



Consolider



MINISTERIO  
DE ECONOMÍA  
Y COMPETITIVIDAD



# Chemical solution deposition growth of low fluorine thick coated conductors of $\text{YBa}_2\text{Cu}_3\text{O}_7$ and $\text{YBa}_2\text{Cu}_3\text{O}_7$ nanocomposites with preformed $\text{BaZrO}_3$ nanoparticles

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Generalitat  
de Catalunya



EUROPEAN DEVELOPMENT OF SUPERCONDUCTING TAPES

# CSD methodology – ex situ growth

➤ LOW COST, VERSATILE and SCALABLE path to grow superconductor YBCO layers

TFA route



+

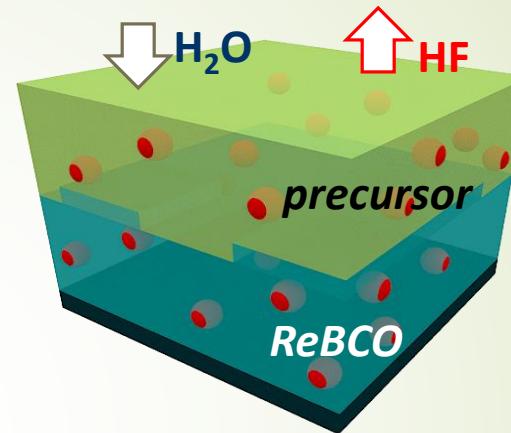


Decomposition  
Conversion

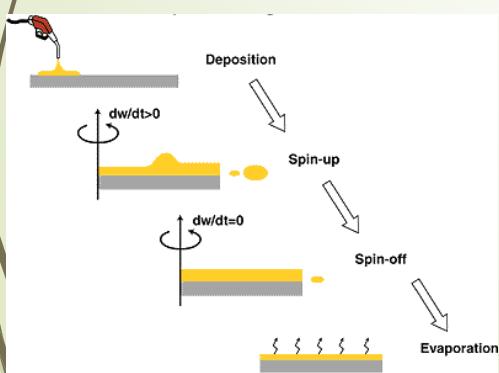
LF route

Precursors:  $\text{Y}(\text{TFA})_3$ ,  $\text{Ba}(\text{TFA})_2$ ,  $\text{Cu}(\text{TFA})_2$

≈80 % Fluorine reduction !!!



Spin coating

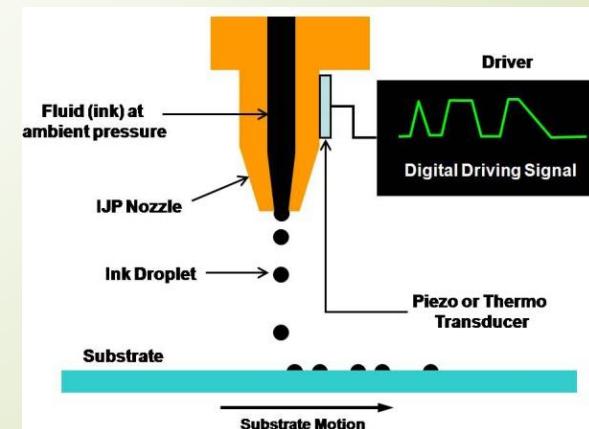


Deposition by

Inkjet Printing

Thick films from  
one single  
deposition

Thick films by  
multidepositions

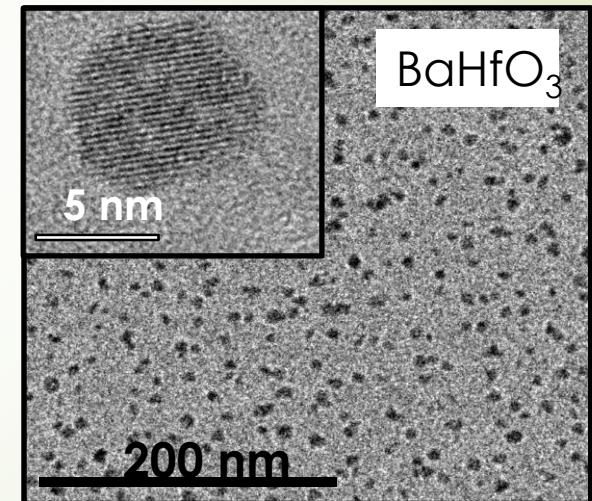
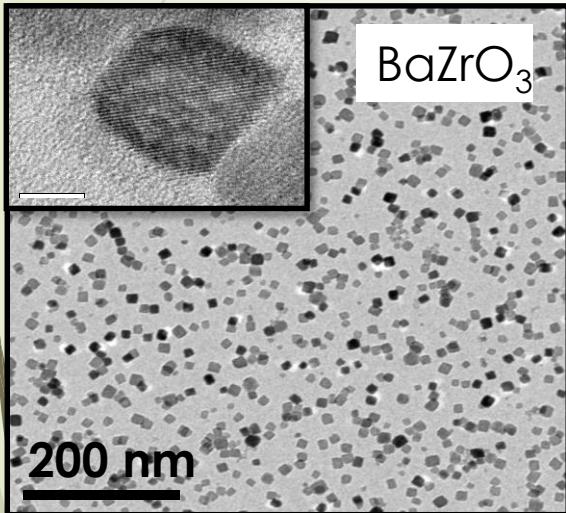
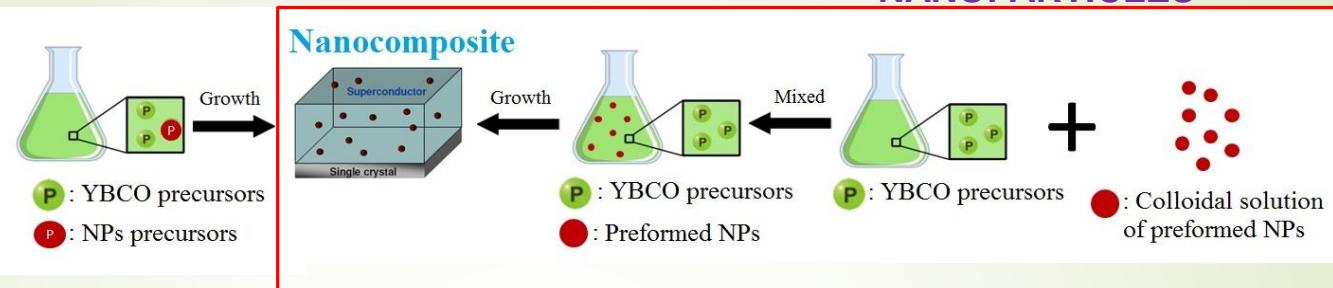


# CSD approach for YBCO nanocomposites (TFA Route)

SPONTANEOUS  
SEGREGATION

Novel  
Process

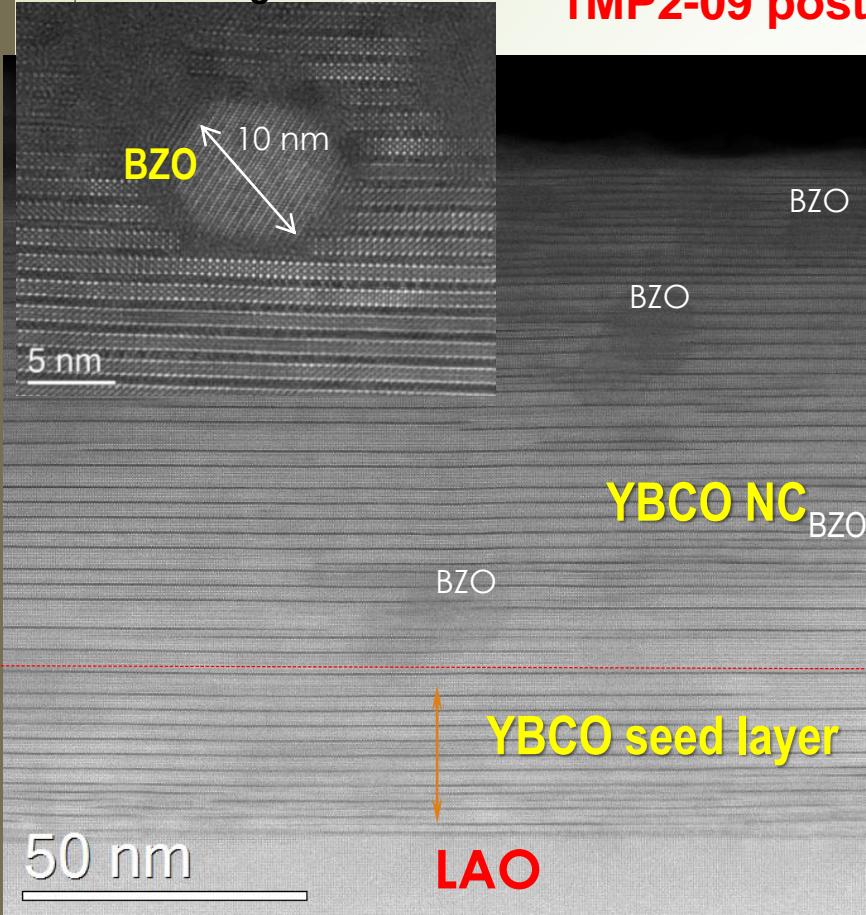
PREFORMED  
NANOPARTICLES



Oxide non-reactive nanoparticles were stabilized in alcoholic and ionic environment of YBCO precursor solution at high concentrations

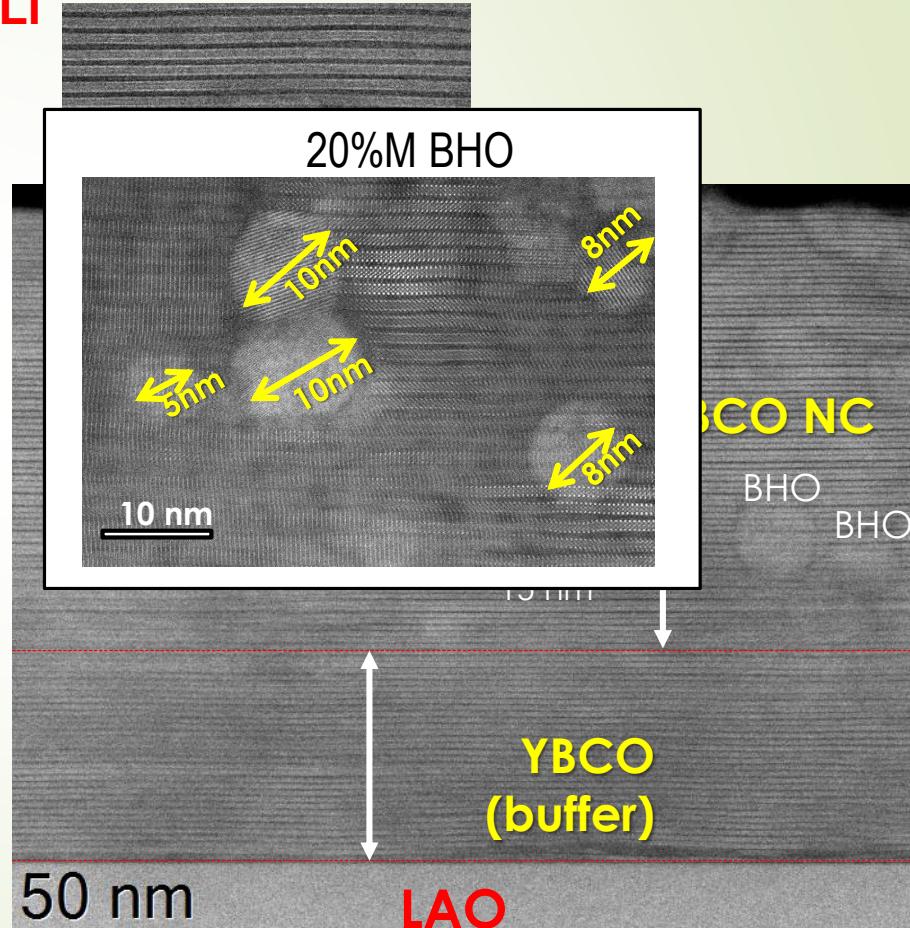
# Nanocomposites of non-reactive preformed $\text{BaZrO}_3$ and $\text{BaHfO}_3$ nanoparticles

Flash heating: 20%M BZO



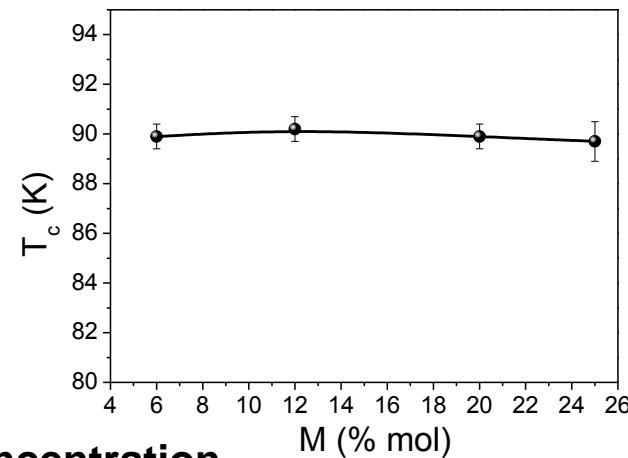
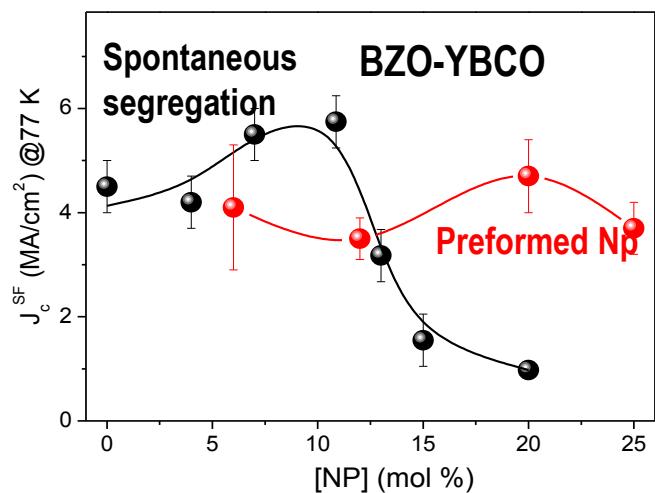
1MP2-09 poster Z. Li

12%M BHO



High homogeneity in Np dispersion at high Np concentrations. No reactivity. Randomly oriented.  
 $J_c = 3-5 \text{ MA/cm}^2$  at 77 K, 200 nm

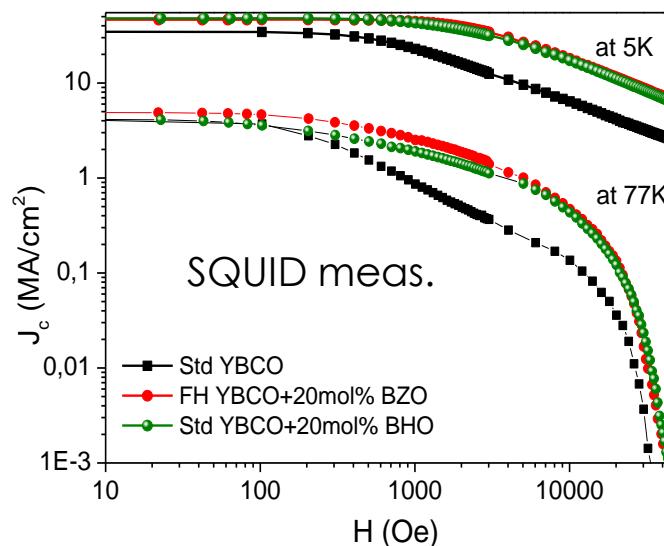
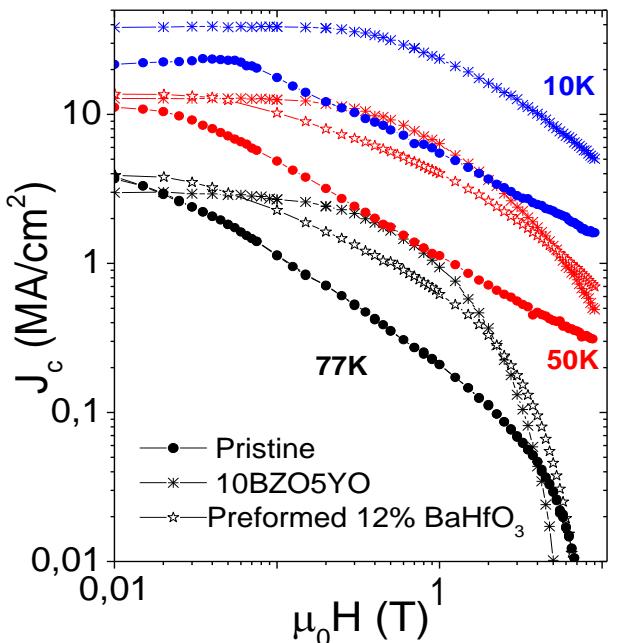
# Nanocomposites w/preformed BaZrO<sub>3</sub> and BaHfO<sub>3</sub> Np



Higher concentration  
of Np without current  
blocking

1MP2-09 poster Z. Li

High performance at all temperatures



# Growth of thick YBCO layers on LAO single crystals (LF Route) MULTIDEPPOSITION

Success of multideposition

(200) LAO  
(006) YBCO

(005) YBCO

(222)  $\text{Y}_2\text{O}_3$

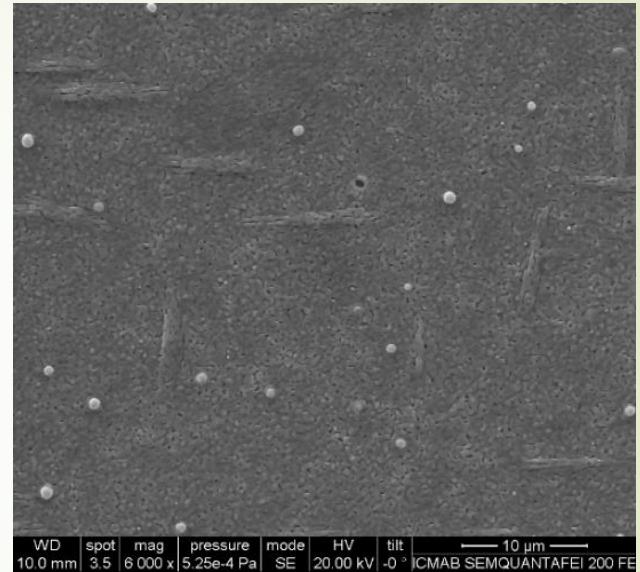
(004) YBCO

(100) LAO

$J_{\text{C}}(77\text{K}) = 2 \text{ MA/cm}^2$

HIGH REPRODUCIBILITY

1,2  $\mu\text{m}$  thick  
YBCO film by  
multidepositions



Further optimization is  
needed beyond 1.2  $\mu\text{m}$

By controlling the supersaturation  
(T,  $\text{PH}_2\text{O}$  and Ag) we have  
reached thick high performance  
layers of up to 1.2  $\mu\text{m}$

# Growth of thick YBCO layers on LAO single crystals (LF Route) MULTIDEPPOSITION

FIB

TEM

2000 nm

IJP

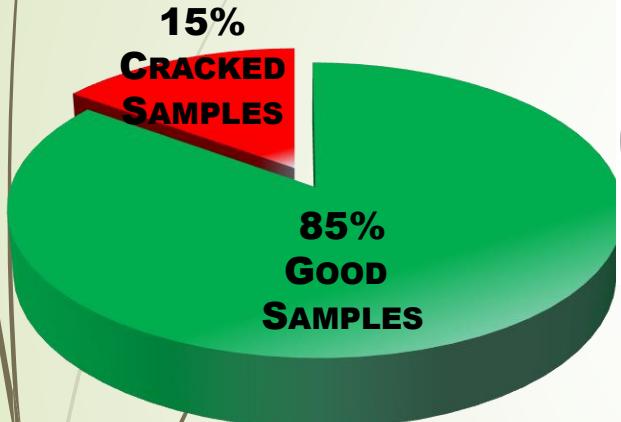
Mag = 75.00 K X      200 nm  
FIB Lock Mags = Yes

Aperture No. = 1      EHT = 5.00 kV      Signal A = SE2      FIB Imaging = SEM      Time :15:58:43  
Aperture Size = 30.00  $\mu\text{m}$       WD = 5.1 mm      FIB Probe = 30KV:50 pA      Date :17 May 2016      J.Llobet @ CNM-IMB & ICN

# IJP deposition and pyrolysis of thick YBCO layers

- In situ visualization of the pyrolysis
- Thermo mechanic study
- Decomposition study
- Thickness evolution study

## LF inkjet precursor solution design



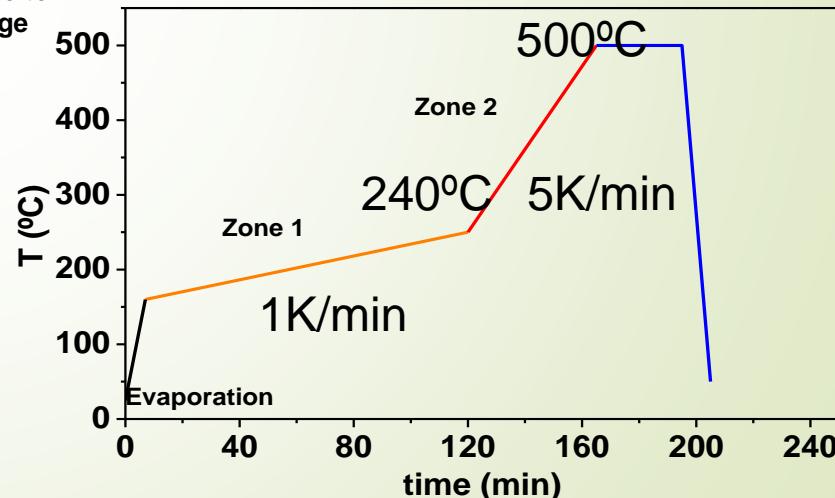
- Colloidal solutions compatible with IJP
- Thick layer and CC are reachable

**Robust and reproducible  
process in one single  
deposition up to  $\approx 900$  nm!!!**



**Pyrolyzer**

**4MP7-03 poster B. Villarejo**

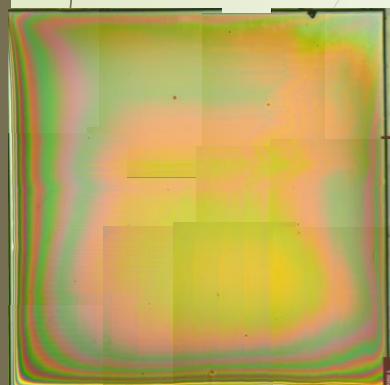


**Heating ramp optimized to avoid  
buckling and cracking**

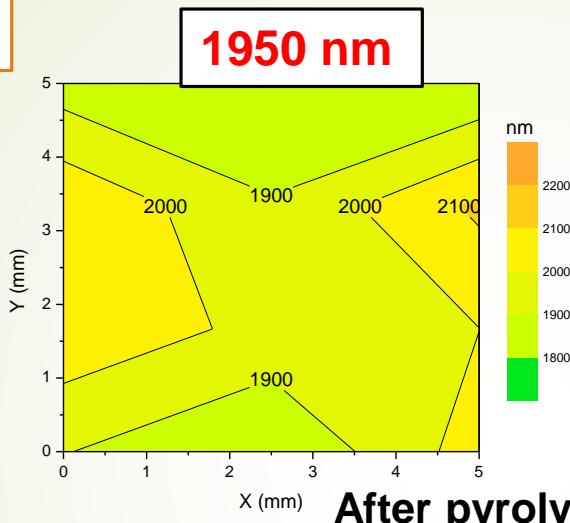
# IJP deposition and pyrolysis of thick YBCO layers

4MP7-03 poster B. Villarejo

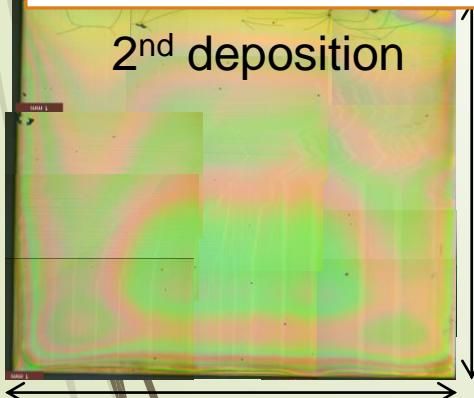
Single deposition



MO image

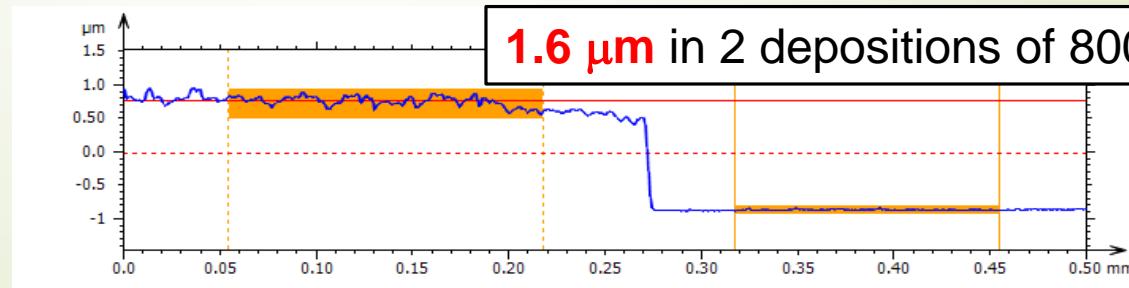


Multi deposition



Multideposition by inkjet printing is presented as an effective route to achieve high thicknesses in a cost effective process

1.6  $\mu$ m in 2 depositions of 800 nm

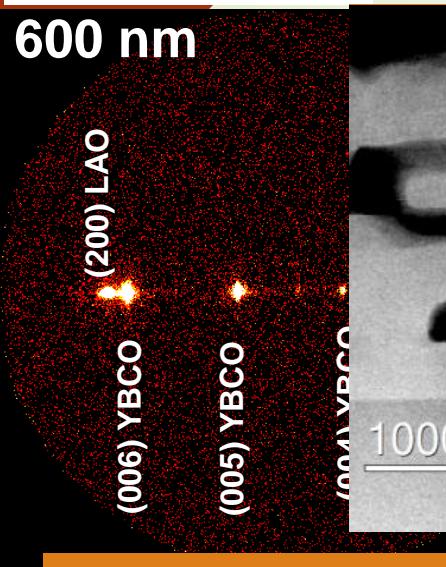


After growth

# IJP thick YBCO films on LAO substrates. New supersaturation conditions

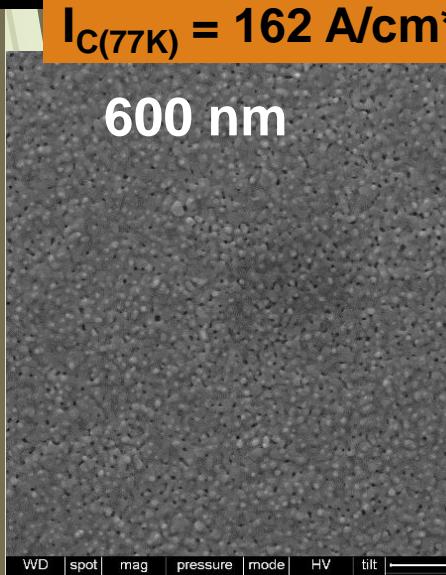
Pristine YBCO

600 nm



$I_c(77K) = 162 \text{ A/cm}^2$

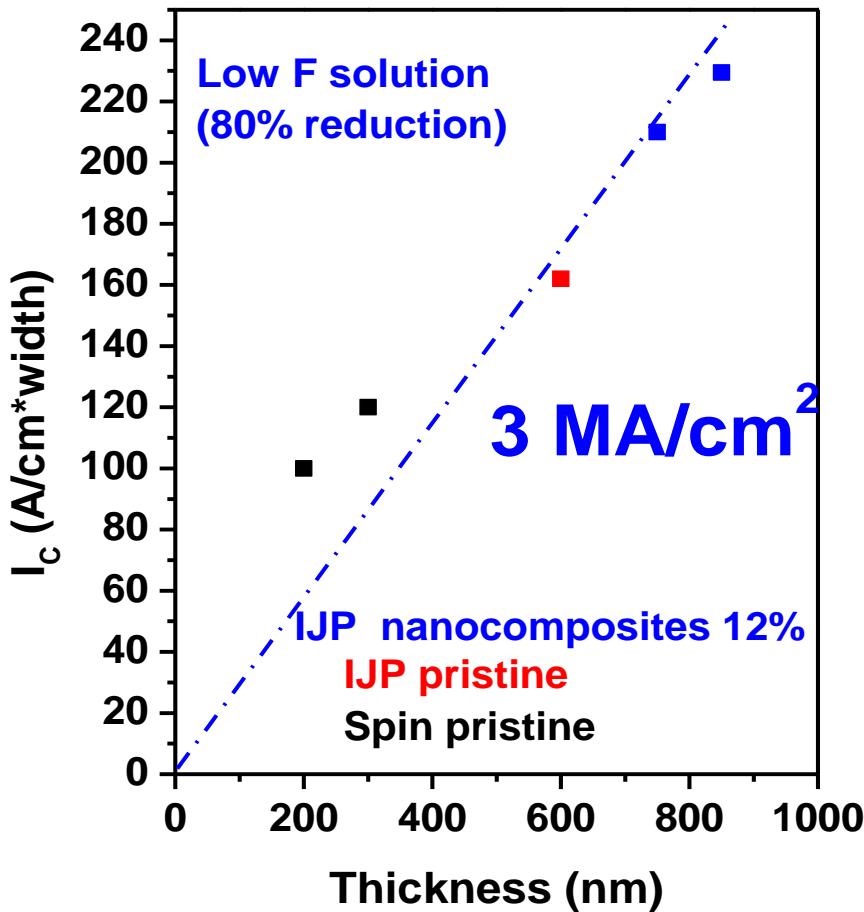
600 nm



WD | spot | mag | pressure | mode | HV | tilt | 10  $\mu\text{m}$   
9.9 mm | 3.5 | 10 000 x | 6.72e-4 Pa | SE | 15.00 kV | -0° | ICIMAB SEM QUANTAFEI 200 F

High performances YBCO thick films (600 nm - 1  $\mu\text{m}$ ) achieved by IJP and using the supersaturation conditions for thick YBCO films growth

77K sf



Uniformly distributed BZO NP's

YBCO 12 %BZO

7 MA/cm<sup>2</sup>

(10) BZO

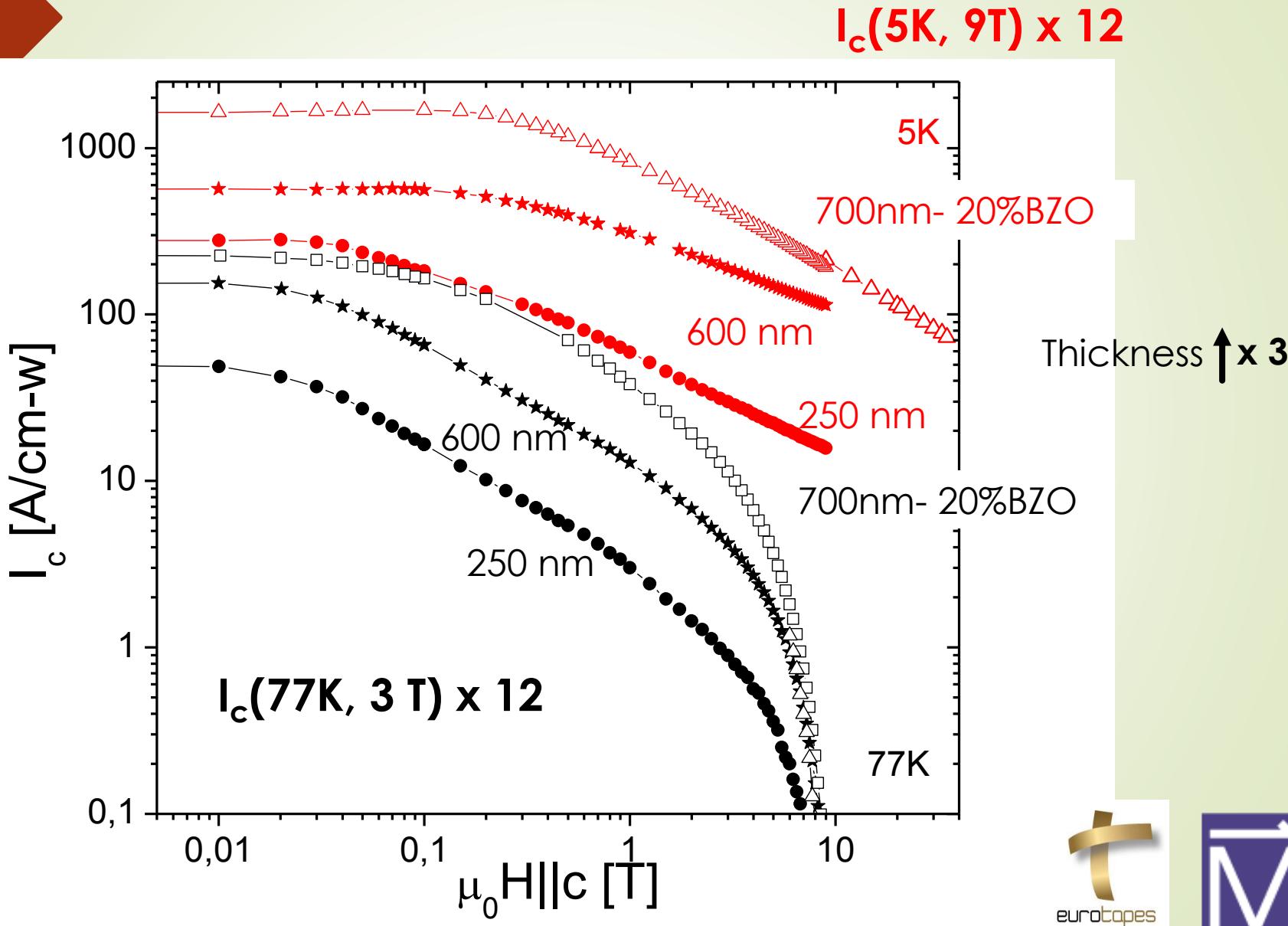
(100) LAO  
(003) YBCO  
(004) YBCO  
(005)

= 229,5 A/cm<sup>2</sup> width

50 nm

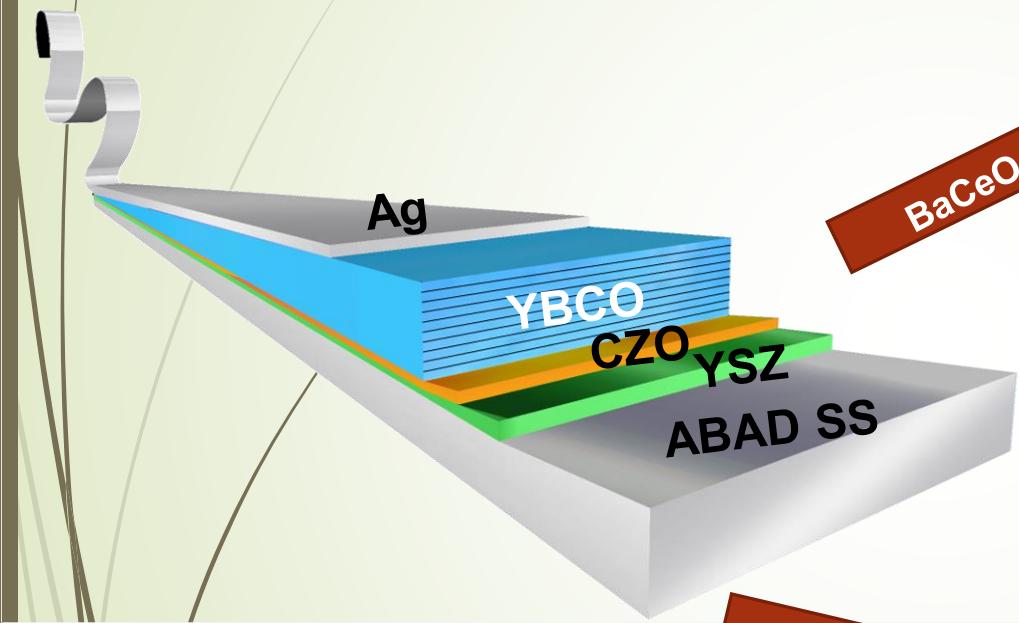
WD | spot | mode | HV | tilt | 10  $\mu\text{m}$   
10.0 mm | 3.5 | SE | 15.00 kV | 0° | 10 000 x | ICIMAB SEM QUANTAFEI 200 FEG-ESEM

# Increase of $I_c$ with thickness by IJP deposition of nanocomposites



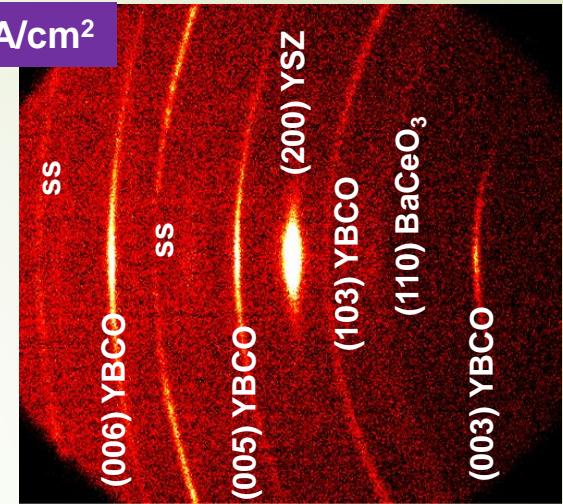
# YBCO coated conductors: solving reactivity issues

CSD YBCO / CSD CZO / PLD YSZ / ABAD SS



$$J_{C(77K)} \sim 0 \text{ MA/cm}^2$$

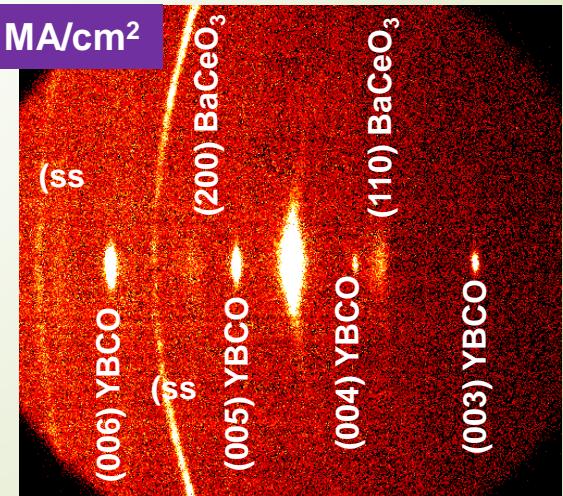
BaCeO<sub>3</sub> first



$$J_{C(77K)} = 1,5 \text{ MA/cm}^2$$

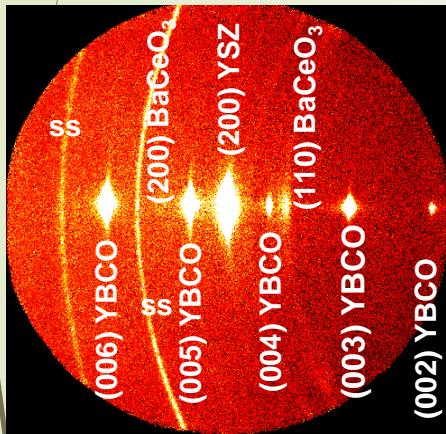
YBCO first

Again supersaturation conditions must be tuned in order to ensure c-axis growth of YBCO on metallic tapes



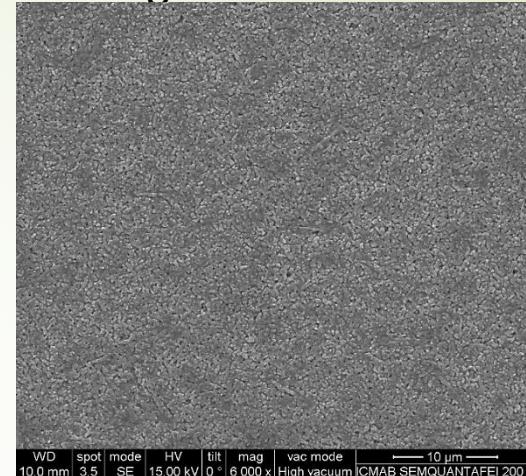
# Thick YBCO coated conductors

Epitaxial growth is achieved in 2 step process:  
nucleation in new supersaturation conditions and growth at 800 °C



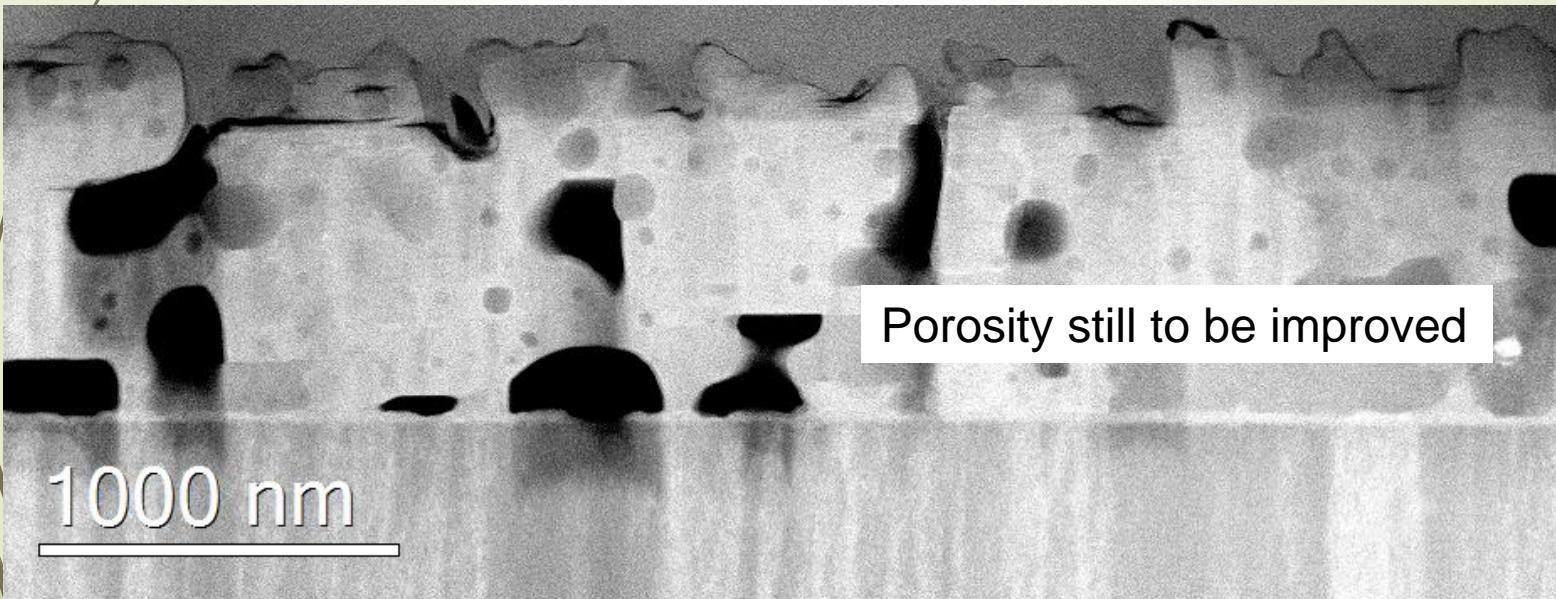
**Thickness 1µm !!!  
one single deposition**

$$J_{C(77K)} = 1 \text{ MA/cm}^2$$
$$I_{C(77K)} = 100 \text{ A/cm*width}$$

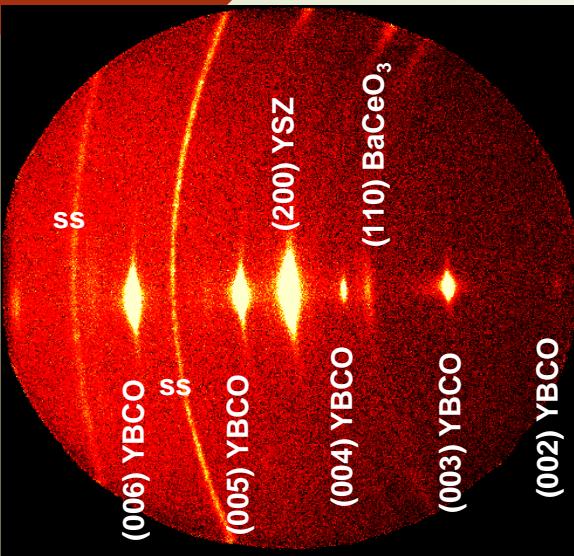


Highly epitaxial !!!

No a-b grains!!!

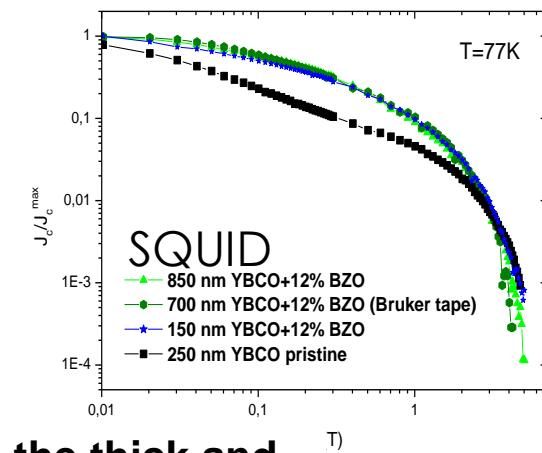


# Thick YBCO + 12 % BZO NPs coated conductors

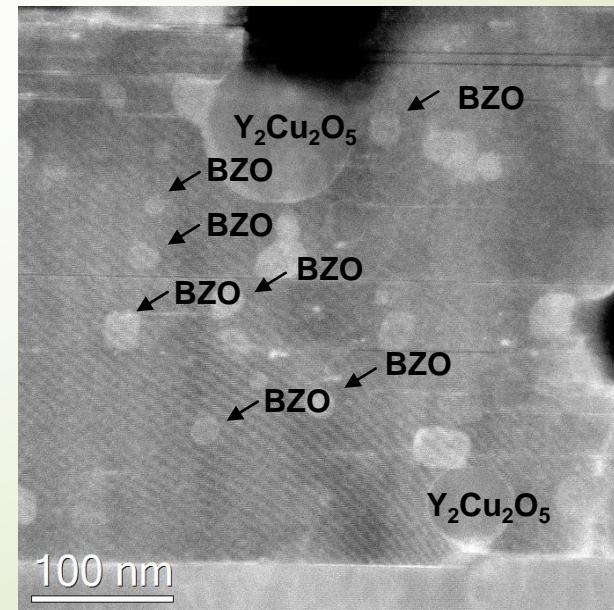
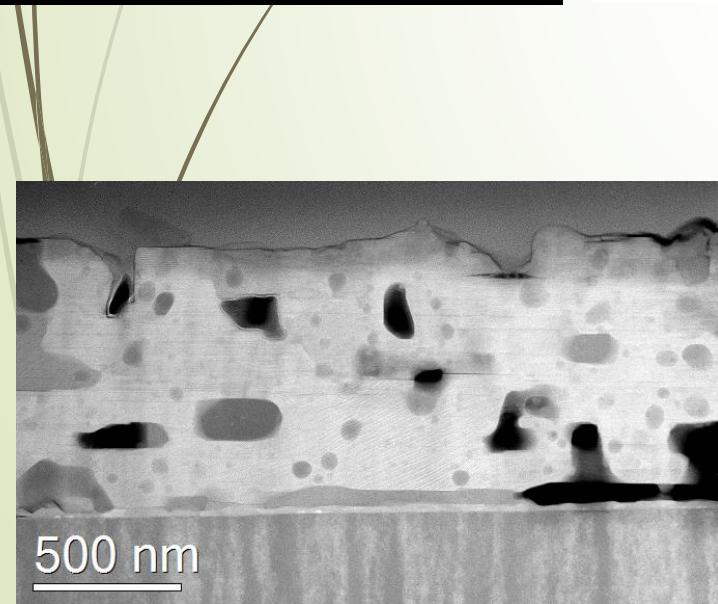


700 - 800 nm of thickness  
one single deposition

$$J_{c(77K)} = 1,4 \text{ MA/cm}^2$$
$$I_{c(77K)} \sim 100 \text{ A/cm*width}$$



Similar field dependence to the thick and thin nanocomposites on single crystal for the same Np concentration



# Conclusions

- The addition of non-reactive preformed nanoparticles has been proved to be a very effective pathway to achieve high performances YBCO superconducting layers
- The inkjet printing has been enabled as an effective deposition method to achieve high quality thick superconducting layers from one single deposition (1,1 µm from one single deposition, 1,6 µm from 2 depositions)
- The studies of the pyrolysis and growth processes of thick YBCO layers generated a large amount of knowledge. We designed pyrolysis and growth processes that lead to high performances thick superconducting layers ( $I_{c(77K)}^{sf} = 230 \text{ A/cm}^2 \text{width}$  for 900 nm).
- Thick YBCO coated conductors from one single deposition become a reality both for pristine YBCO and YBCO nanocomposites. These coated conductors have a lot of potential since there is room for improvement ( $I_{c(77K)}^{sf} = 100 \text{ A/cm}^2 \text{width}$ ).



CSIC



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EXCELENCIA  
SEVERO  
OCHOA



EUROPEAN DEVELOPMENT OF SUPERCONDUCTING TAPES



Xarxmae  
Xarxa de Referència  
en Materials Avançats per a l'Energia  
Generalitat de Catalunya



Thank you very much  
for your attention!!!!

