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Governing growth and performance of Fe(Se,Te) epitaxial superconductors on TiN buffered metal substrates

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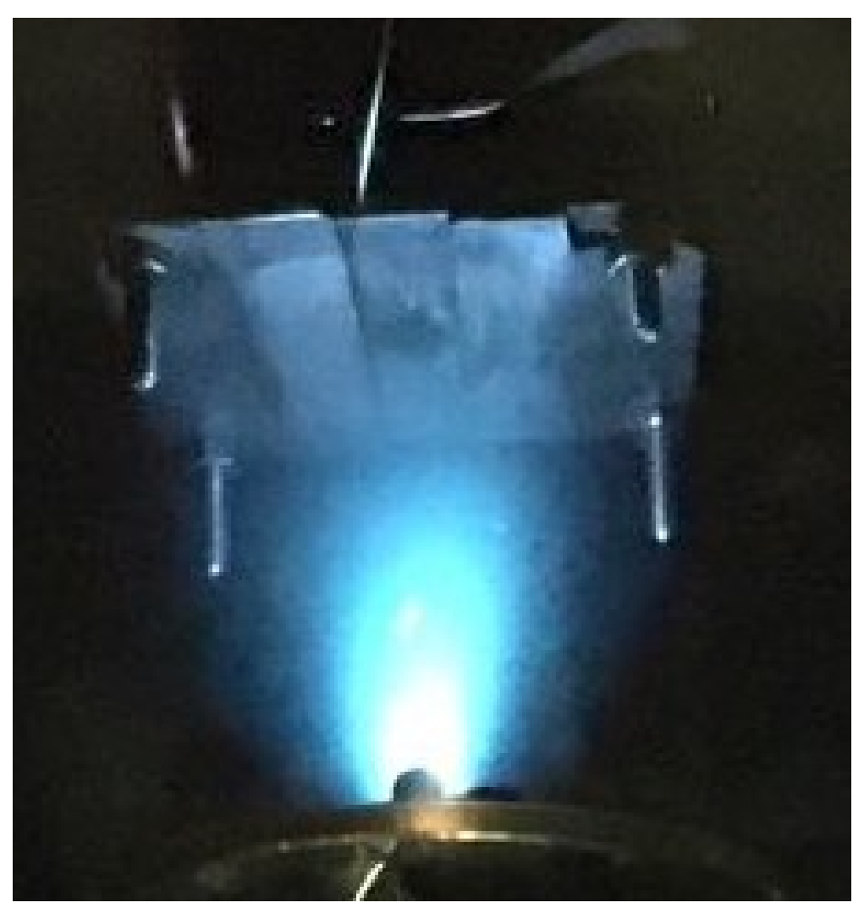
INTRODUCTION & AIM

- Epitaxial thin films assume nowadays the leading role as functional material in several applications: among these, the deposition of cuprates High Temperature Superconductors (HTS) as modern Coated Conductors (CCs), where the epitaxial growth of the material is enabled through the design of multiple oxide buffer layers, led to huge advancements in the high field magnet sector and thus fusion technology.
- Iron-based superconductors (IBS) such as Fe(Se,Te) constitute a novel class of superconducting materials, with critical temperatures in the 10 – 60 K range and extremely high critical magnetic fields. For IBS CC, the materials characteristics reduce the need for strict texturing and deposition conditions are less demanding than those required for HTS.
- A thin TiN film can represent an effective single buffer layer for the Fe(Se,Te) superconductor, enabling the oriented growth of high-performance films on biaxially textured Ni-W. This single buffer layer is furthermore appealing because TiN is electrically conductive [1].

METHOD



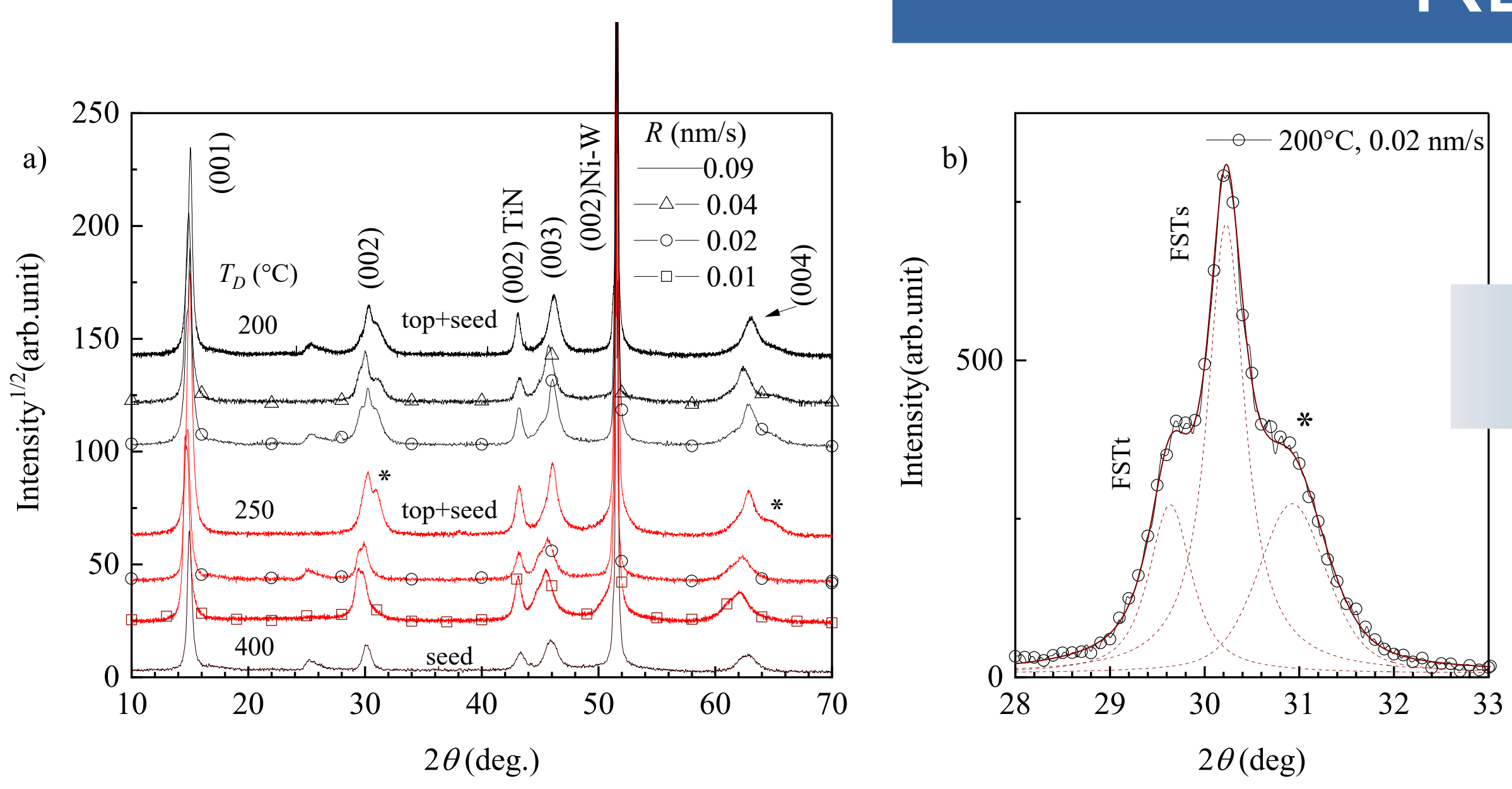
- TiN and [Fe(Se,Te) films deposited via Pulsed Laser Deposition on cube textured NiW substrates.
- Structural characterization with XRD and HR-TEM.
- Superconducting characterization by means of electrical measurements on patterned samples.

To optimize the properties of the superconducting film due to the loss of volatile elements, the Fe(Se,Te) is grown in two step, with a first layer deposited at higher temperature (**seed**) to promote crystallinity, and a second layer that grows homoepitaxially on the first one (**top**) characterized by correct stoichiometry [2].

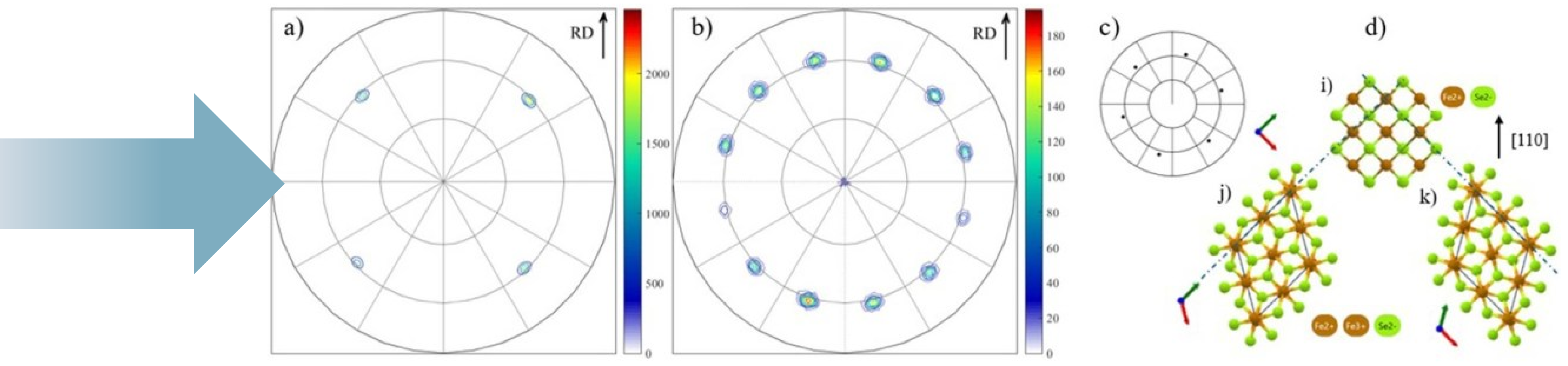
Aim:

- **Reduce the number of buffer layers.**
- **Shifts thermal/electrical stabilization to the metallic substrate.**
- **More compact and potentially more scalable design.**

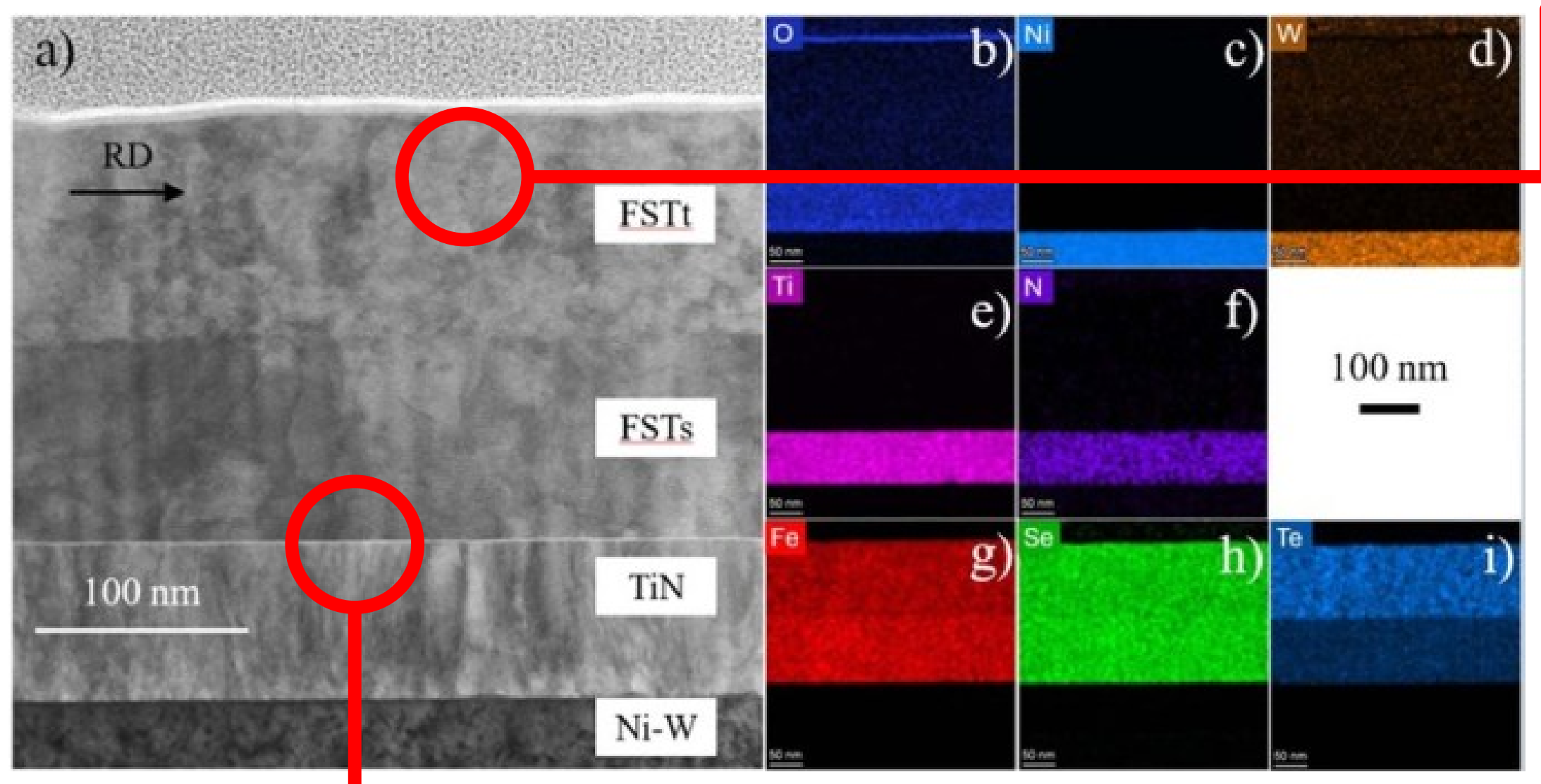
RESULTS & DISCUSSION



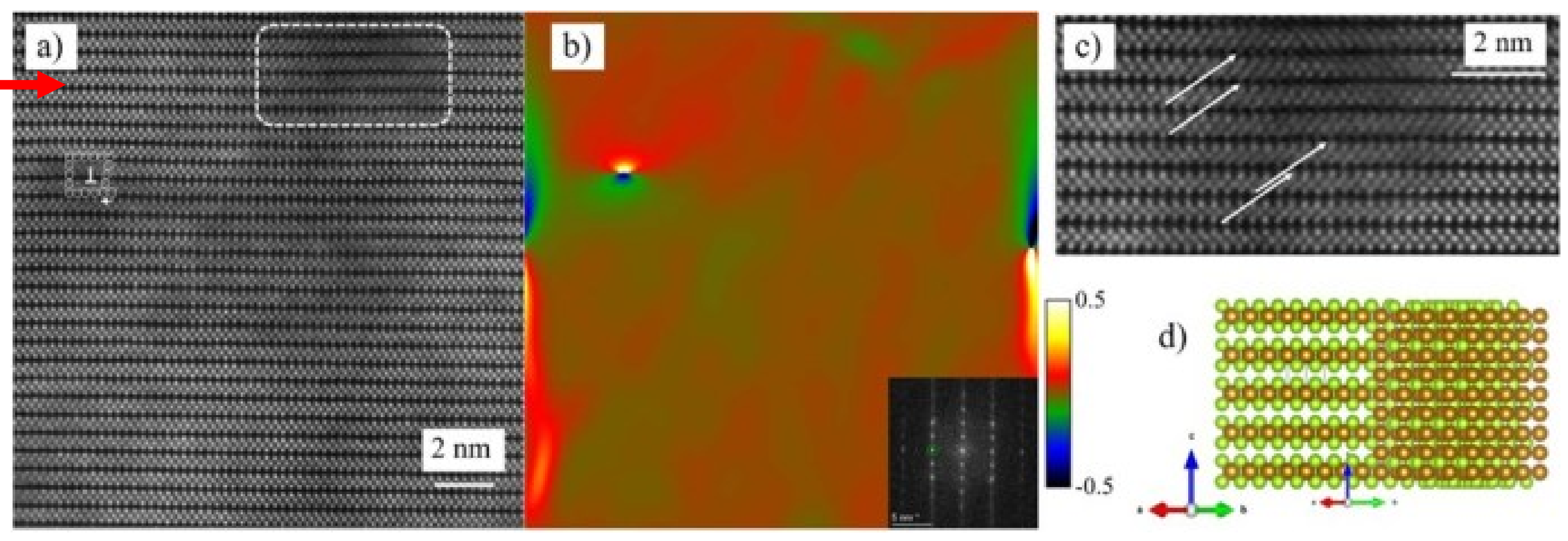
- XRD measurements show that the deposition produces films where the Fe(Se,Te) P4nmm phase grows with the *c* axis perpendicular to the substrate (only 00l peaks visible).
- Low temperature and fast deposition rate promote the formation of a secondary phase (*).



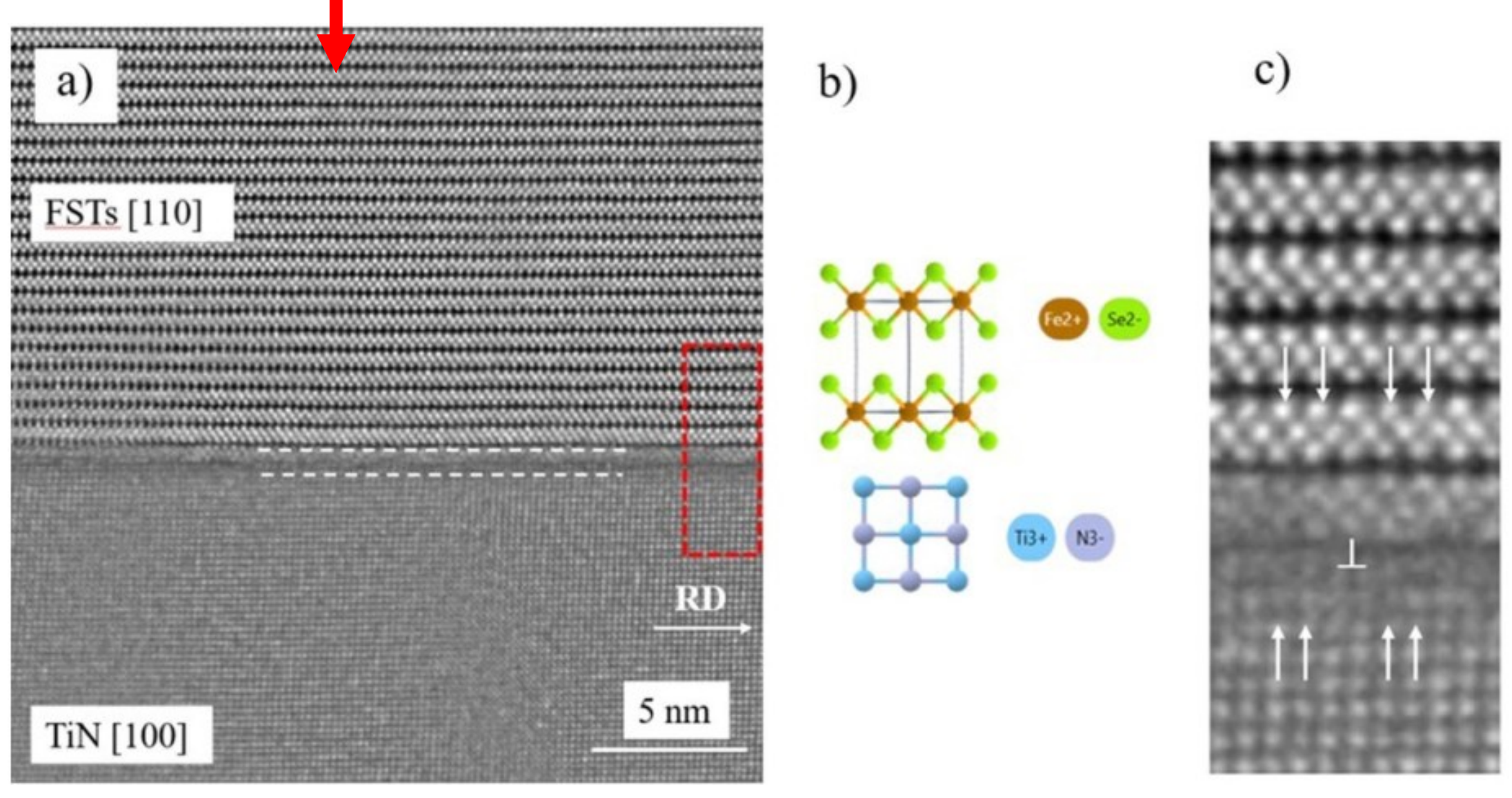
- The P4nmm Fe(Se,Te) phase grows with a single in plane orientation (a).
- The secondary phase is characterized by an in plane 6-fold symmetry with a possible 30° misalignment (b).
- This is ascribable to the presence of a hexagonal-like FeSe or Fe_7Se_8 phase that can grow coherently with the P4mmm lattice (in plane view) with two orientations (j and k) .



- The TEM analysis of the film section shows the layered structure, with the TiN buffer layer, the Fe(Se,Te) seed layer and the Fe(Se,Te) top layer.
- The seed layer is Te-deficient (with respect to the top layer) due to its evaporation during the higher temperature deposition process (400 °C vs 200 °C).

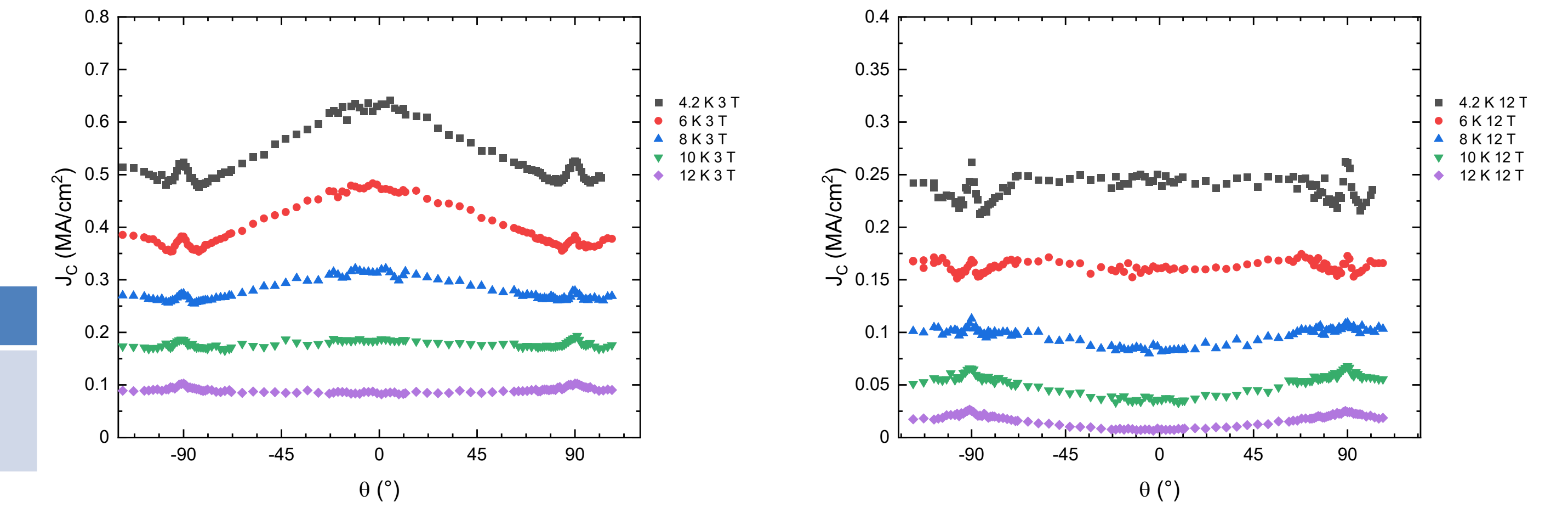


- HR-TEM analysis show defects in the Fe(Se,Te) top layer, such as and **nano-inclusions** of the secondary phase and dislocation (panel c).
- This intricate pinning landscape results in **high quasi-anisotropic critical currents**, with critical currents in self-field comparable if not higher with respect to single-crystal substrates and oxide buffers.



- The interface between the TiN and the Fe(Se,Te) seed layer shows a clean structure, exhibiting a **Domain-Matching Epitaxy mechanism (DME)**. This is due to the large reticular mismatch between TiN and Fe(Se,Te) .

Phase	*a* (Å)	ε	ε DME
Fe(Se,Te)	3.79 → 5.36 (a ·√2)	26 %	5%
TiN	4.241		



Critical currents at different temperatures and fields (3T – left and 12 T – right) as a function of the angle θ between the film and the magnetic field

CONCLUSIONS

- The growth of Fe(Se,Te) thin films is governed by an intricate equilibrium between temperature and deposition rate, driven by selective evaporation of Se and Te and by the strain induced by the substrate/buffer layer.
- The optimization of deposition conditions is needed in order to promote the formation of a superconducting layer characterized by the correct stoichiometry, and possibly by the presence of secondary phase nano-inclusions, that promote isotropic pinning and thus critical current enhancement at all temperature-field-angle regime.
- The Fe(Se,Te)/TiN/NiW architecture is a promising approach to produce the next generation of coated conductors, characterized by low cost, high performance in the low temperature – high field regime, and intrinsic stabilization granted by the electrically conducting buffer layer.

REFERENCES/ACKNOWLEDGMENT

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