ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

SuperMAD update meeting

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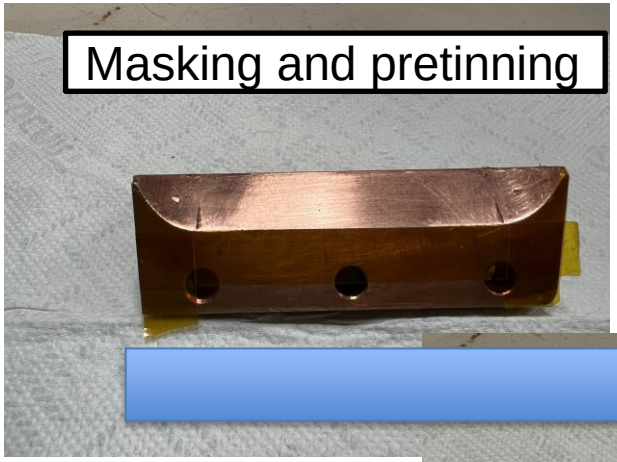
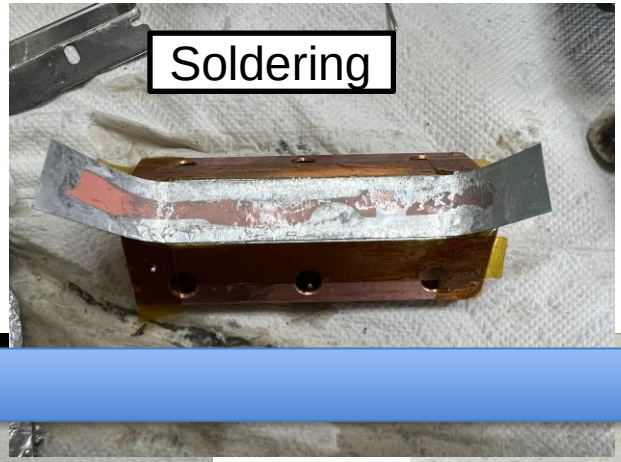
Teams, 13/5/2025

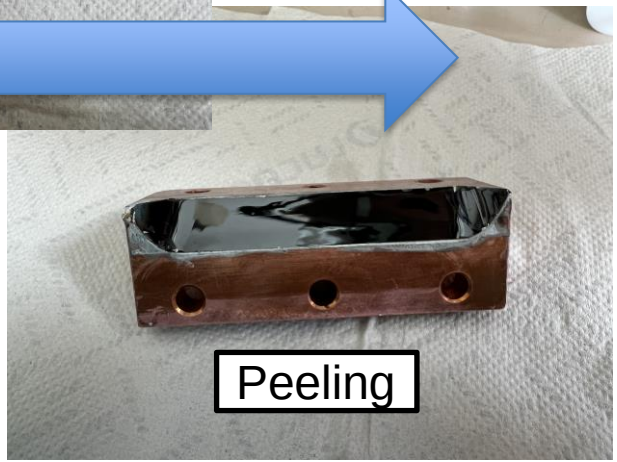
ENEA (current) involvement in SUPERMAD

WP	Task and sub-task description	Units involved
WP1 – Superconducting Materials	**Task 1.1 - REBCO cladding**	
	1.1.1 Development of fixture methods (M1-M12)	**LNF, ENEA, RM3**
	1.1.2 Evaluation of REBCO exposure procedure (M2-M12)	**LNF, ENEA, RM3**
	1.1.3 Cladding of reference cavity for WP3, task 3.2 (M13-M18)	LNF, ENEA, RM3
	1.1.4 Optimization of cladding procedure on haloscope cavity for task 3.1 (M19-M34)	LNF, ENEA, RM3
	1.1.5 Planar Sample for WP2 (M3-M10)	**LNF, ENEA, RM3**
	Task 1.3 – Iron Based SC	
	1.3.1 Development of Fe(Se,Te) tape (M1-M12)	**RM3, ENEA**
	1.3.2 Development of Fe(Se,Te) tape: large area deposition (M13-M36)	RM3, ENEA
	1.3.3 Electrodeposition of FeSe films (M9-M36)	RM3, ENEA
	1.3.4 Planar Sample Fe(Se,Te) for WP2 (M13-M24)	RM3, ENEA
	1.3.5 Planar Sample FeSe for WP2 (M25-M36)	RM3, ENEA

Task 1.1 – REBCO Cladding







1. Soldering alloy (T)
2. Tape producer

Task 1.1 – REBCO Cladding

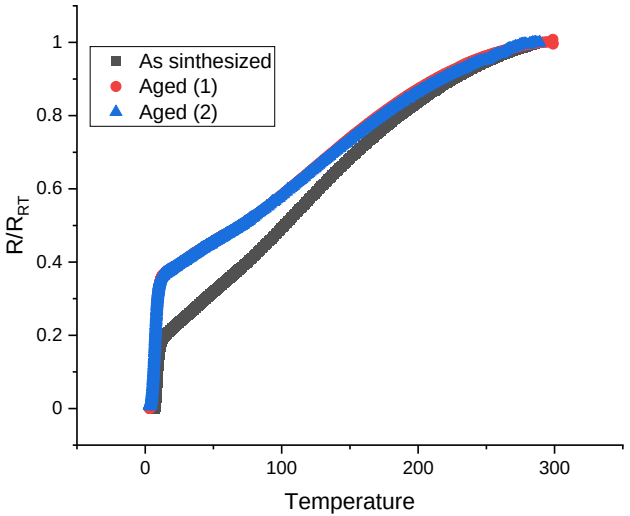
1.1.1 & 1.1.2:
Test cavity (4 pieces) and reference 10 piece received beginning of May

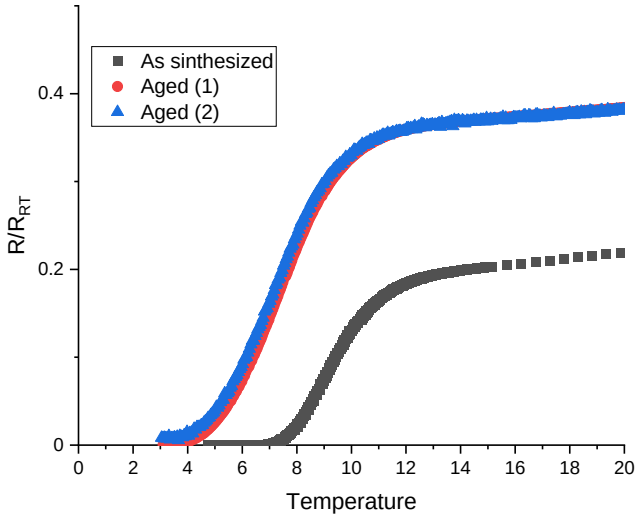
1.1.5: (REBCO Planar Sample for WP2)
To produce small samples on copper planar substrate for RM3 and PoliTO

1. 1mm thick copper ok?
2. Size?
3. What is tolerable on the REBCO surface? i.e., the presence of an oxide layer or oxide layer residues from the buffer layer affects the performance?

REBCO sensitivity to H_2O: Prepare and measure

Task 1.3 - FeSe - Handling

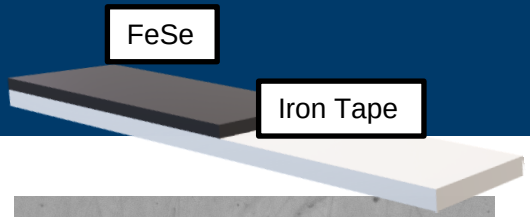




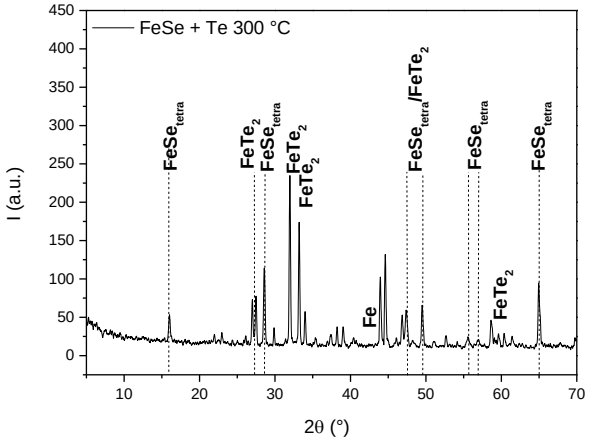
Onset retained, probably grain boundary oxidation

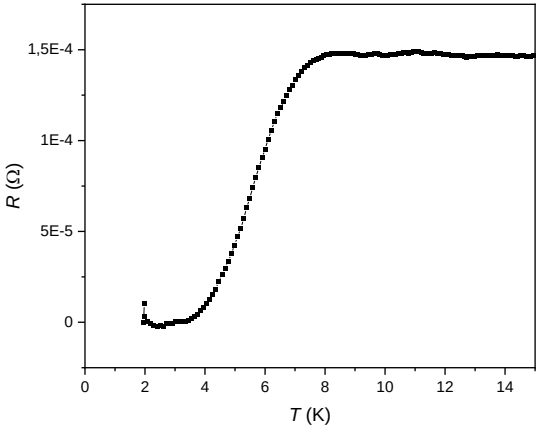
- To be stored in dessiccator (under vacuum?)
- Avoid water adsorption

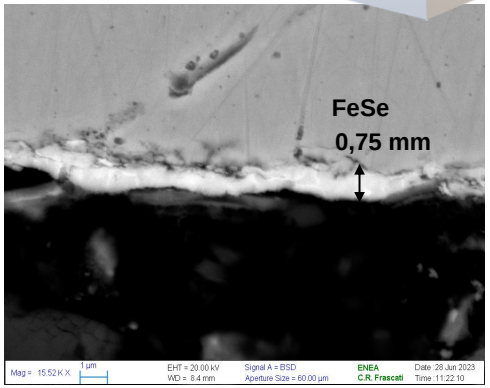
FeSe - Electrochemistry



REPRODUCIBLE 3-STEP METHOD FOR THICK FeSe FILMS ON IRON SUBSTRATES

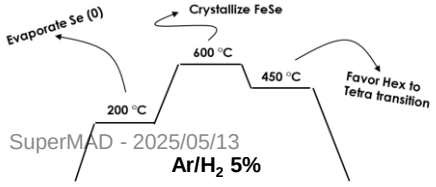




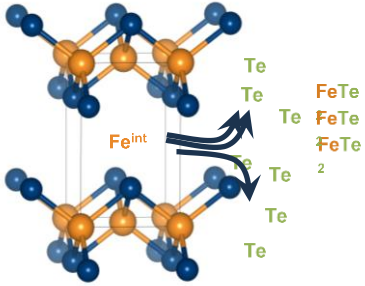


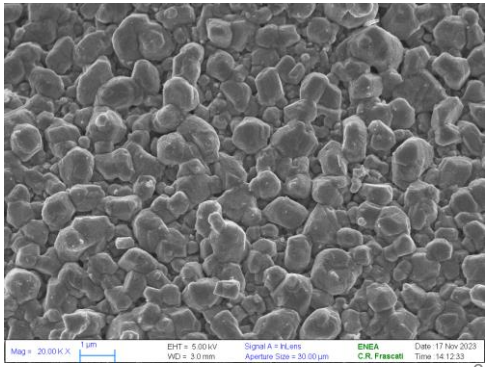
STEP 1 ELECTROCHEMICAL SOLUTION for FeSe:
SeO_2 0.08 M +FeSO4 0.42 M, pH 2
70 °C, 5 min
V = -1,1 vs Ref (Ag)
WORKING ELECTRODE: Fe
COUNTER ELECTRODE: Pt

STEP 2 SINTERING THE THERMAL TREATMENT



STEP 3 INTERSTITIAL Fe REMOVAL IN Te VAPOUR





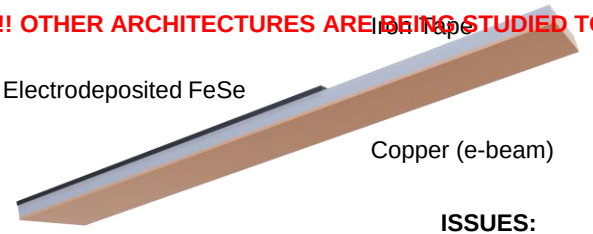
Electrodeposition on cavities

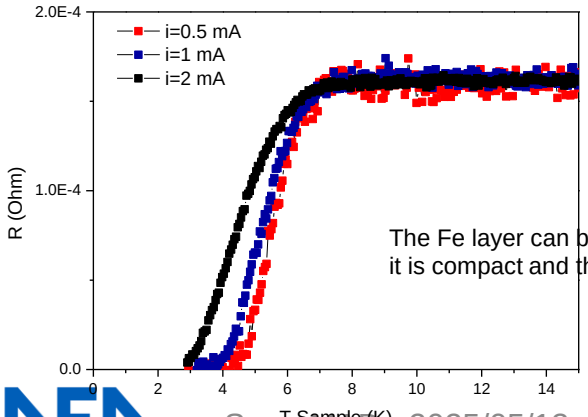
Chemical compatibility with cavities - Copper-coated Iron Substrates

WE KNOW IRON SUBSTRATES ARE NOT SUITABLE!! OTHER ARCHITECTURES ARE BEING STUDIED TO REDUCE ITS THICKNESS!!!

Cu is a huge problem since it diffuses easily into the superconducting layer.

We could combine the FeSe need of a Fe substrate to the necessity of blocking Cu diffusion





The Fe layer can block Cu diffusion as long as it is compact and thick (100 mm)!!

ISSUES:

- Samples are brittle an fragile

- FeSe shows degradation in time if stored in air

- **We can no longer work with Te (safety issues, cancerogenic)**
- **First results on thinner Fe substrates (40 mm) unsuccessful**

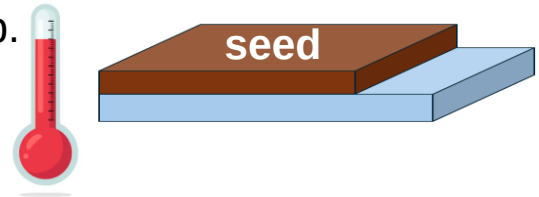
NEXT STEPS:

- **Other samples on thin Fe substrates (40 mm)**
- **Find effective ways to reduce interstitial Fe without Te (S, Se)**

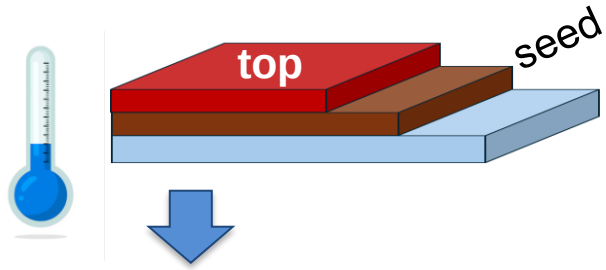
PLD Fe(Se,Te)bi-layer – the seed approach

seed	**Good epitaxial growth** Loss of volatile elements	crystalline structure of the superconducting compound	Fe(Se,Te) top layer epitaxy at low T_D, with proper stoichiometry

Fe(Se,Te) dep.
T_D
450-400°C



Fe(Se,Te) dep.
T_D
350-200°C



Se/Te >1
semiconducting behavior or low-T_c superconductivity
(on MgO or CaF_2 single crystals)

Homoepitaxy
Stoichiometry control Se/Te~1

High-T_c superconductivity and reproducibility

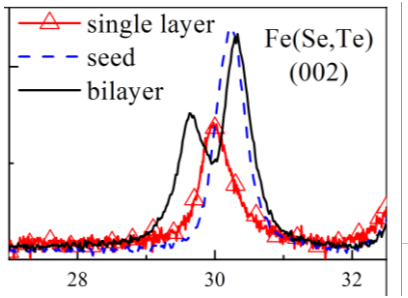
Molatta, S. et al. *Sci.* Rep., 2015, 5
Mancini, A. et al. IEEE TAS, 2024, 34-3, 7500205

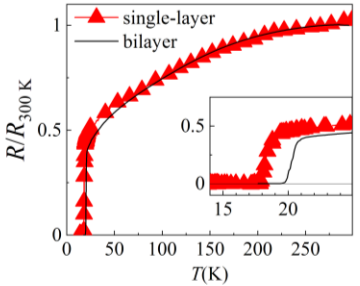
Bilayer vs single-layer

- T_C increase
- In-field J_C improve

FST	T_D (°C)	$\Delta\omega^{\#}$ (°)	c (nm)	t* (nm)
Single layer				
	300	1.2	0.597	110
Bilayer				
seed + top	400	0.7	0.590	140
	250	1.1	0.601	
Bilayer + lower T_D seed				
seed + top	400	0.6	0.594	200
	200	1.0	0.603	

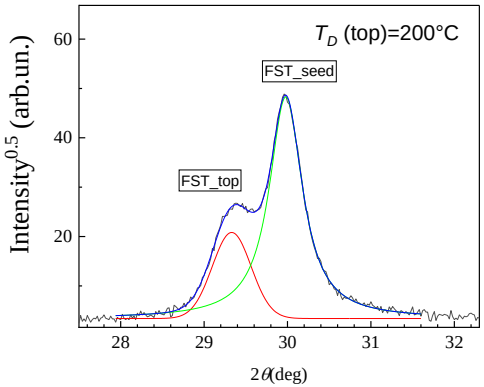
(001)CaF_2 substrates

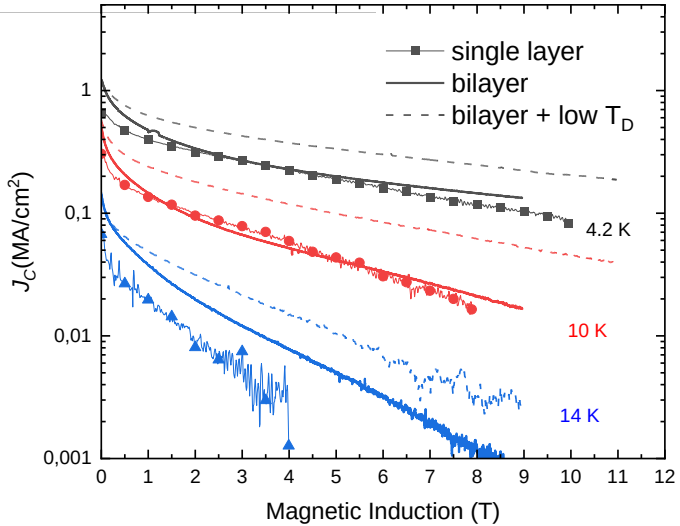




T_{C0}=17,8 K

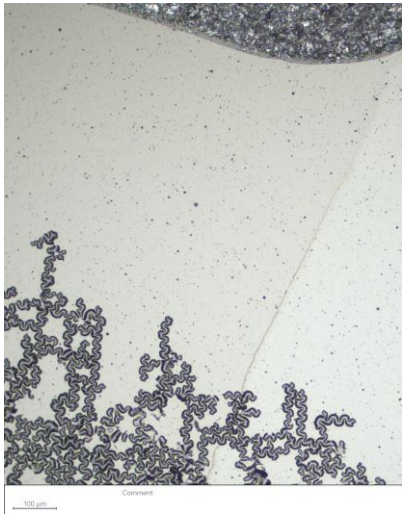
T_{C0}=19,8 K





Increasing of Fe(Se,Te) film thickness

- Doubled laser energy for Fe(Se,Te) top layer deposition



Nominal thickness ~300 nm (total)

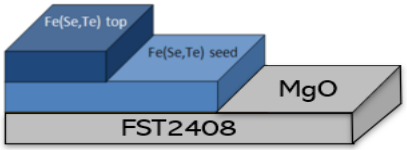
T_{C0}=17.4 K

Film instability: Telephone cord blisters

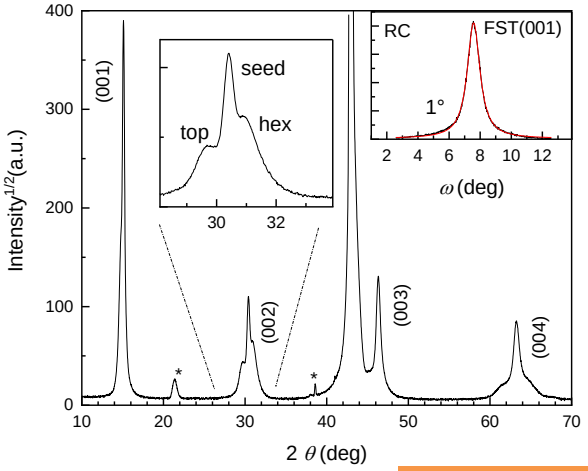
- thermal and/or epitaxial strain relaxation

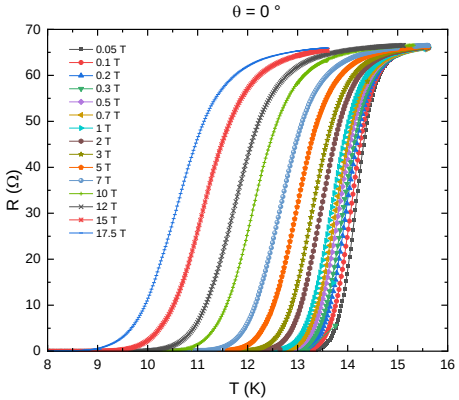
(001)CaF_2 substrates

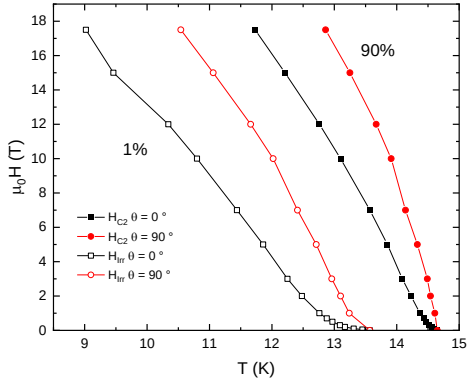
(001)MgO substrate

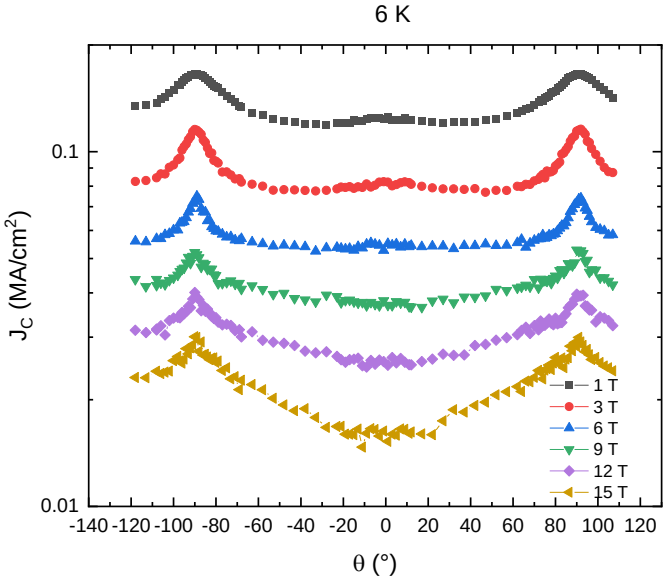


Seed Layer 400 °C , Top Layer 200 °C, total thickness ~200nm







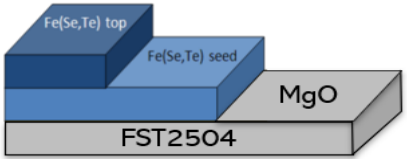


T_C(K) (90%)
14.7

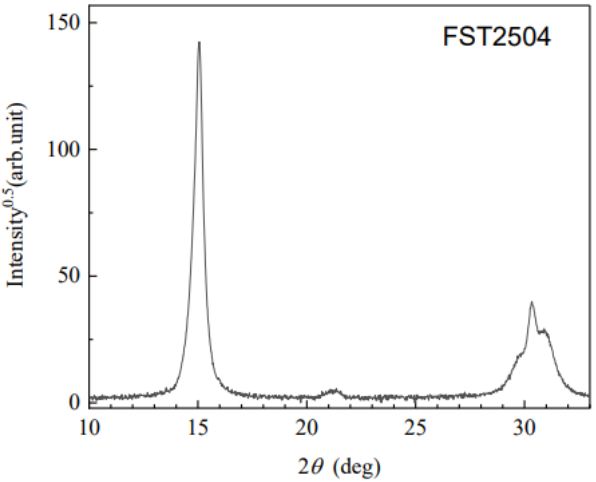
- Isotropic J_C behaviour

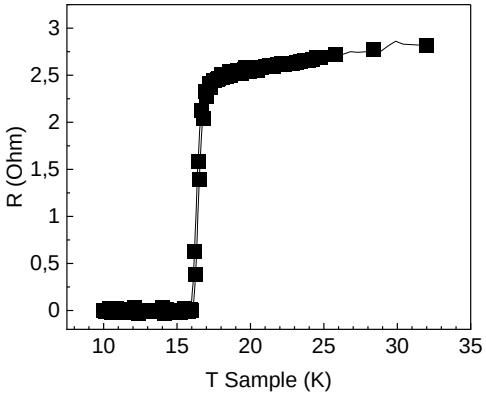
$$\frac{\mu_0 H_{c2}^{ab}}{\mu_0 H_{c2}^{c}} \sim 1.5$$

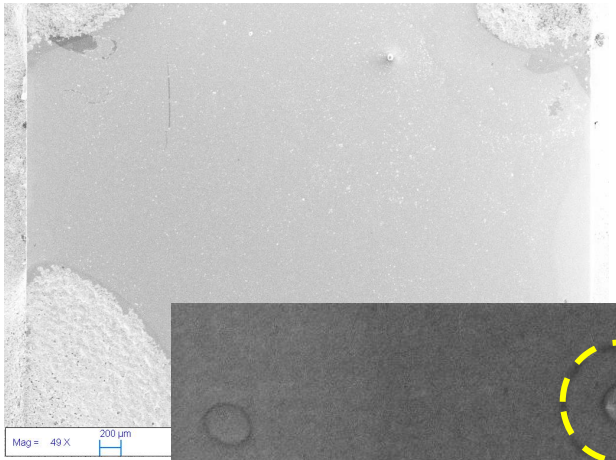
(001)MgO substrate: increasing of thickness (…)

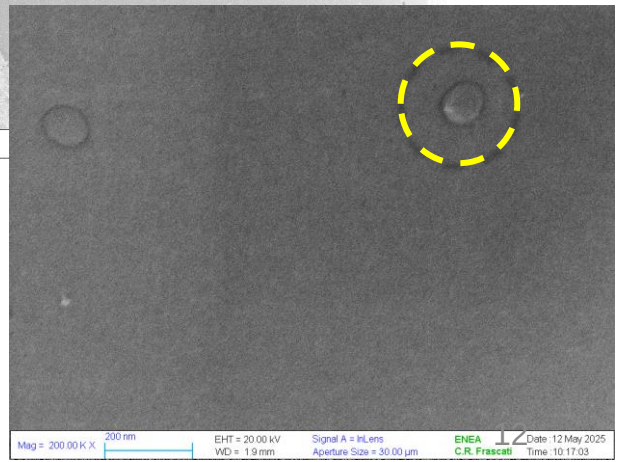


Seed Layer 400 °C , Top Layer 250 °C,
total thickness ~ 210 nm







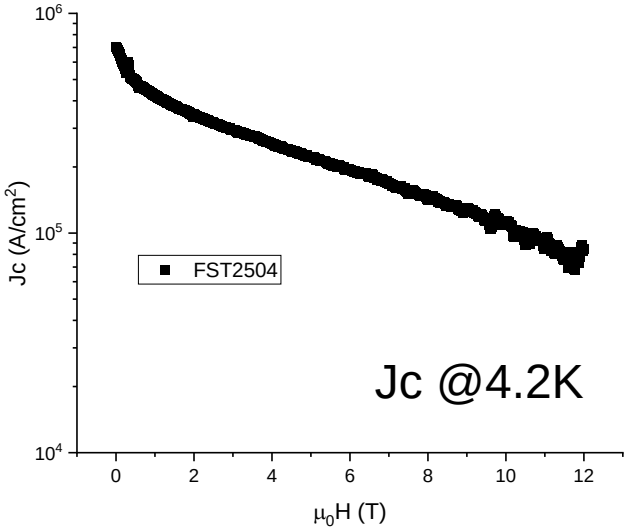


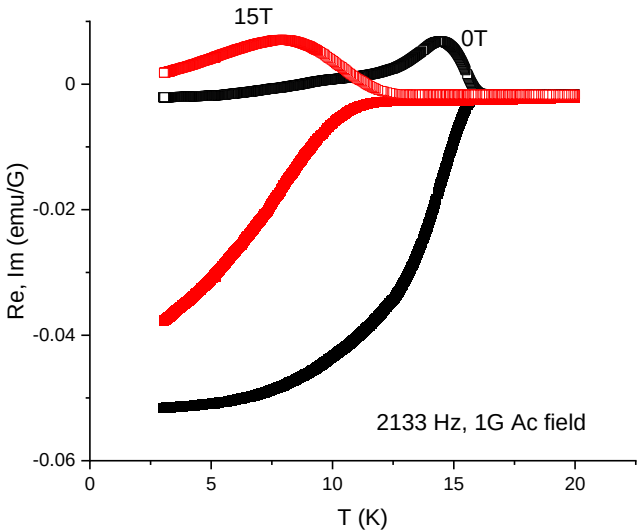
T_C(K) (0)
16

Isolated grains:
Density 0.55 µm^{-2},
Average Diameter 120 nm
EDX: hexag. Fe_7Se_8

Fe(Se,Te) on Mgo

Characterization ongoing
(VSM and ACS)





- Improved Fe(Se.Te) film properties on CaF_2 and MgO single crystal substrates
- Isotropic J_C behaviour
- Thick film: instability on CaF2, in progress on MgO

Thank you for your attention