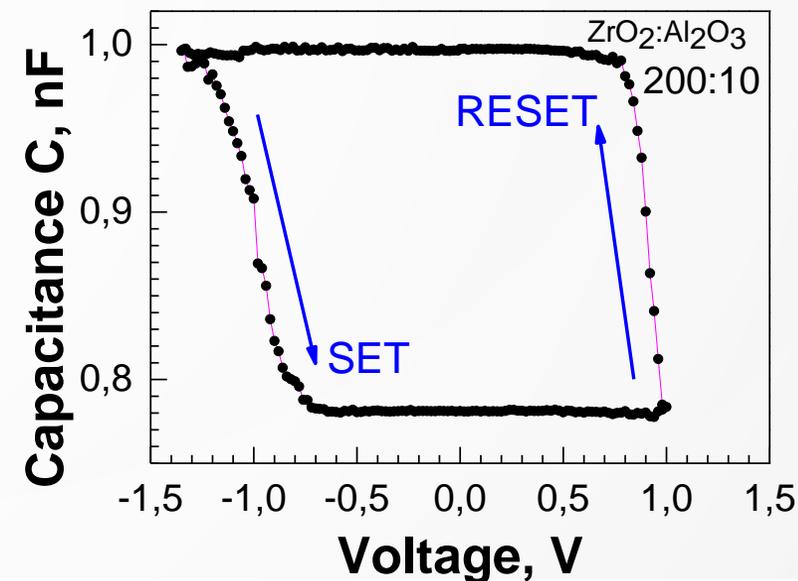
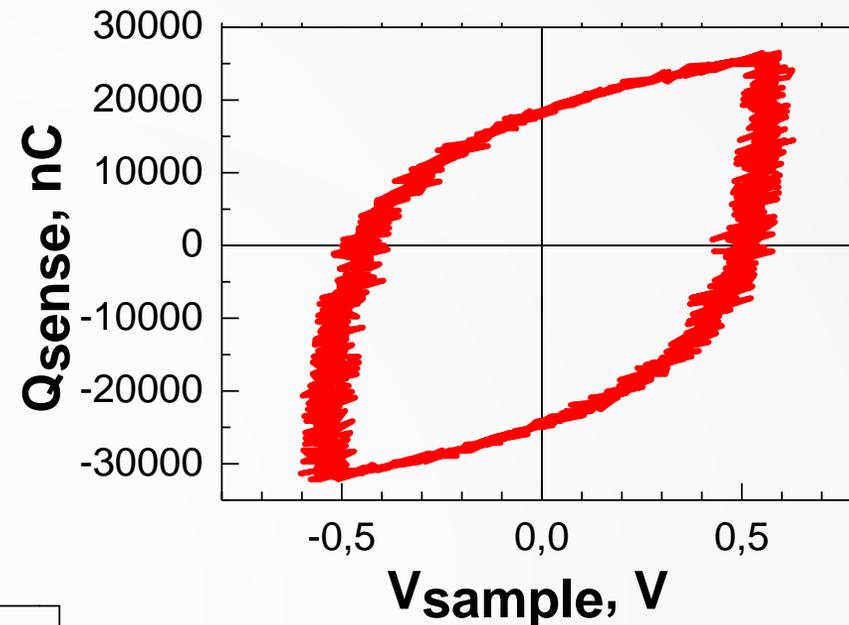
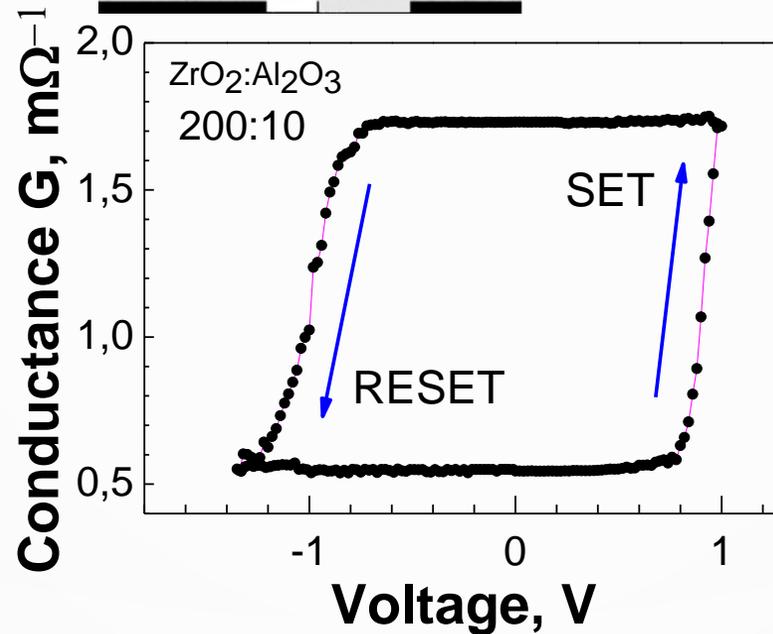
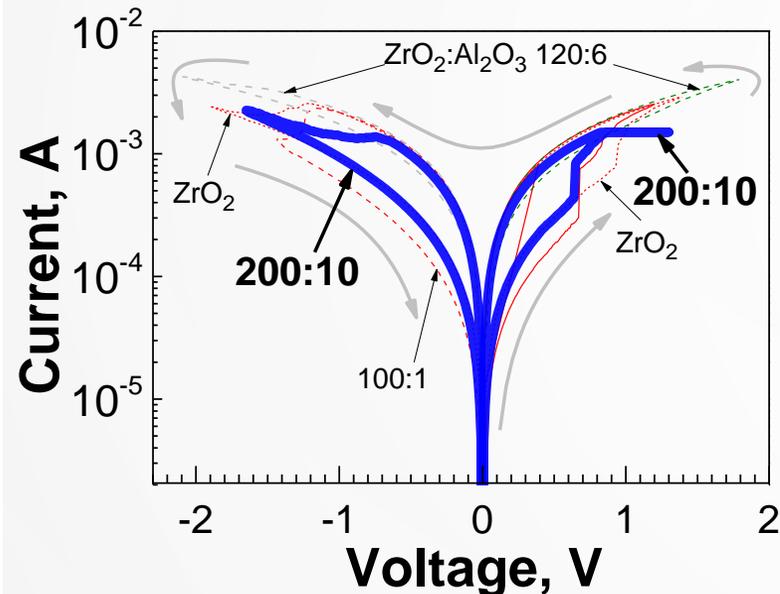
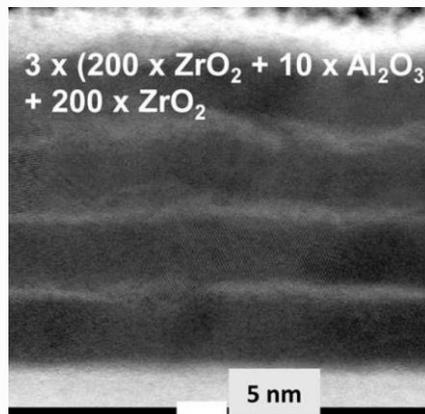




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Polarization and switching, $\text{ZrO}_2\text{-Al}_2\text{O}_3$ nanolaminate

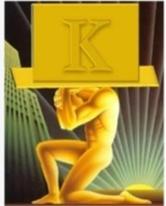




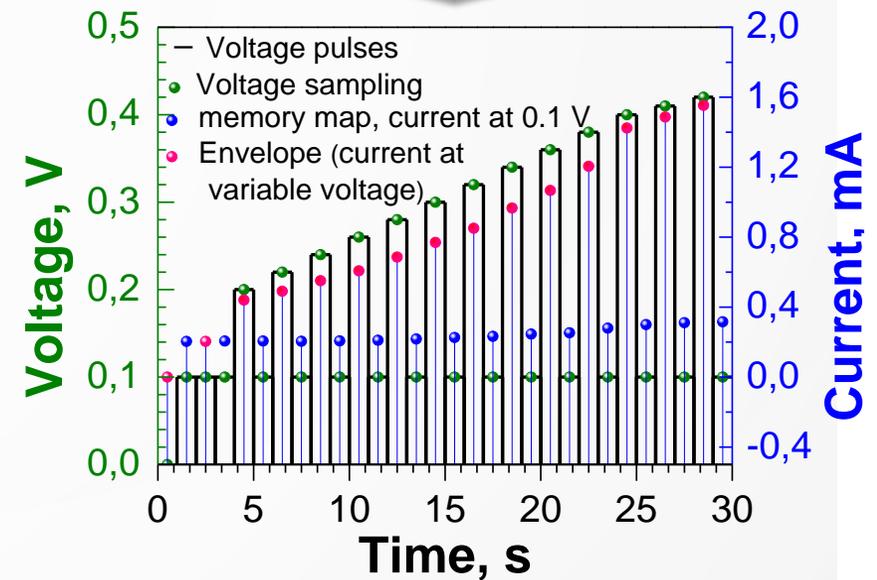
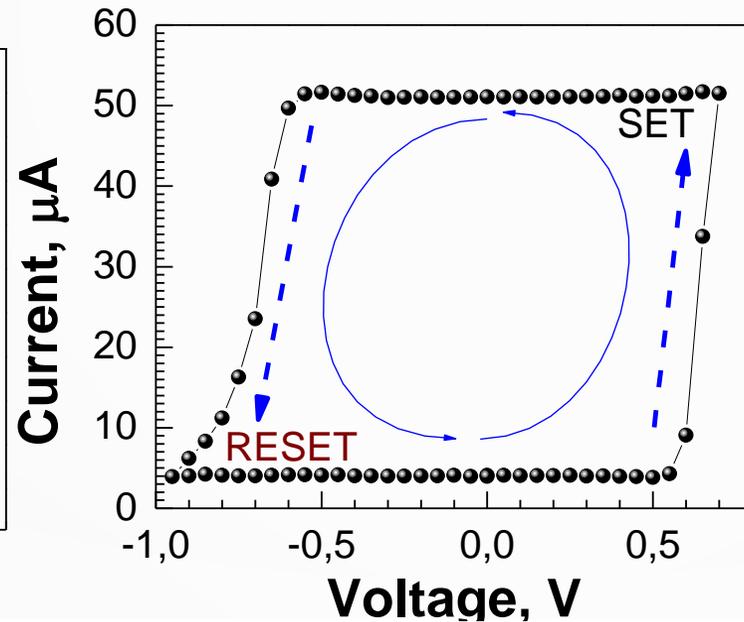
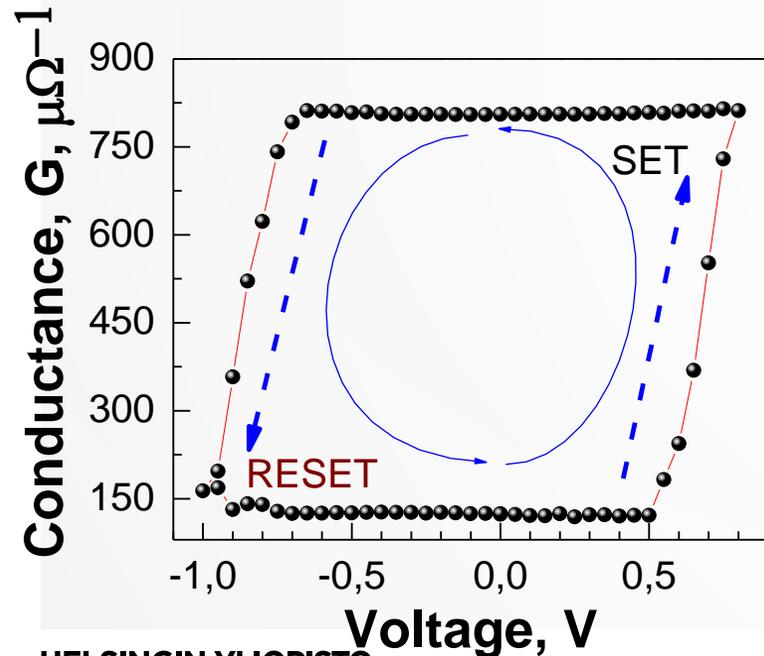
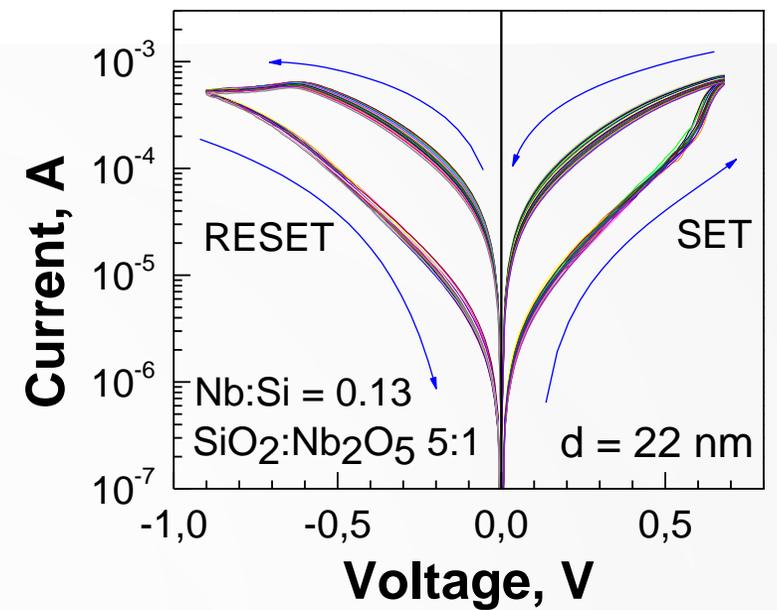
SiO₂-Nb₂O₅ mixture film

SiO₂:Nb₂O₅ ALD cycle ratio 5:1

Resistive switching



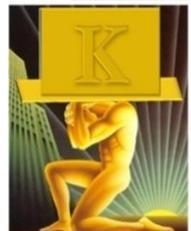
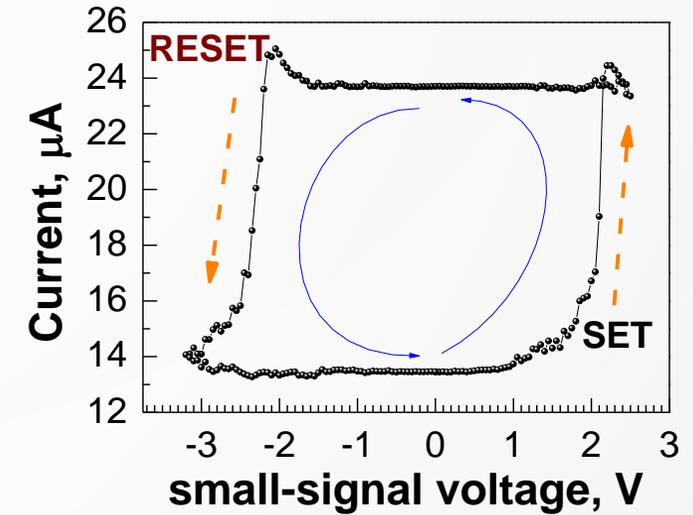
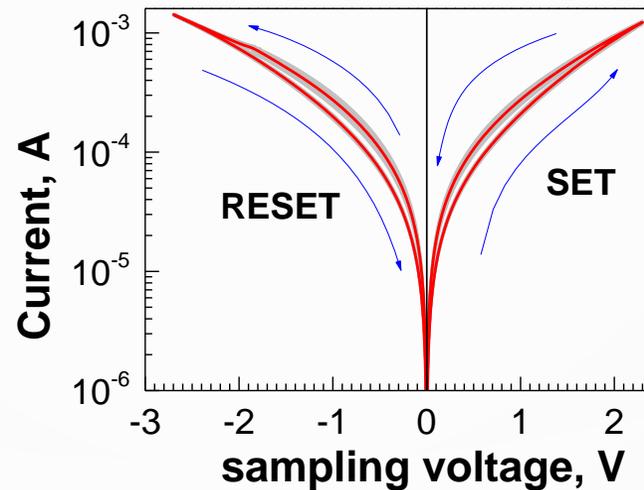
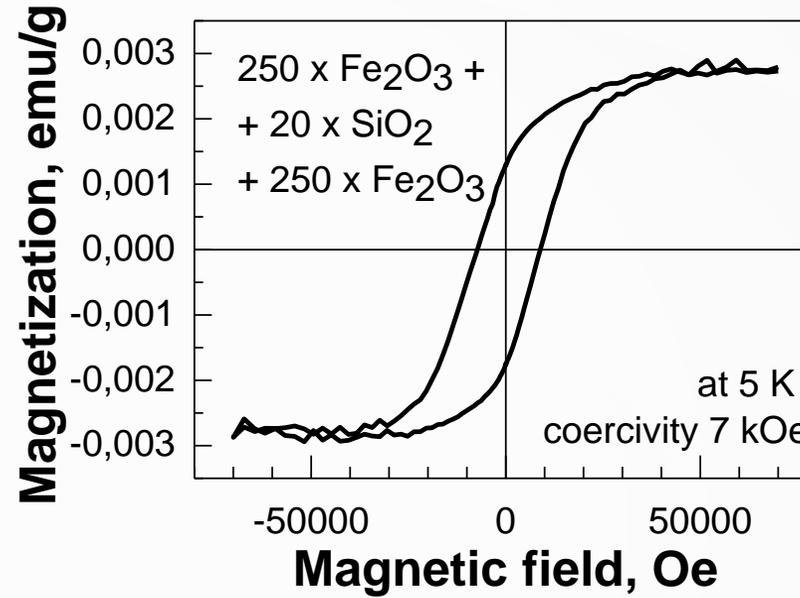
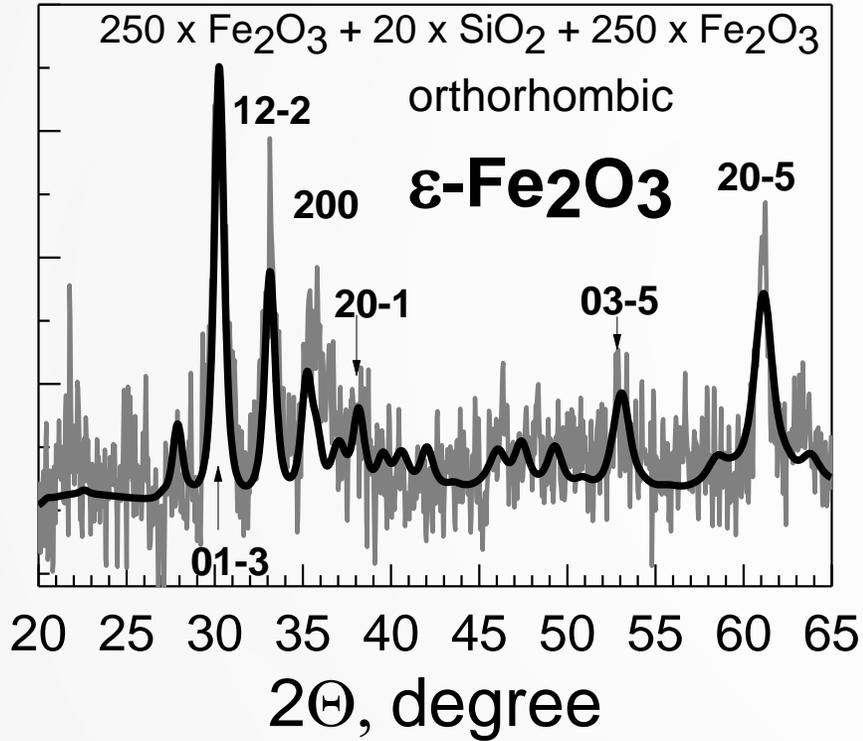
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Behavior of Fe₂O₃ embedding SiO₂ layer



XRD intensity, arb. units



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Bottomlines

*) No couplings between magnetization, electric polarization, and conduction were tested yet.

A material should exhibit all the following properties:

- ferromagnetic-like magnetization,
- ferroelectric-like charge polarization,
- resistive switching between low and high resistivity (conduction) states.

We can find materials combinations enabling appearance of all those properties, measured separately, and at room temperature.

(+) Crystallization in metastable phase, and, presumably, with marked defect densities, promote magnetization.

(-) Defects in a solid film increase leakage, harming ferroelectric-like performance and, further in larger contents, resistive switching.



ACKNOWLEDGEMENTS

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...and to the audience for your attention!