Work is supported by

PTI+ TransENER

Transient Liquid Assisted Growth (TLAG)

A method to increase CC throughput and meet applications requirements

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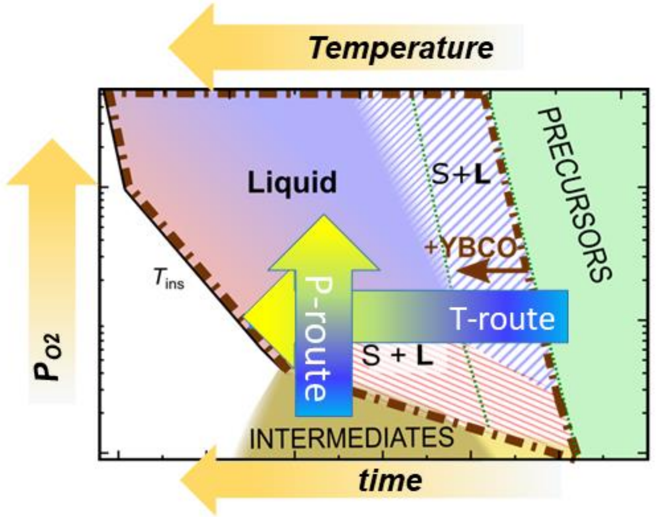

IEEE-CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), June 2023. Presentation given at Coated Conductors for Applications Workshop, Houston, TX, USA, April 2023.

TRANSIENT LIQUID ASSISTED GROWTH: TLAG

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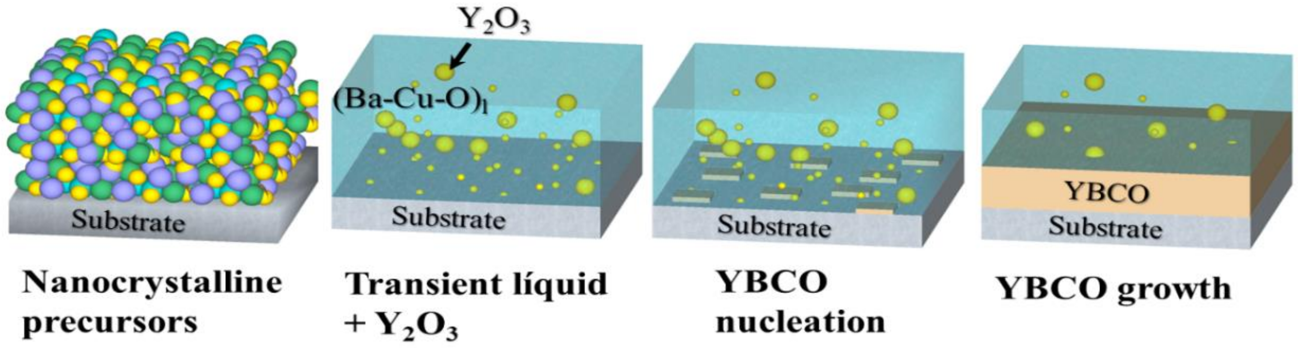
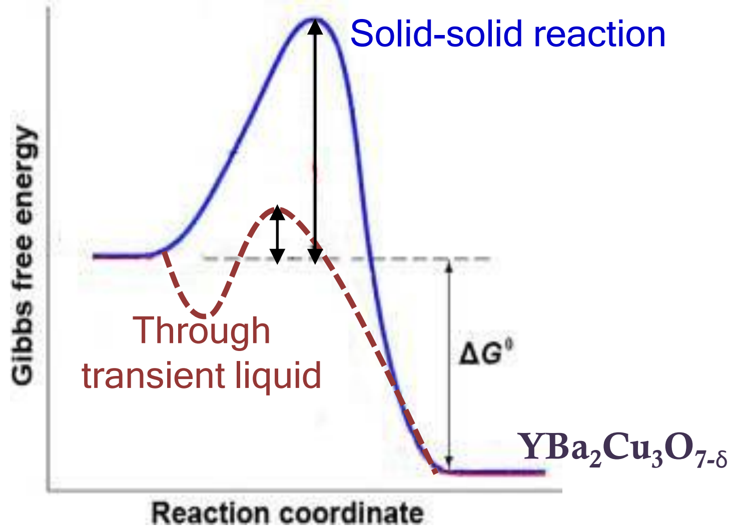
A high throughput non-equilibrium kinetically controlled growth process

DEPOSITION METHOD



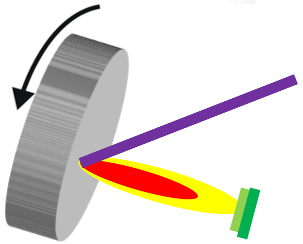


PRECURSORS → $(Ba - Cu^{I/II}\text{-}O)_{(l)} + RE_2O_{3(s)}$ → $REBa_2Cu_3O_{7-\delta}$

L. Soler et al., Nat Comm (2020)
S. Rasi, et al, Advance Science (2022)

$BaCO_{3(s)} + CuO_{(s)} + Y_2O_{3(s)}$ **TLAG-CSD**
FF metal-organic solution

L. Saltarelli et al, ACS Appl. Mat. & Interf. (2022)



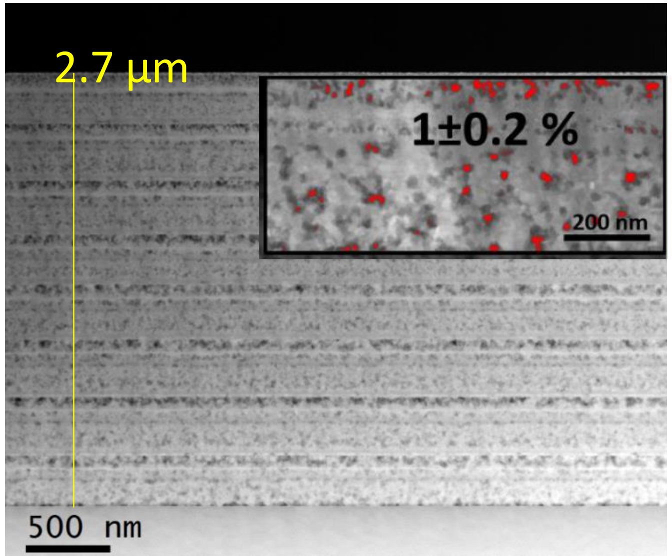
$(Ba\text{-}Cu^{I/II}\text{-}O)_s + Cu_2O_{(s)} + Y_2O_{3(s)}$ **TLAG-CSD**
REBCO target deposited at low T and P_{O2}

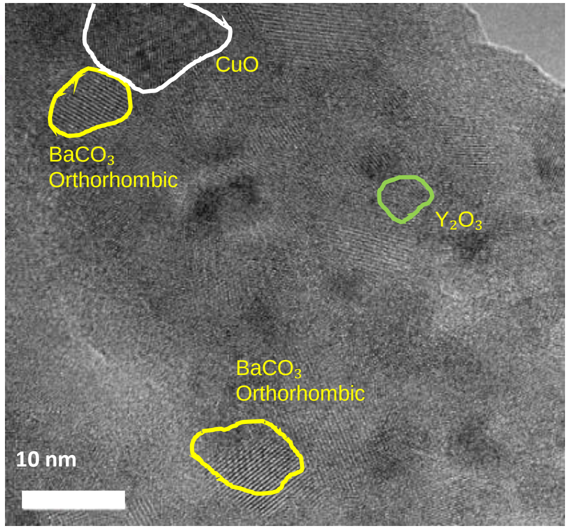
A. Quetalto et al, SUST (2023)

- Fast atomic diffusion
- Ultrafast growth rate, G, up to 2000 nm/s demonstrated
- Large area deposition
- Simple reactor
- High throughput
- Low cost/performance ratio

CSD INKS AND PYROLYZED MULTIDEPOSITED FILMS

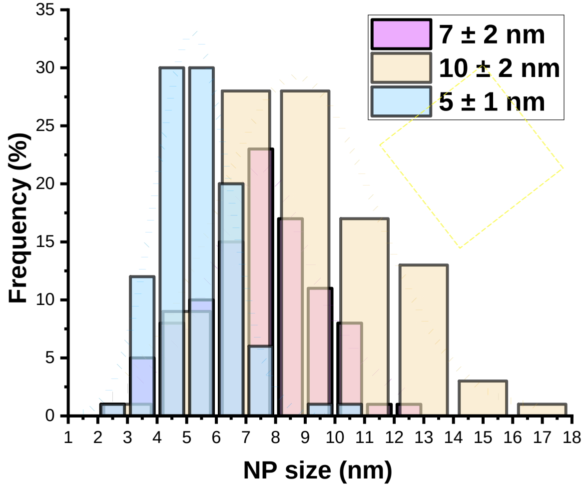
Patent EP22382741

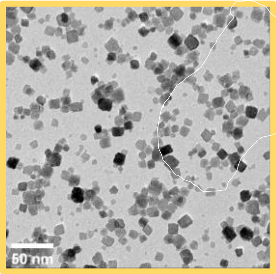


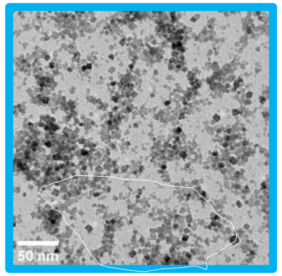


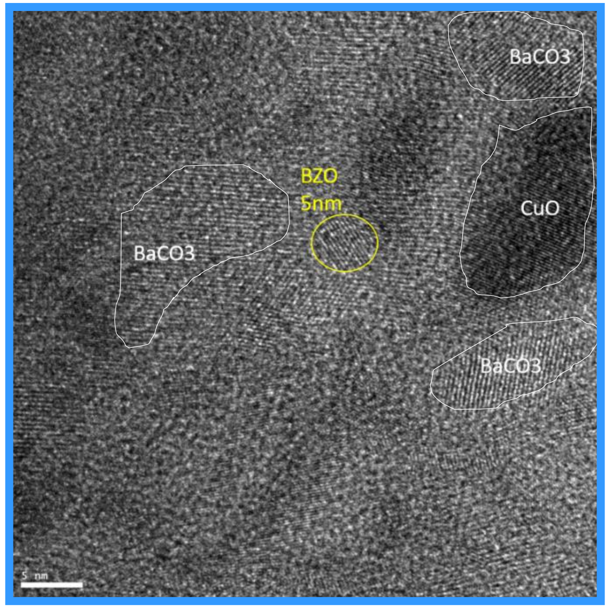
Multifunctional ink formulation

- Uniform pyrolyzed layers
- Low porosity
- Nanocrystalline and homogeneous
- Thickness beyond 3 µm tested
- $BaCO_3$ elimintated in TLAG







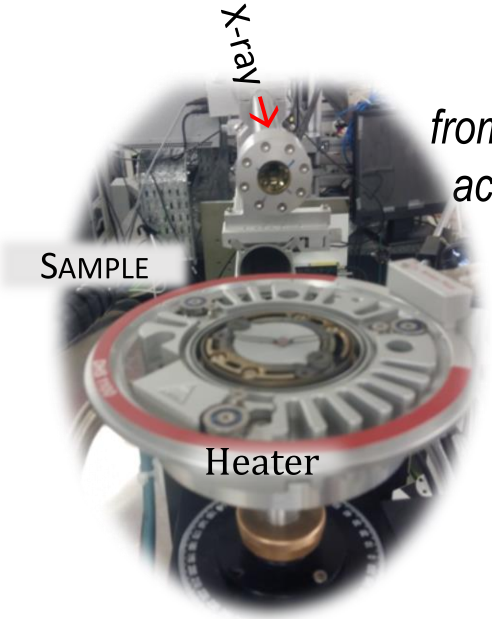


Multifunctional coloidal ink

- Hybrid Hydrolitic-Solvothermal Synthetic Process (H2S2)
- $BaZrO_3$, $BaHfO_3$ Np
- Similar performance
- Crystalline BZO NPs retain their shape and small size in the pyrolysis

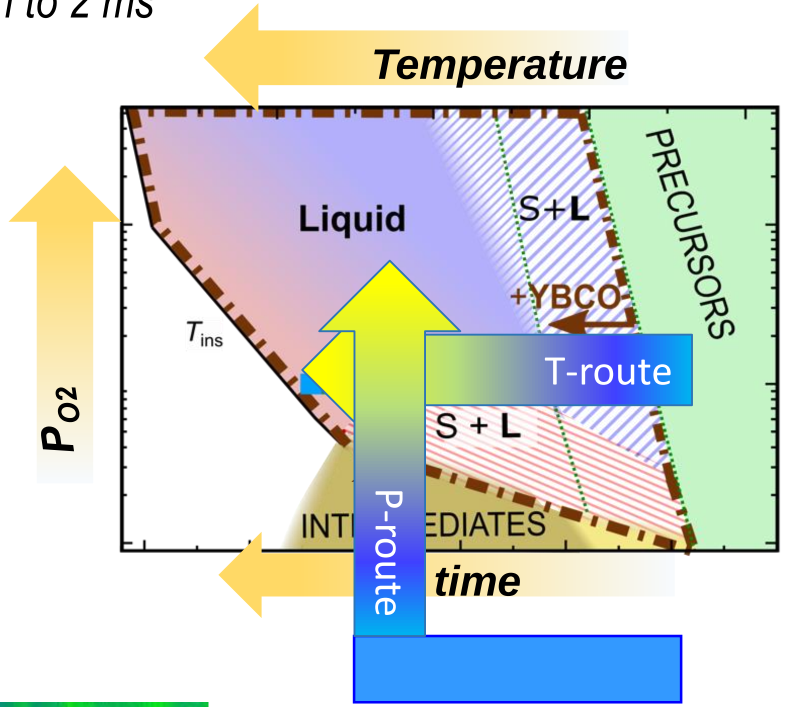
S. Rasi, et al, J. Phys Chem C (2020), L. Saltarelli et al, ACS Appl. Mat. & Interf. (2022), N. Chamorro et al, RSC Adv. (2020)

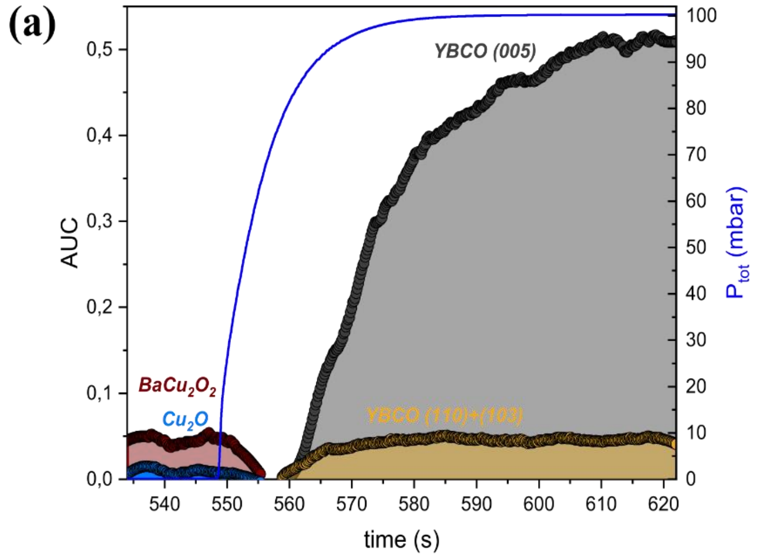
TLAG in-situ growth evaluation

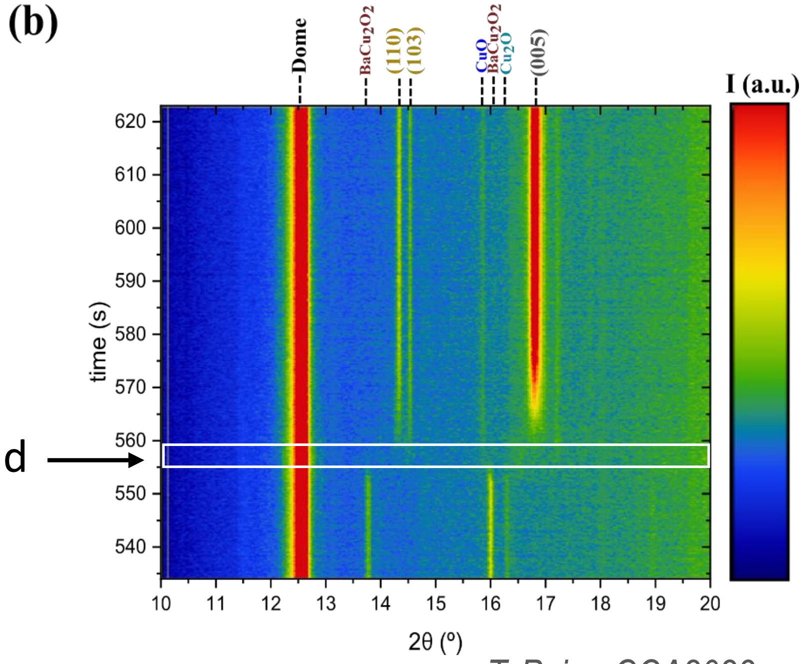


from 100 ms down to 2 ms acquisition time

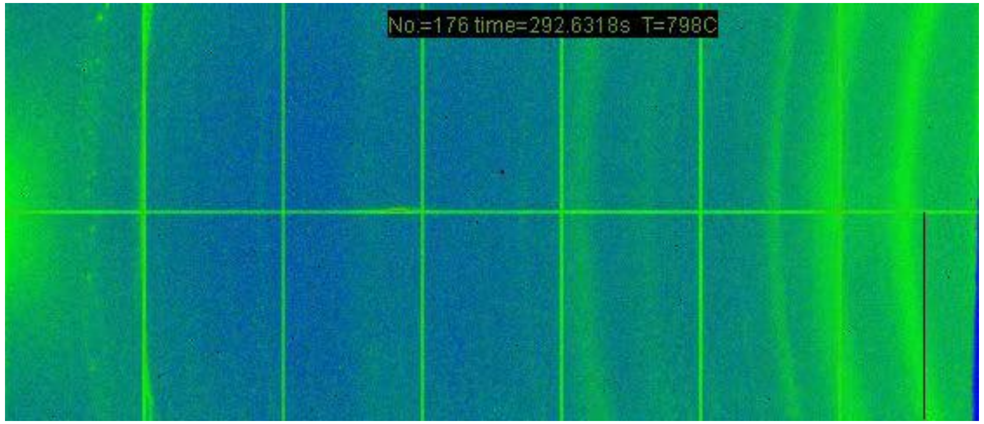
In-situ growth XRD synchrotron experiments







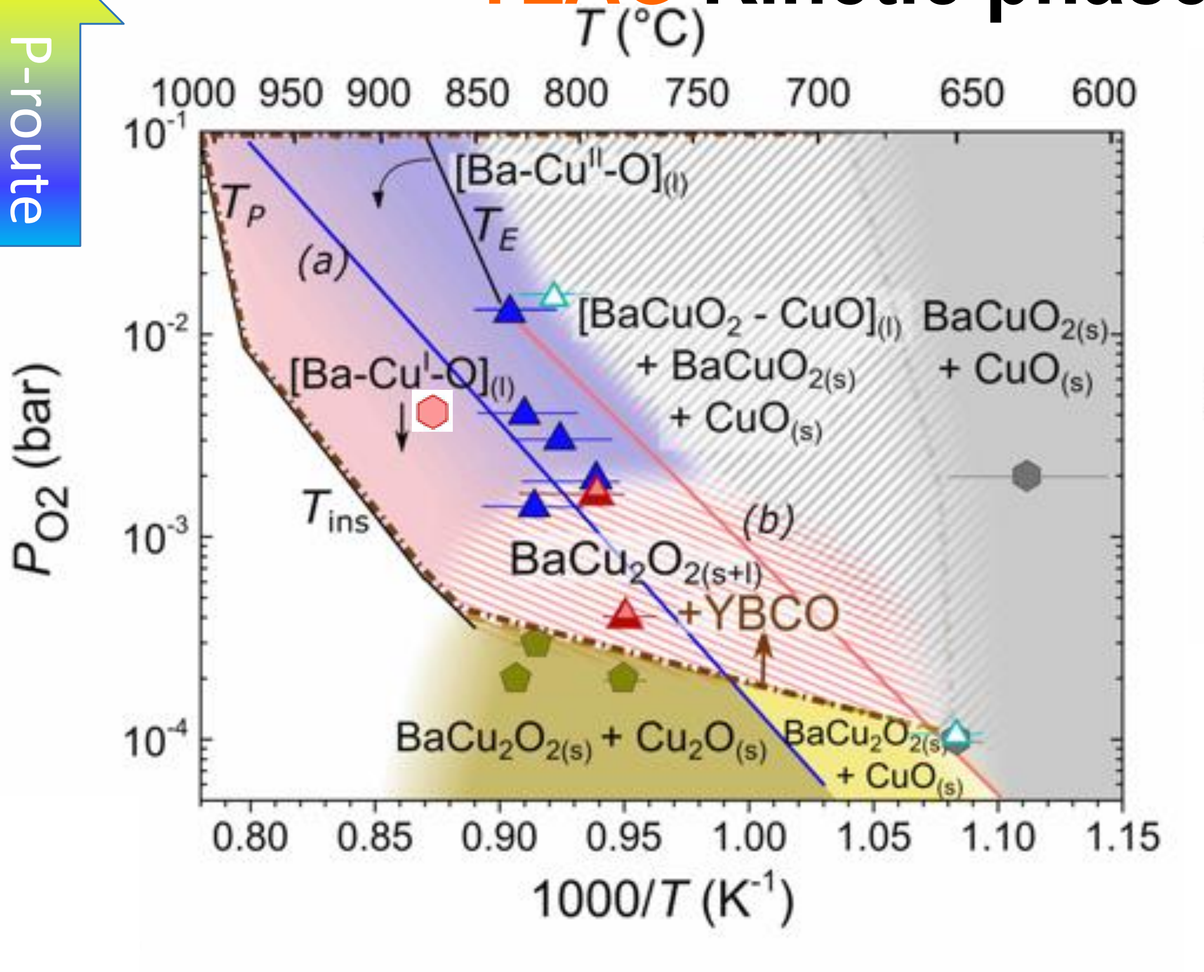
Transient liquid



L. Soler et al Nat Comm (2020), S. Rasi, et al, Advance Science (2022)

TLAG Kinetic phase diagrams

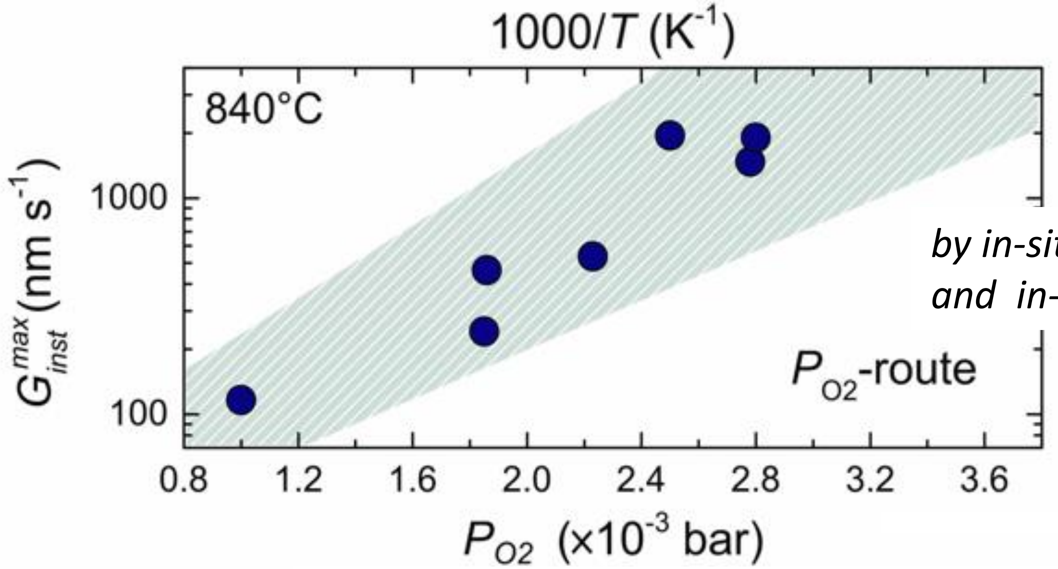
P-route



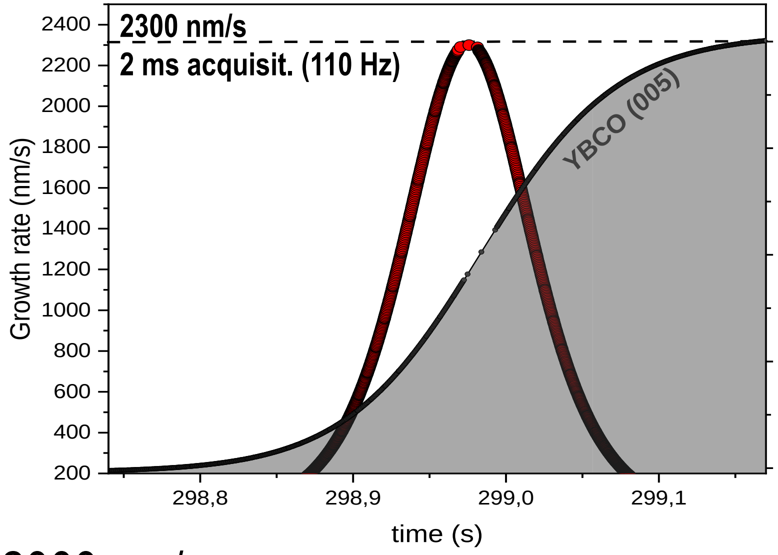
- △ $BaCuO_{2(s)}$+YBCO+$CuO_{(s)}$
- ▲ YBCO+$Cu_xO_{(s)}$
- ▲ $BaCu_2O_{2(s)}$+YBCO+$Cu_xO_{(s)}$
- ⬡ YBCO

T_E	$BaCuO_{2(s)}$+$CuO_{(s)}$ → $[BaCuO_2+CuO]_{(l)}$
T_m	$BaCu_2O_{2(s}$→ $[BaCu_2O_2]_{(l)}$
(a)	$CuO_{(s)}$ → $Cu_2O_{(s)}$
(b)	$BaCuO_{2(s)}$ → $BaCu_2O_{2(s)}$

S. Rasi, et al, Advance Science (2022)



by in-situ resistivity and in-situ XRD



Epitaxial films and nanocomposites at 2000 nm/s

YBCO TLAG-CSD FILMS

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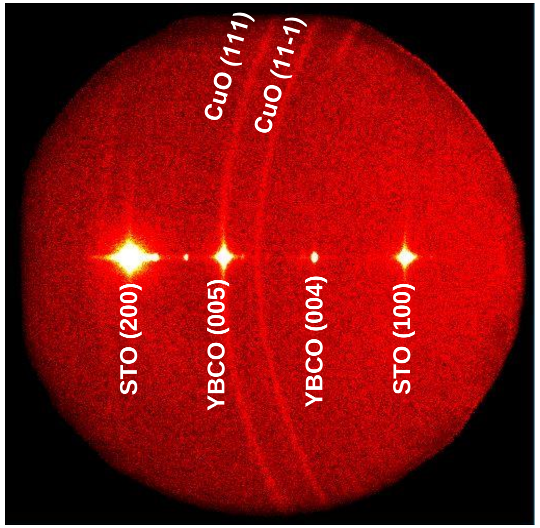
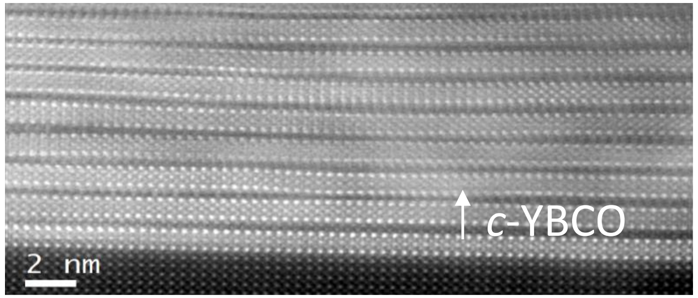
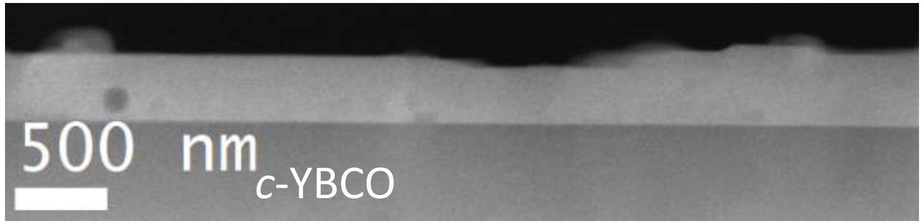
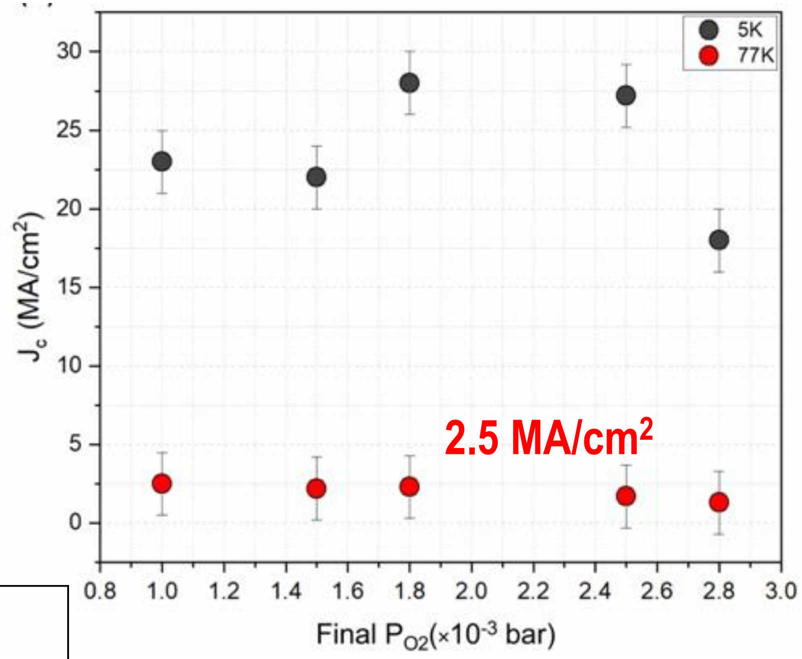




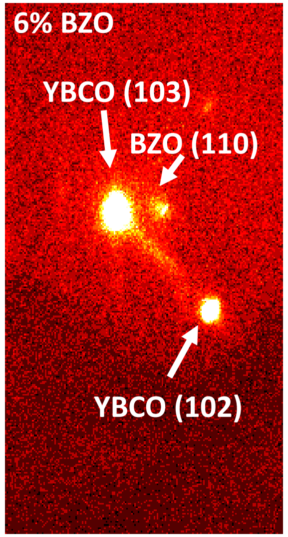


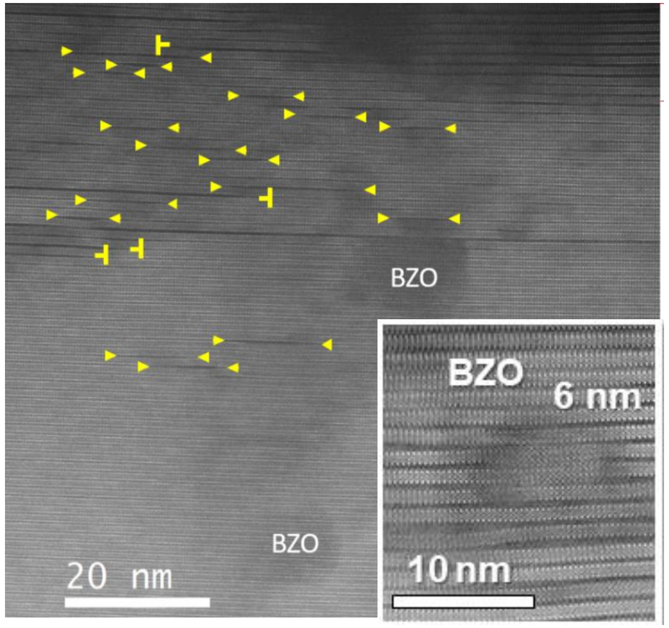
γ_{eff}= 2.5-3.5

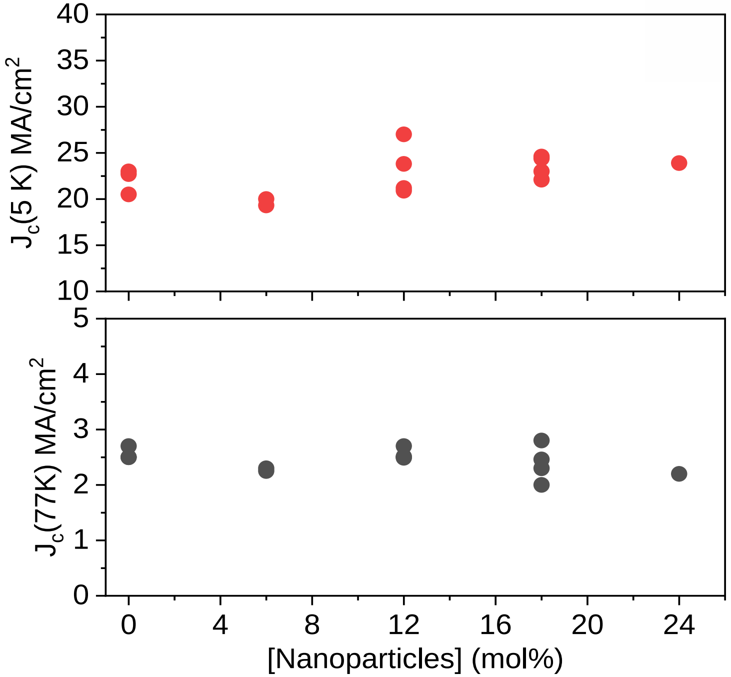
50 nm/s → 1500 nm/s



Nanocomposites







γ_{eff}= 2-2.5

YBCO TLAG-CSD NANOCOMPOSITE FILMS

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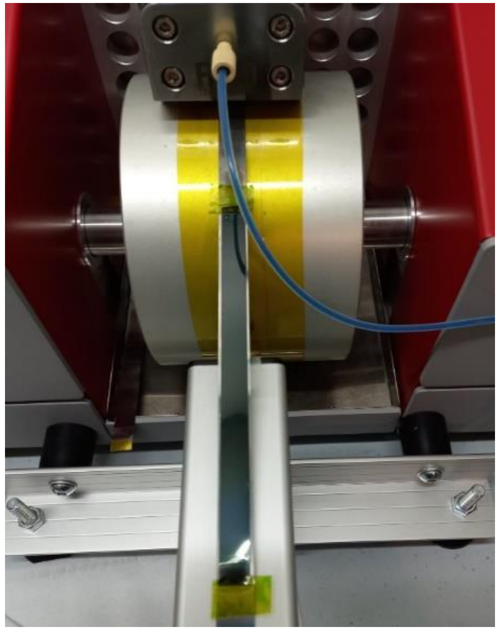
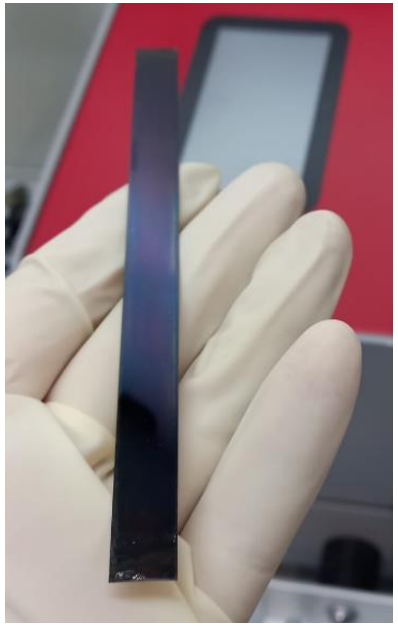
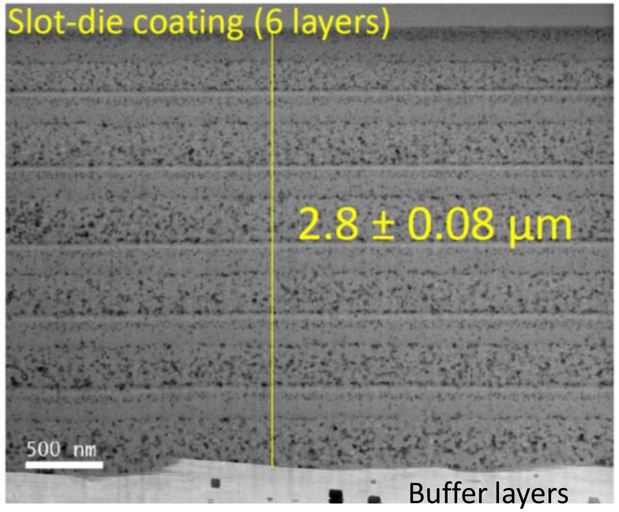
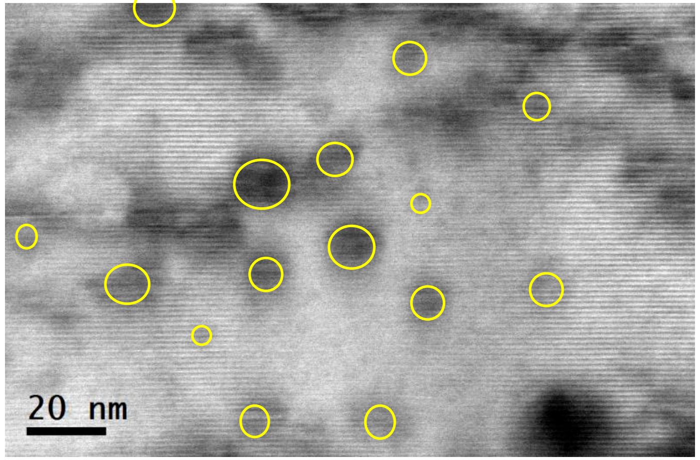
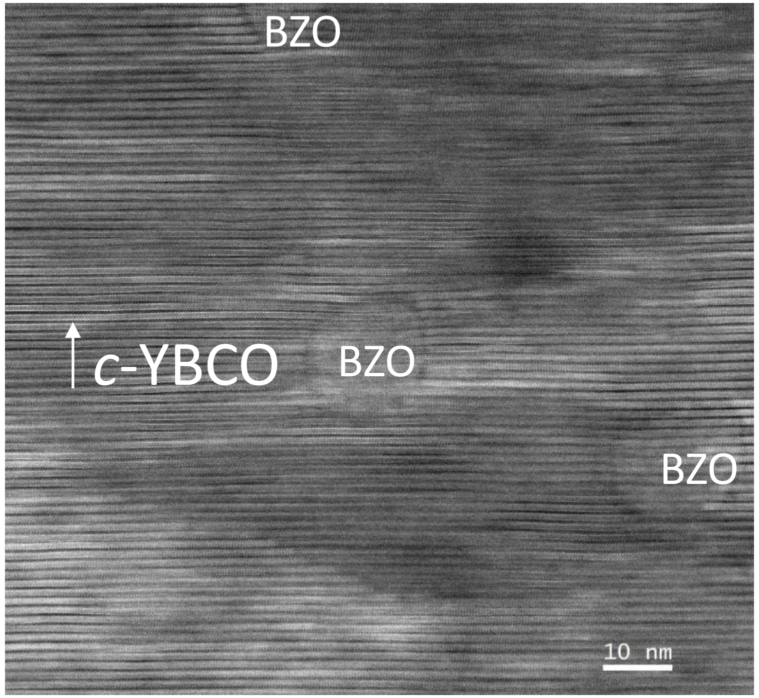
Extended to technical substrates in collaboration with SUMITOMO ELECTRIC







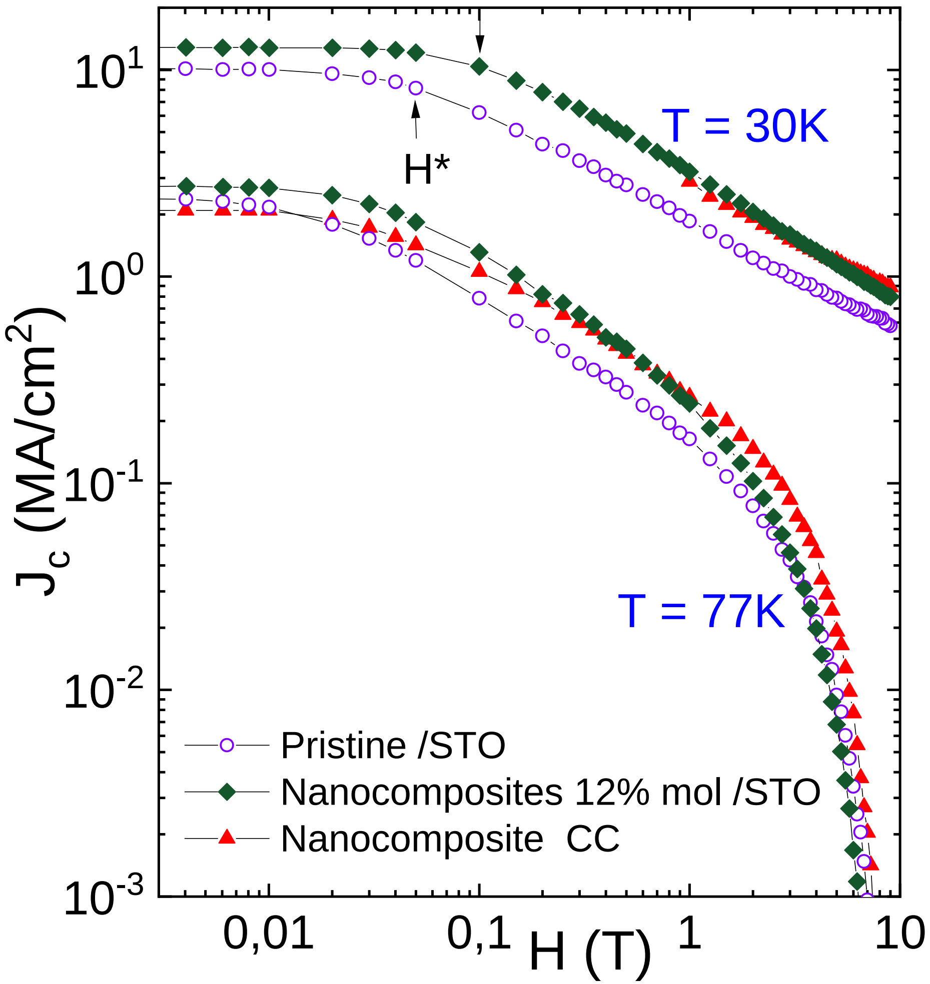


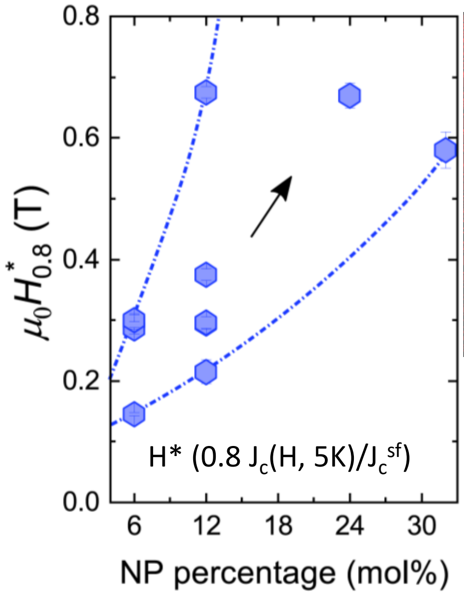


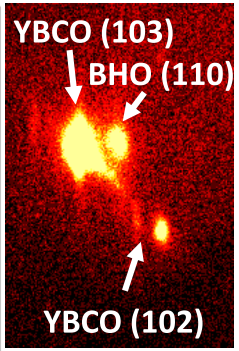
J_c(5K)= 24 MA/cm^2 J_c(77K)= 2 MA/cm^2 , $I_{c,\ 750\ nm}$(77K) = 130 A-w

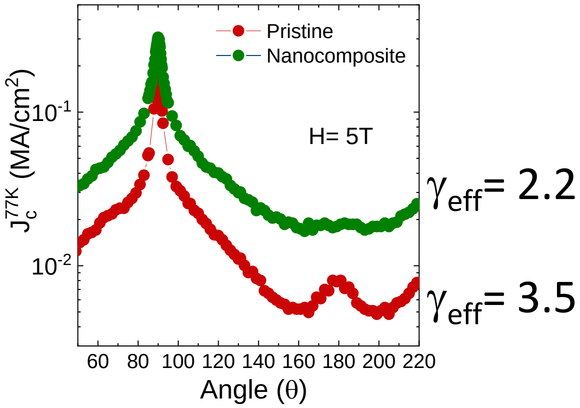
High density of defects is present as well as embeded nanoparticles

VORTEX PINNING IN TLAG-CSD NANOCOMPOSITE FILMS

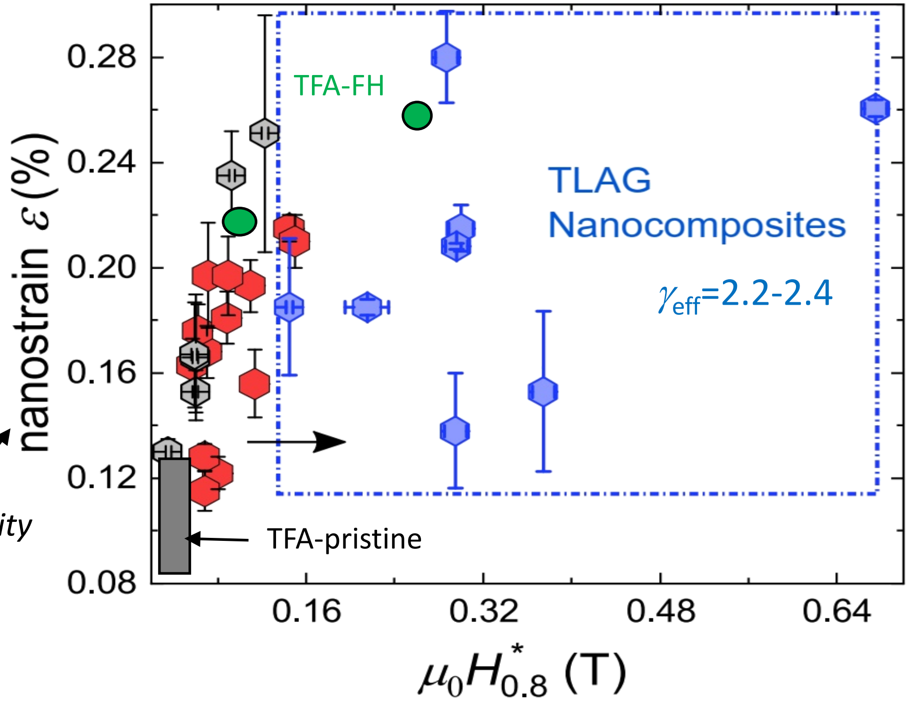








from XRD William son-Hall analysis associated to SF density



TLAG films respond to vortex pinning determined by high density of defects (SF, point vacancies) and nanoparticles

OPTIMIZING PINNING LANDSCAPES

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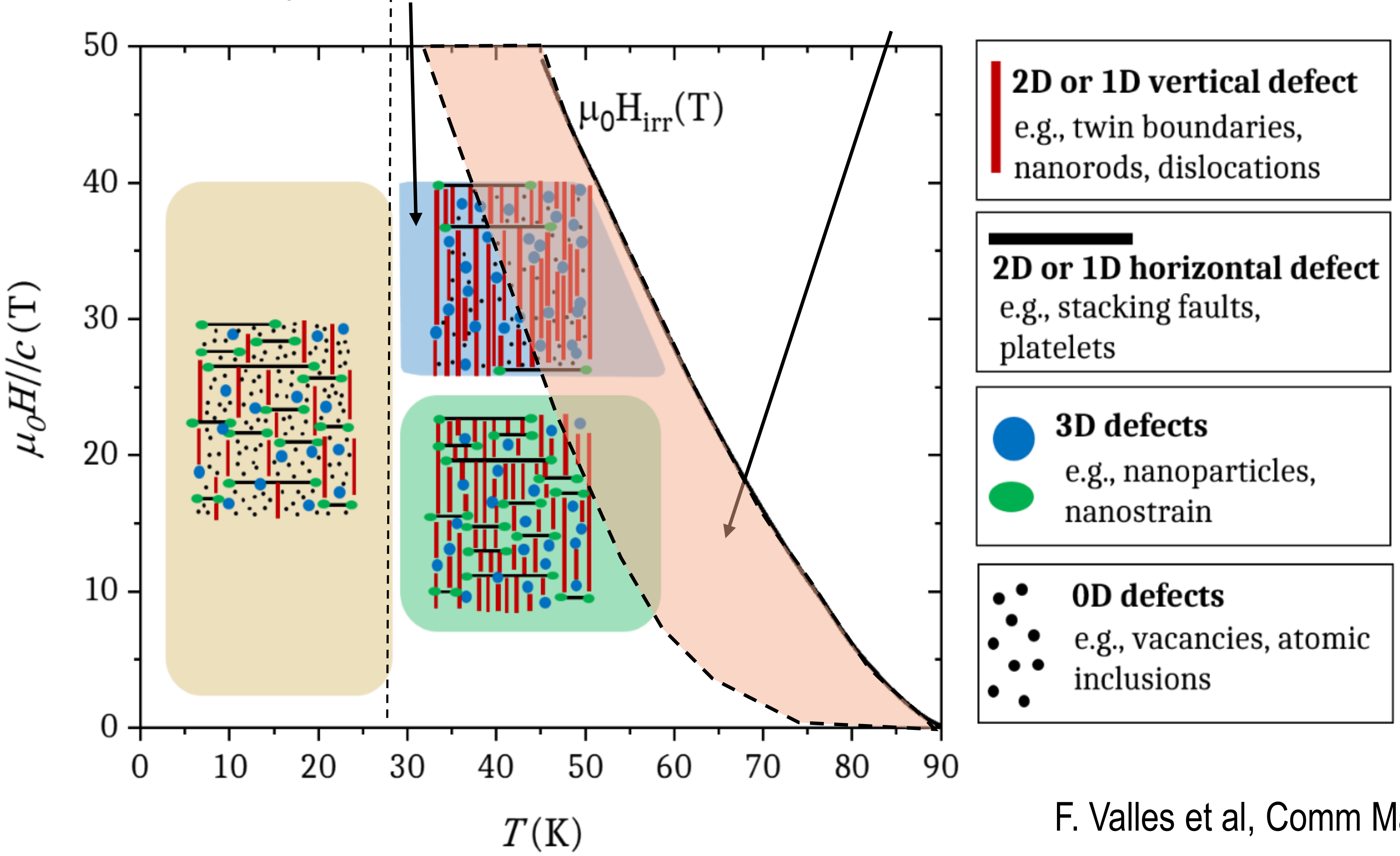
isotropic defects: vacancies,Np

strong isotropic and anisotropic add defects: Nanoparticles, (Nanorods)

anisotropic defects: TB, (Nanorods)



NATIONAL HIGH MAGNETIC FIELD LABORATORY
D. Abaimov
J. Jaroszynski
D. Larbalestier

Different microstructure requirements for different regions

F. Valles et al, Comm Mat. (2022)

OVERDOPING: A ROBUST METHOD FOR PINNING

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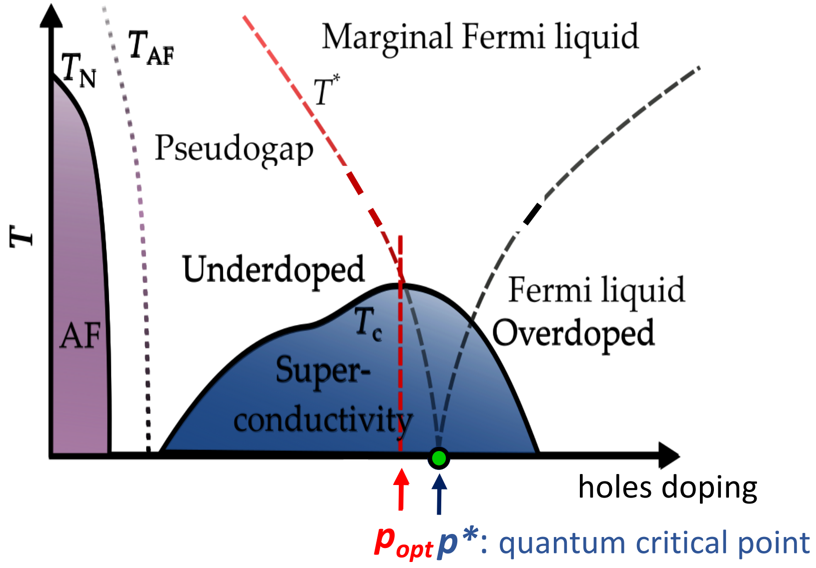
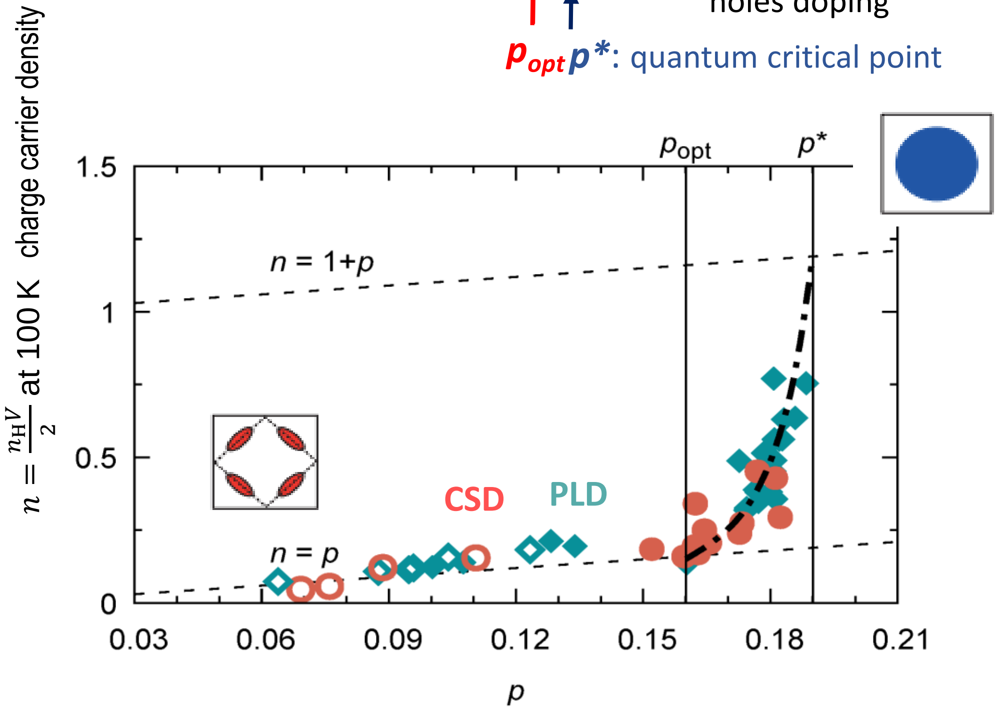
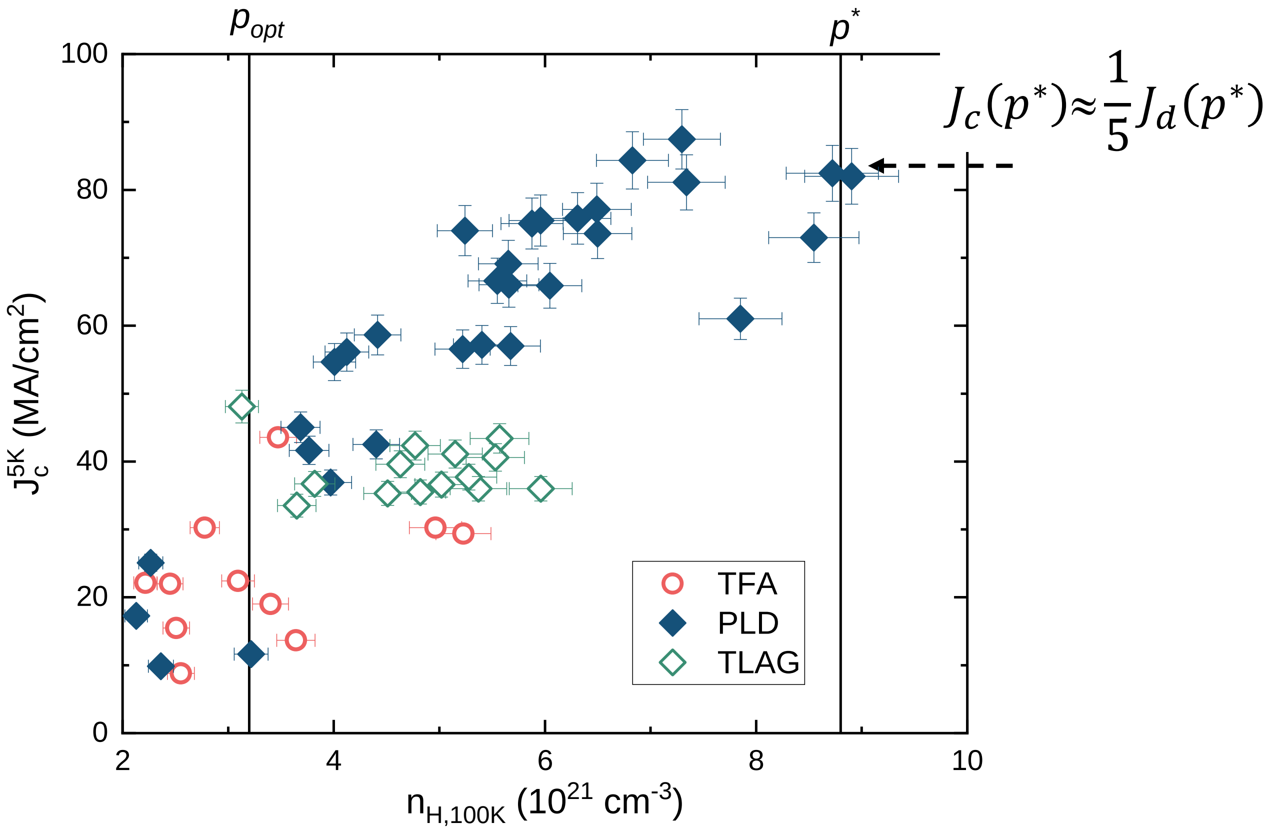




$$J_c^2 \propto n_H E_c(n_H)$$

A. Stangl et al, Sci. Rep. (2021)

Condensation energy and charge carrier density increases in the overdoped state

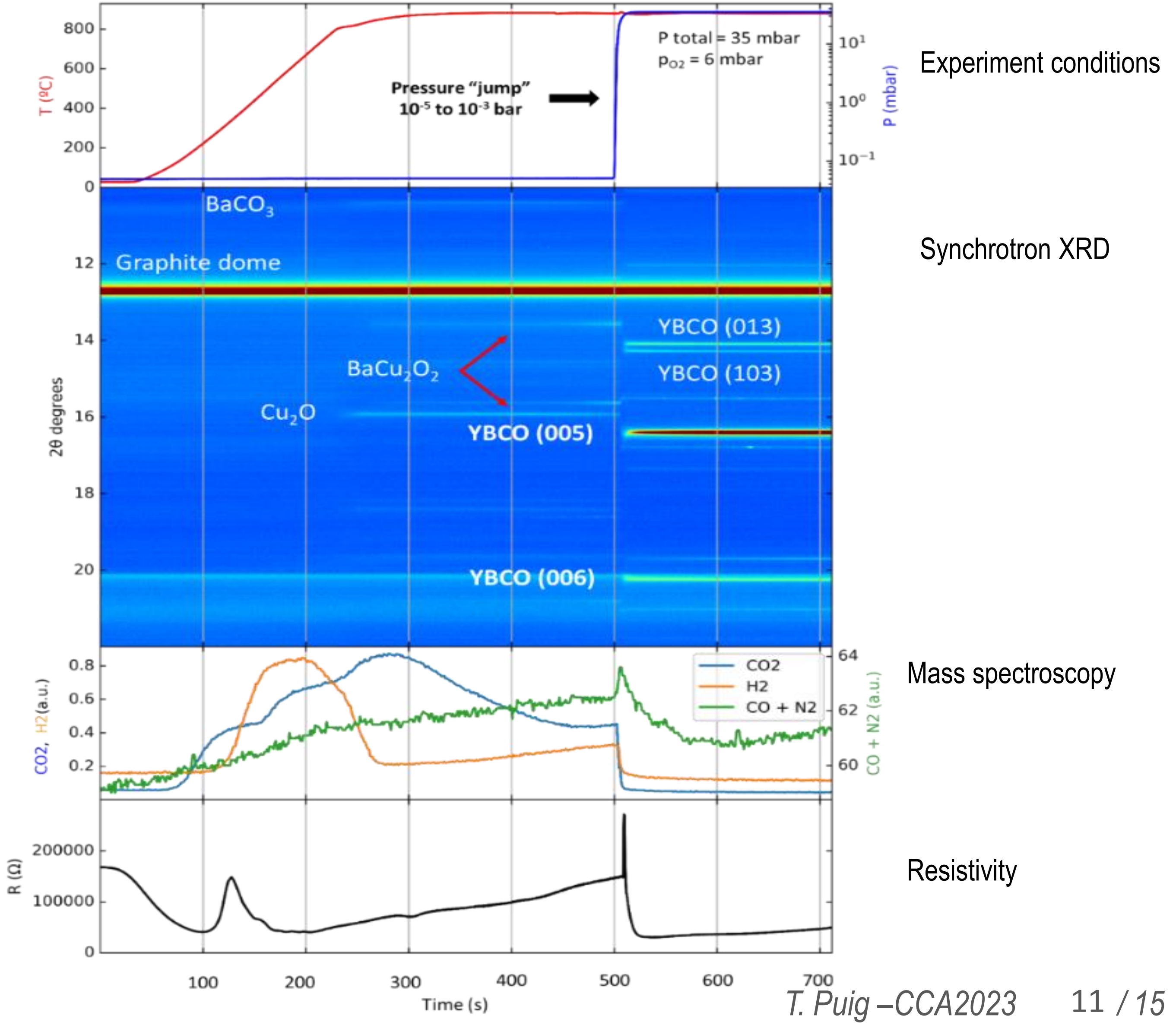


A. Stangl et al, Sci. Rep. (2021)

HIGH THROUGHPUT EXPERIMENTATION

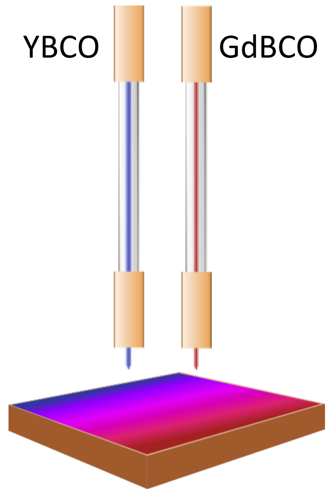
In-Situ ALBA Synchrotron installation

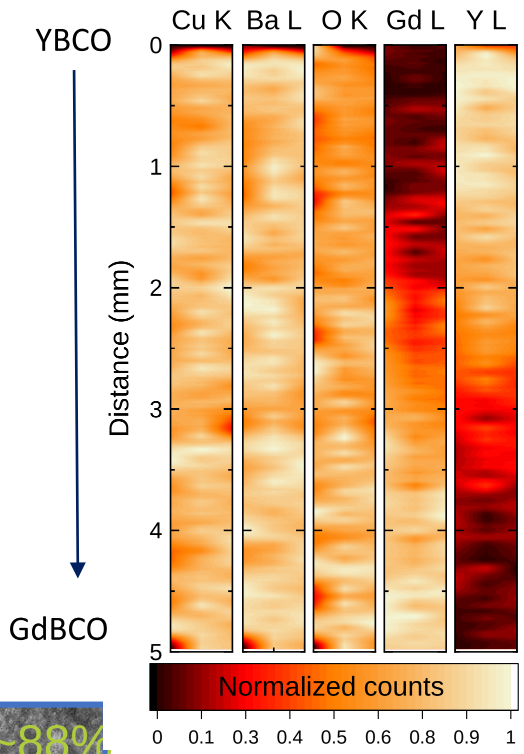
NCD-SWEET BEAMLINE

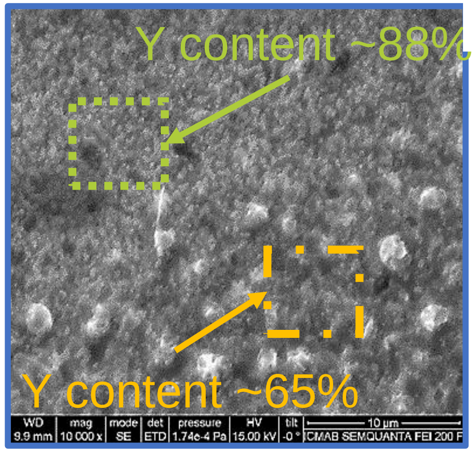


Fast optimization using Compositional Gradients

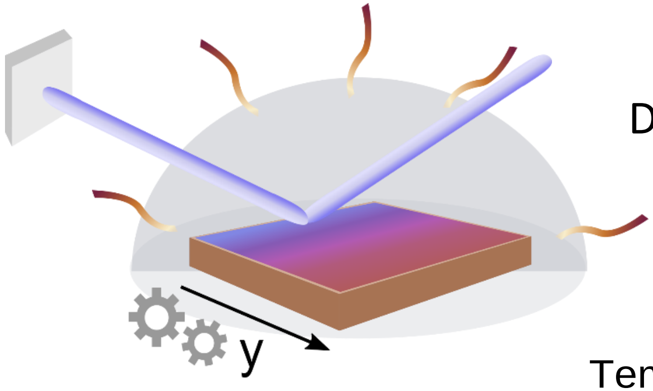
Combinatorial DoD Ink Jet Printing







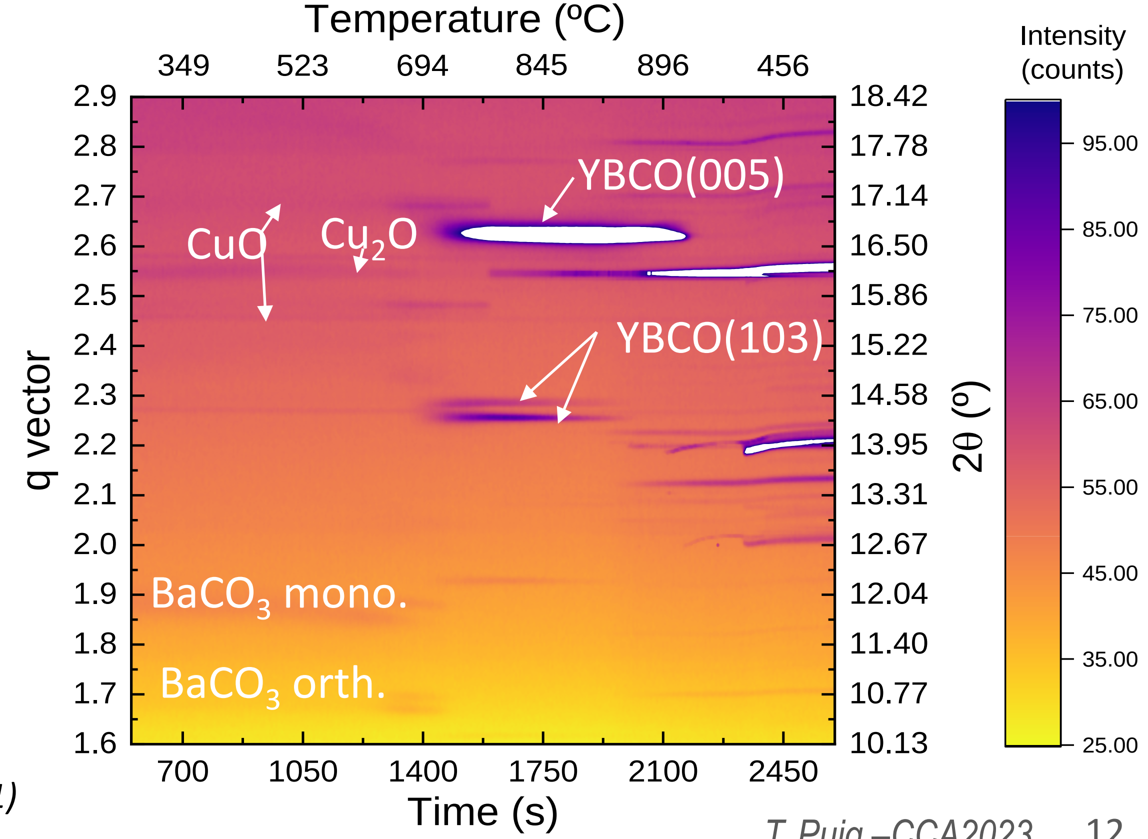
in-situ synchrotron XRD



Data is segmented by positions for analysis

Case position 1

T-route



A. Queralto et al., ACS Appl. Mater. Interfaces (2021)

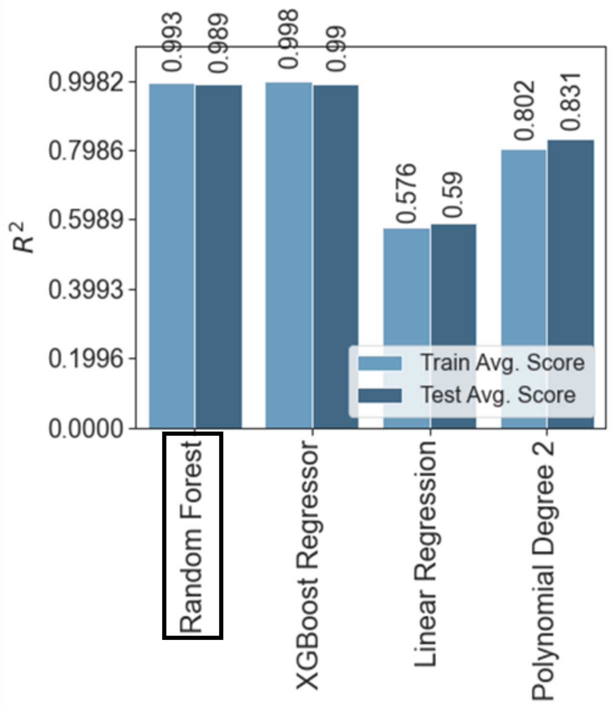
Machine Learning for fast guideness

Dataset

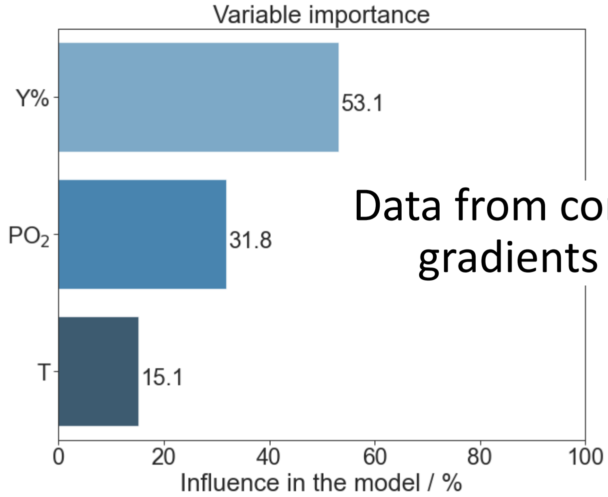
Training | **Testing**

↓

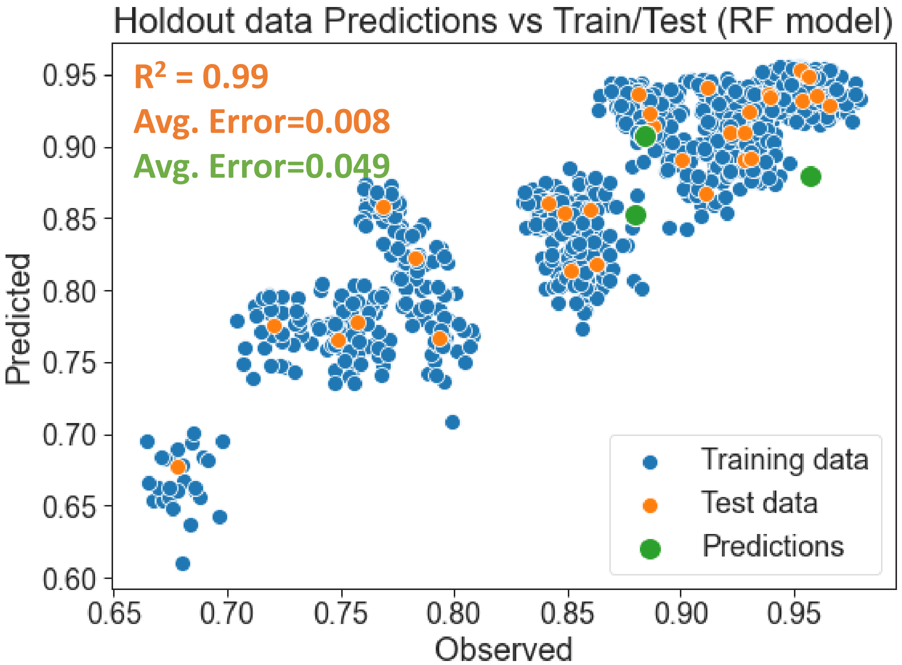
Prediction and evaluation



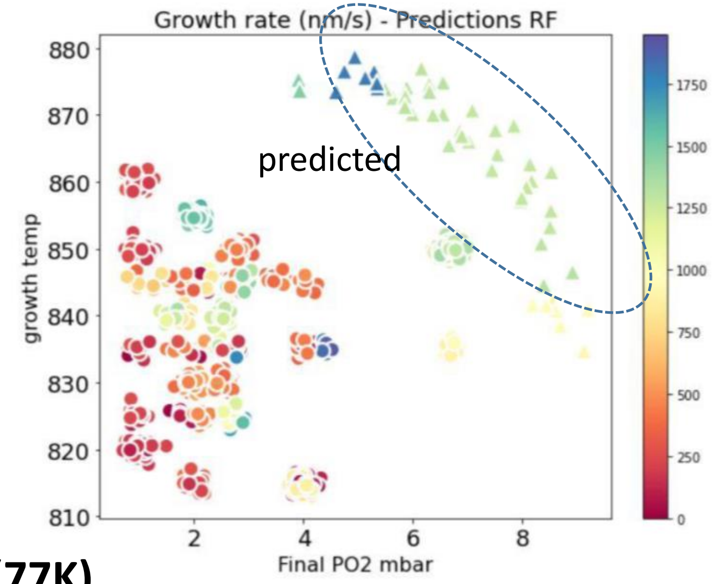
Optimizing c-axis growth by ML



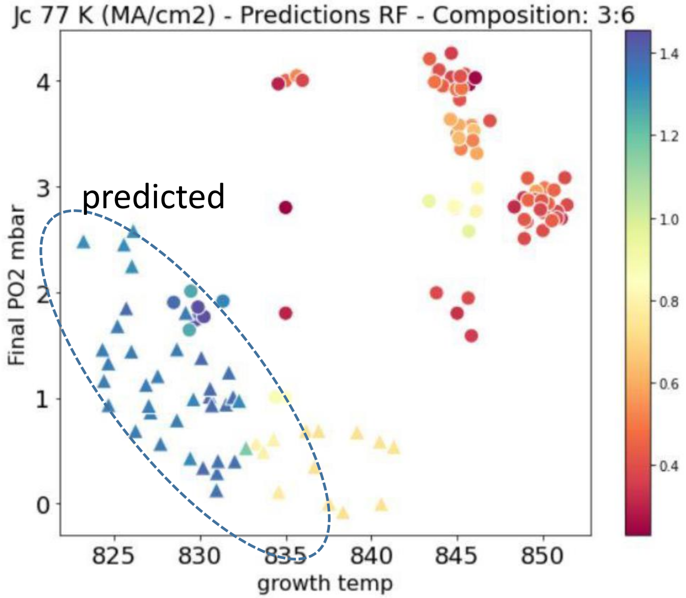
Data from compositional gradients samples



Growth Rate



J_c(77K)



Conclusions

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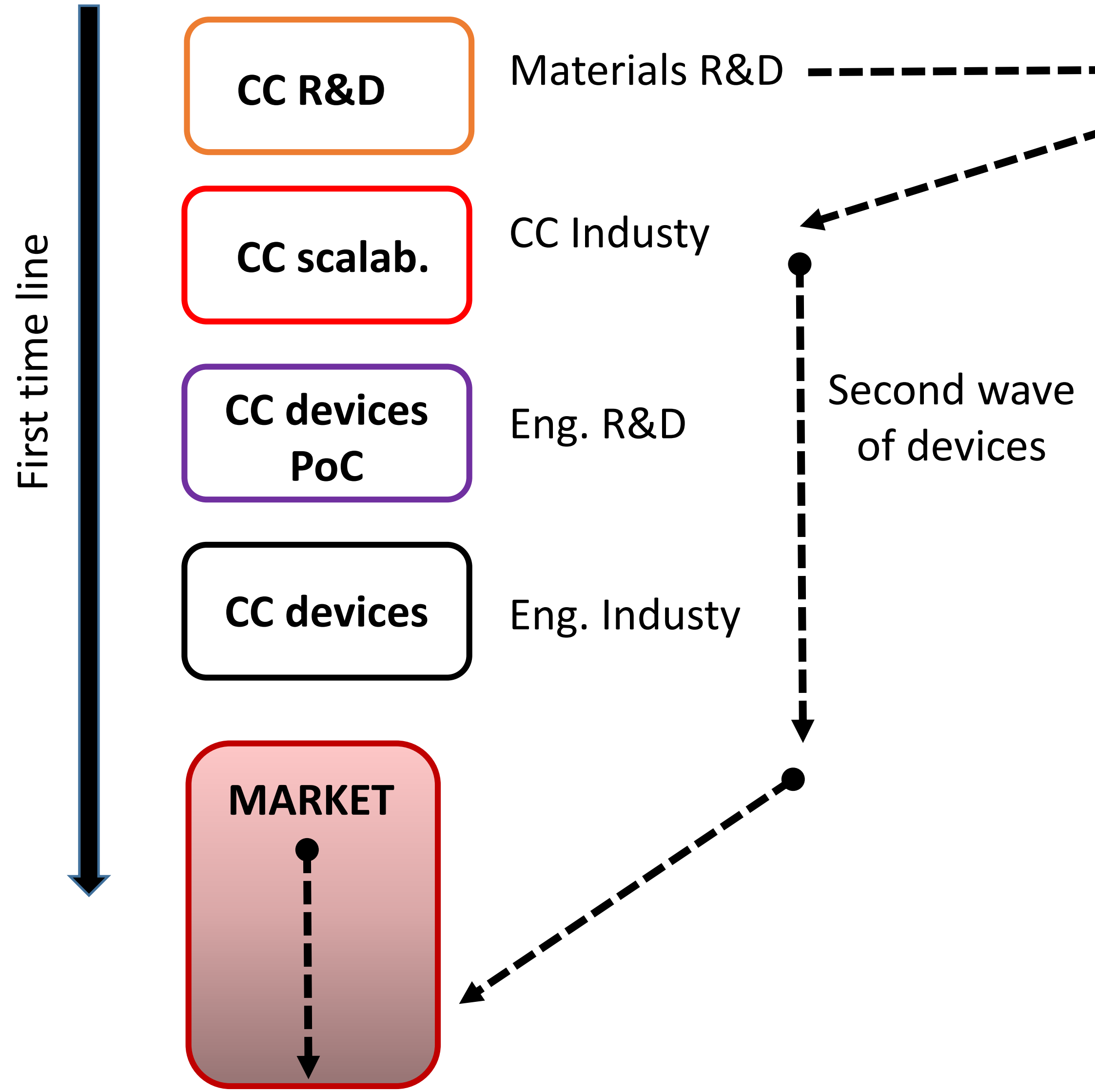
- TLAG is a non-equilibrium growth methodology with ultrafast growth rates achieving high performance Coated Conductors compatible with CSD
- In-situ synchrotron XRD experiments have been essential to understand the kinetic growth mechanisms and obtain epitaxial layers at ultrafast growth rates
- Pinning landscapes can be optimized at different regions depending on applications needs, overdoping being very appealing
- High Throughput Experimentation initiatives are foreseen to fasten optimization schemes
- Industrialization of TLAG should lead to a high throughput manufacturing process which uses simple and large area reactors for R2R CC production

Contributions from CC Materials Research



Low-cost, High-throughput, High-performance

$$\frac{Cost}{Perfomance} = \frac{total\ cost\ per\ year}{G\ x\ L\ x\ W\ x\ J_c} = \frac{€}{kA\ x\ m}$$

- Fast growth-rate methods
- Optimization of robust vortex pinning schemes
- Growth of wide tapes

High-throughput experimentation can be of great help

IEEE-CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), June 2023. Presentation given at Coated Conductors for Applications Workshop, Houston, TX, USA, April 2023.