

# *Ex Situ* Processing of YBCO Precursors

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# Project goal

To understand and explore means to fabricate high performance YBCO using alternative techniques other than PLD.

## Approach

- To perform ex situ conversion of YBCO using a variety of precursors which include:
    - E-beam deposited “BaF<sub>2</sub>” precursor (PVD),
    - Solution TFA precursor,
    - Pulsed Electron Deposition (PED) of “BaF<sub>2</sub>-YF<sub>3</sub>” type precursor,
    - Solution non-fluorine precursor, etc.
- at various pressures.

# Activities in support of the Coated Conductor Development Roadmap

## Faster YBCO Deposition Rates Strategies

- **R&D Needs:**
  - **BaF<sub>2</sub> type precursor:**  
What are the limits to the conversion rate and thickness?
- **Recommended Activities:**
  - Determine process parameter space for YBCO,
  - Develop *ex situ* conversion technology,
  - Develop methods to increase YBCO production rates, increase area.
- **FY2005 Performance Target:**
  - Rates 50m/h/cm-width,
  - at  $I_c > 200A$  77K, s.f.

# FY2003 objectives

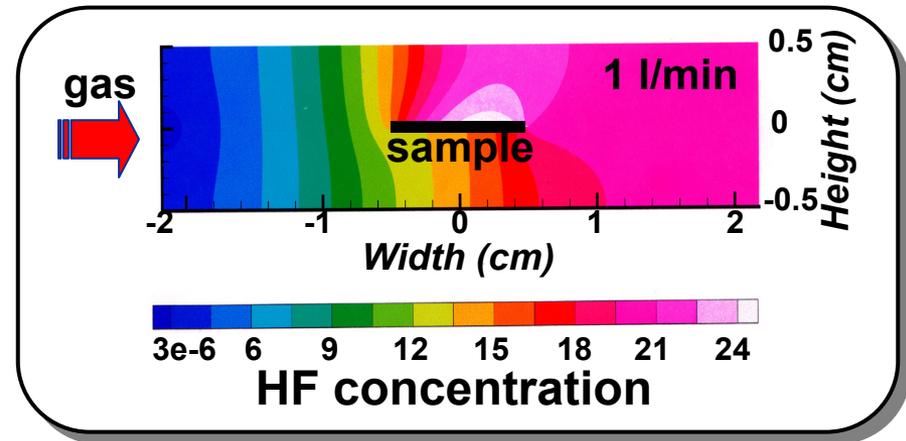
- Explore YBCO conversion characteristics over all pressure ranges allowable by our atmospheric, reduced-pressure and low-pressure conversion systems:
  - (0.3 $\mu\text{m}$  YBCO, > 1 MA/cm<sup>2</sup>).
- Study the effect of precursor thickness on conversion parameters in all pressure ranges:
  - (>0.5 $\mu\text{m}$  YBCO, > 1 MA/cm<sup>2</sup>).
- Examine the effects of conversion pressure on sample homogeneity.
- Compare the conversion characteristics of different precursors - TFA (partnered with Sandia National Lab).

## Reviewers' suggestions:

- Separate YBCO presentation.
- More fundamentals → conversion behavior,  $I_c$ , reaction rates.
- Partner with other labs.

# HF buildup in fluorine-type precursor can increase sample inhomogeneity and decrease YBCO growth rate

- Buildup of HF within the chamber.
- HF concentration is highest at the surface (downstream).
- HF concentration lowered by increasing the gas flow.



## Lower conversion pressures can reduce the HF buildup and provide other advantages

- By simply pumping on the outlet:
  - HF removal greatly enhanced [V. F. Solovyov et al. BNL],
  - Gas usage greatly reduced.
- In addition, by reducing the chamber to low pressure:
  - Flow is more modular and nozzle jetting is reduced,
  - Gas diffusivities are increased,
  - Total heat consumption is reduced.
- Much faster conversion rates on thick films with high  $I_c$ 's have been reported on TFA precursor [Cima et al. MIT].

Three systems are being used to explore the different pressure ranges

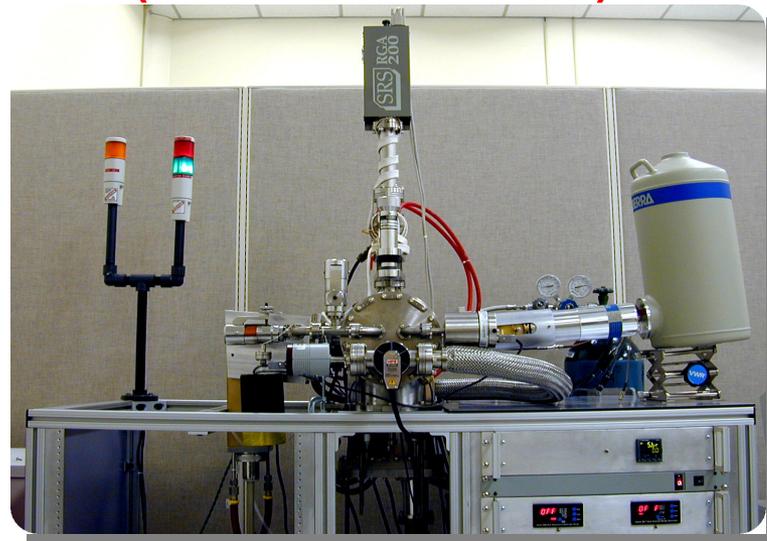
“Atmospheric” R2R furnace  
(1.4 to 1.6 atm)



“Reduced” pressure chamber  
( $<0.1$  to 1.3 atm)



“Low” pressure vacuum system  
( $2 \text{ E-}6$  to  $2 \text{ E-}3$  atm)



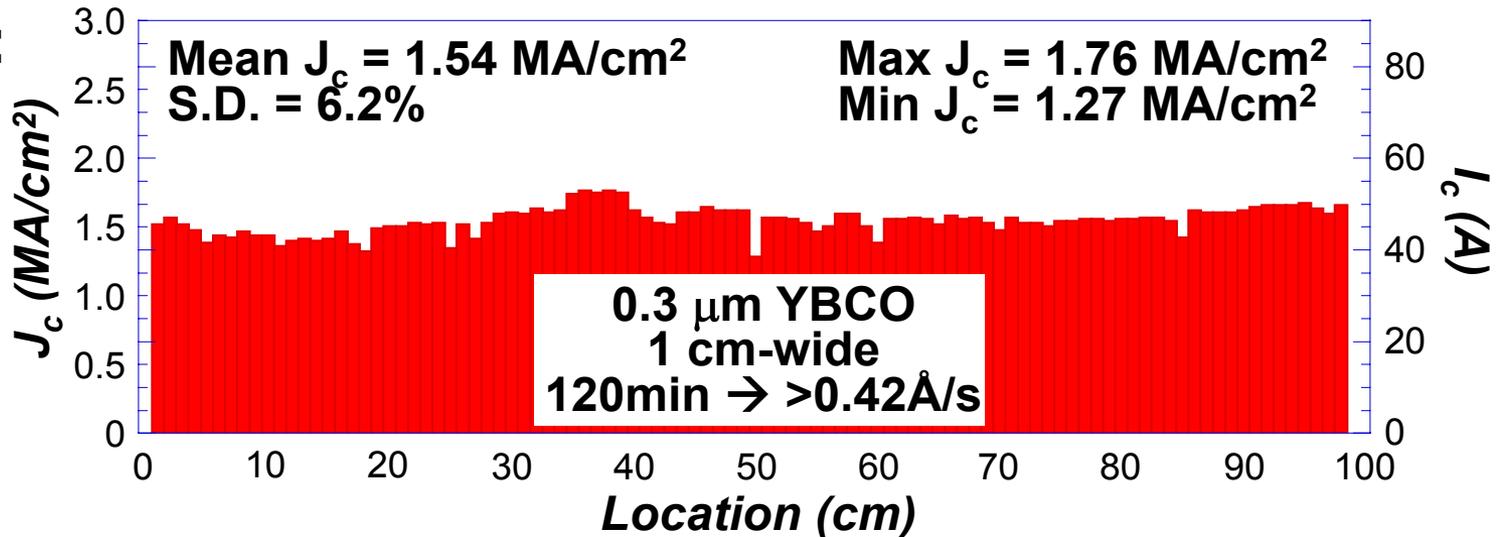
# FY2003 Results Outline

- **“Atmospheric” reel-to-reel furnace:**
  - Moving e-beam (PVD) “BaF<sub>2</sub>” precursor.
- **“Reduced pressure” chamber:**
  - Short stationary e-beam (PVD) “BaF<sub>2</sub>” precursor.
- **“Low pressure” vacuum system:**
  - Short stationary precursors: → e-beam (PVD) “BaF<sub>2</sub>”, solution TFA, PED “BaF<sub>2</sub>-YF<sub>3</sub>”.
- **FY2003 performance.**
- **FY2004 plans.**
- **Research integration.**

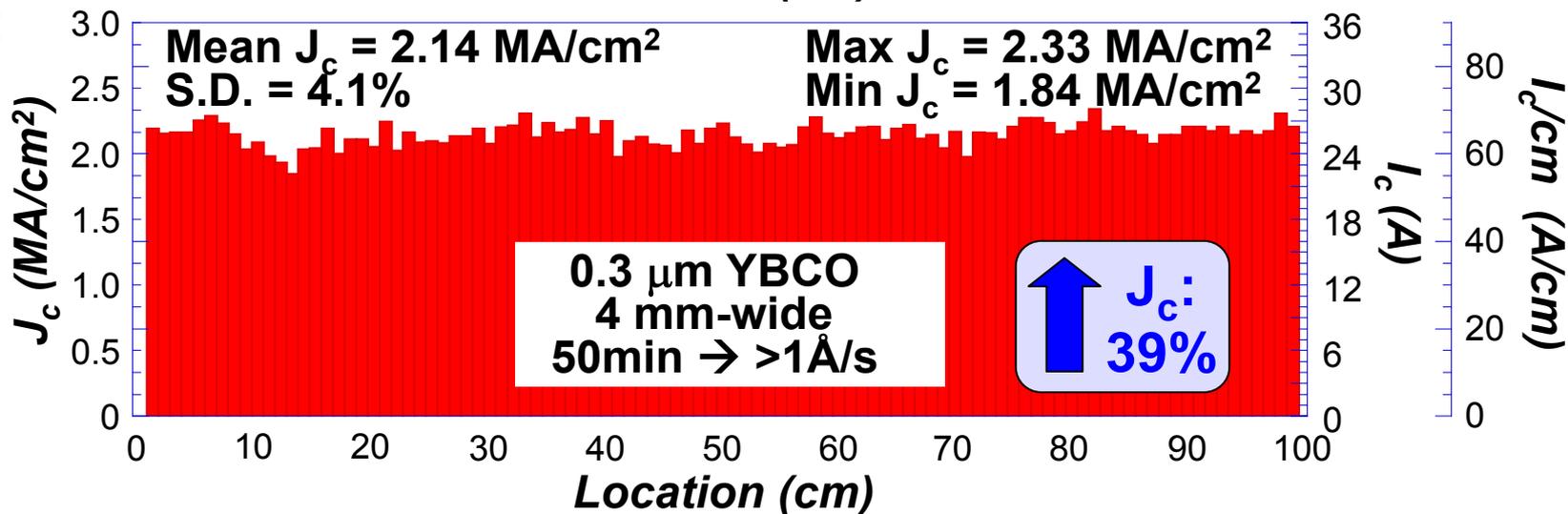
**FY2003 Results:**  
**1. “Atmospheric” R2R furnace**

# 1 meter-long 0.3 $\mu\text{m}$ YBCO on Ni-W RABiTS has been converted at faster rates with better $J_c$ . BUT....

**FY2002:**



**FY2003:**



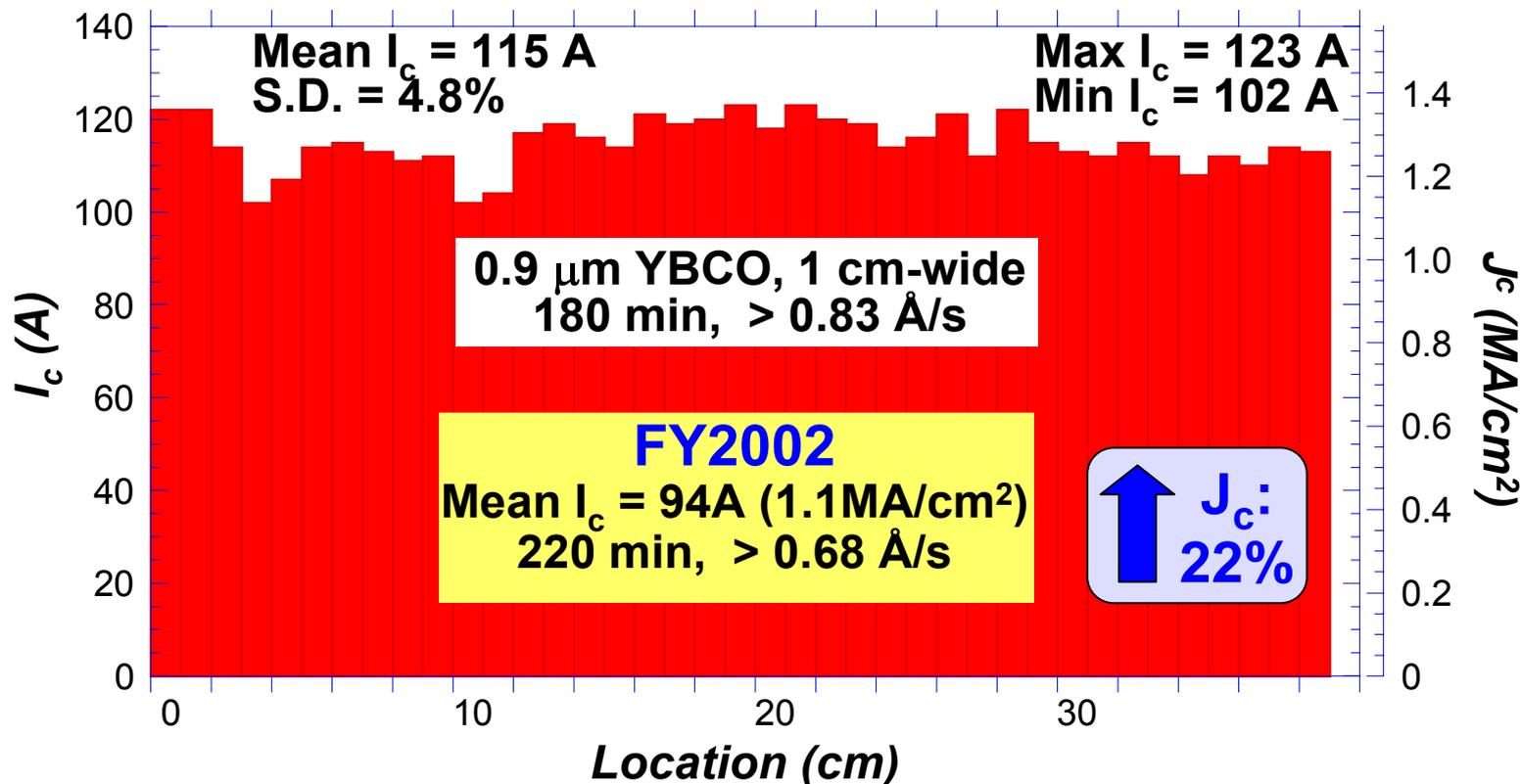
... faster rate and better uniformity are believed to be due to reduced HF buildup.

# Processing parameters in the “atmospheric” R2R furnace need to be adjusted as precursor thickness increases

- High  $J_c$  0.3  $\mu\text{m}$  YBCO were converted using the following parameters:
  - Temp = 740°C,  $P(\text{O}_2) = 135$  mTorr,  $P(\text{H}_2\text{O}) = 35$  Torr.
- When same parameters are used for thicker precursors (>0.5  $\mu\text{m}$ ), the films possess low YBCO XRD intensities (with random and a-axis YBCO), and are non-SC.
- Meter-long tapes with 1  $\mu\text{m}$  PVD  $\text{BaF}_2$  precursor were partially converted and quenched to examine the phase development under different processing conditions:
  - NiO outgrowths present when temperature is higher than ~ 770°C → depends on buffer quality,
  - $\text{BaF}_2$  crystallization and decomposition rates are affected by both temperature and  $P(\text{H}_2\text{O})$  → influence YBCO growth,
  - Using **low  $P(\text{H}_2\text{O})$**  during the initial YBCO nucleation stage favors c-axis growth with complete coverage [Cima et al. MIT].

# High and uniform $I_c$ 's have been obtained on RABiTS with 0.9 $\mu\text{m}$ YBCO

- Temp = 740°C  
P(O<sub>2</sub>) = 135 mTorr  
P(H<sub>2</sub>O) = 4 → 42 Torr  
Time = 180 min

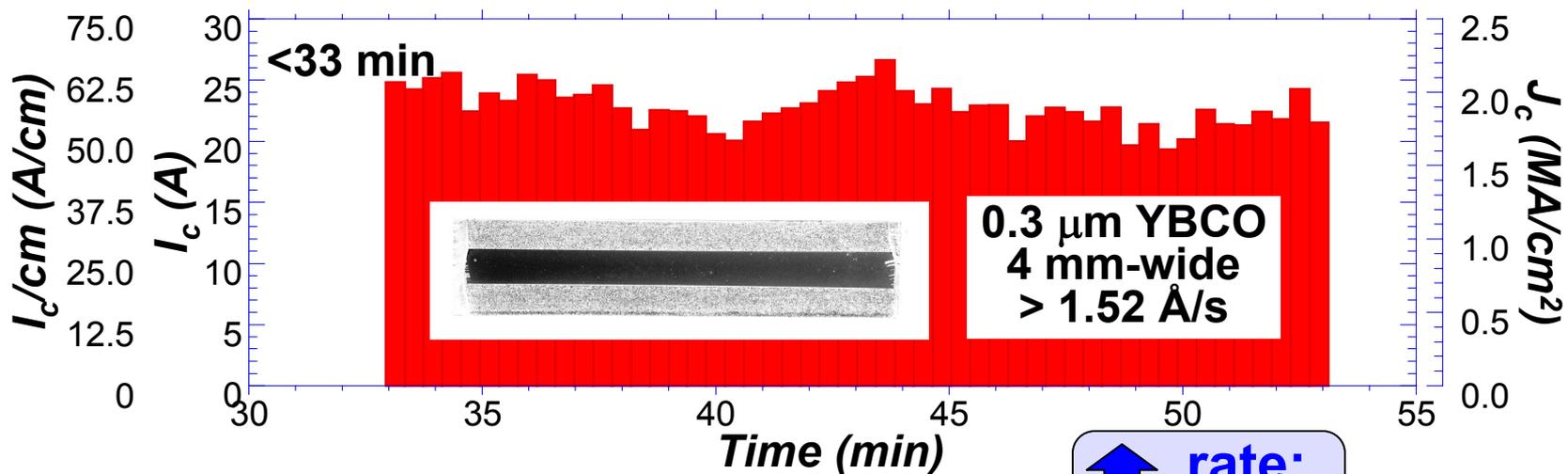
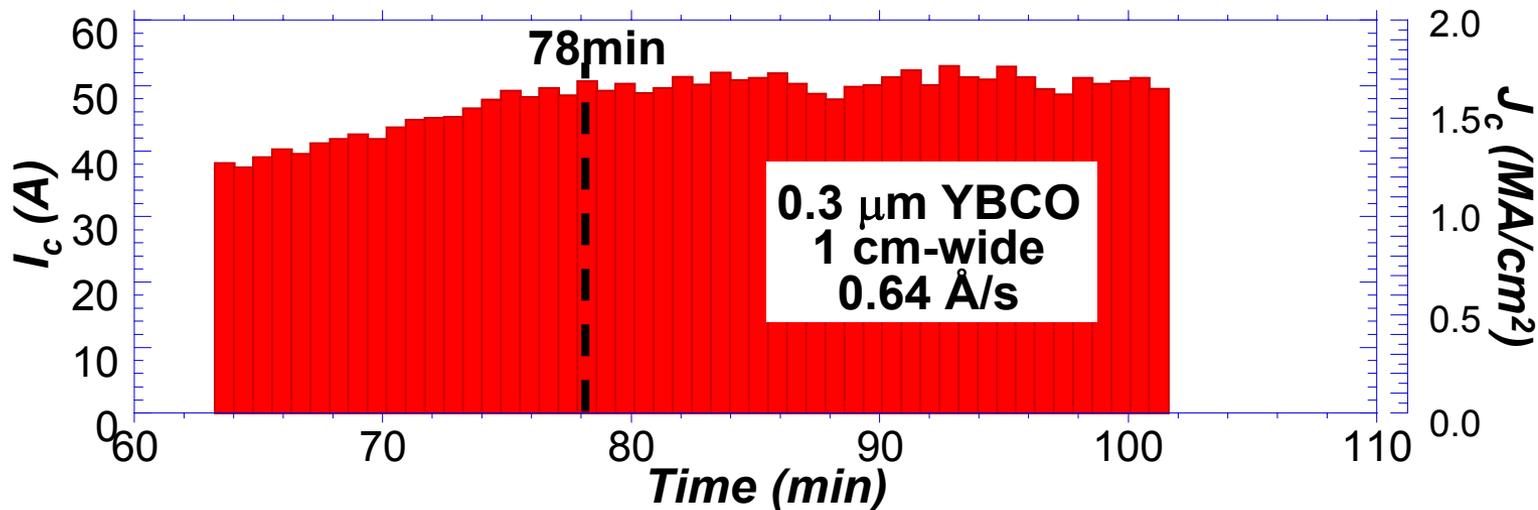


- Highest  $I_c$  for 0.9  $\mu\text{m}$  YBCO (10 cm-long) is 138A ( $J_c = 1.53$  MA/cm<sup>2</sup>)  
→ increase of 47% → better YBCO processing and better buffers.

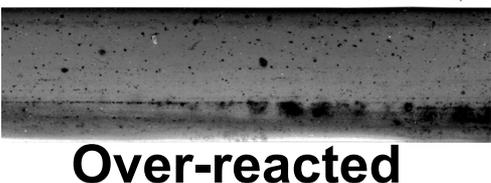
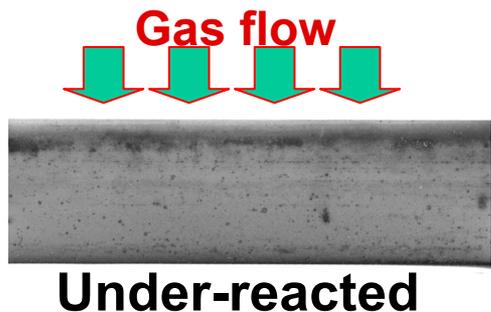
# What about 1.5 $\mu\text{m}$ YBCO?

- Assuming a constant growth rate, a 1.5  $\mu\text{m}$  PVD “BaF<sub>2</sub>” film requires ~300 min conversion time:
  - Imposes a max pull-through ramp-up rate of <math>13^\circ\text{C}/\text{min}</math> → random YBCO,
  - Cannot convert long-lengths by pull-through → short samples only.
- Using near identical processing parameters (except for time) as 0.9  $\mu\text{m}$  films:
  - Fully converted after ~ 275 min (i.e. no BaF<sub>2</sub> XRD signal),
  - c-axis YBCO (~96% cube), but lower counts than 0.9  $\mu\text{m}$  films!
  - $J_c = 0.3$  to  $0.4$  MA/cm<sup>2</sup> ( $I_c/\text{cm} = 48\text{A}$  to  $62\text{A}$ ).
- Latest results indicate that a higher  $P(\text{O}_2)$  may be favorable for thicker YBCO conversion in our atmospheric chamber:
  - Higher XRD counts than previous  $P(\text{O}_2)$ .
  - Best 1.5  $\mu\text{m}$  YBCO film:  $I_c = 160.2$  A ( $J_c = 1.07$  MA/cm<sup>2</sup>,  $0.83$  Å/s).
- Challenging to process thick PVD “BaF<sub>2</sub>” precursors with high  $J_c$  at these growth rates (<math>1\text{Å}/\text{s}</math>) within this available processing window.

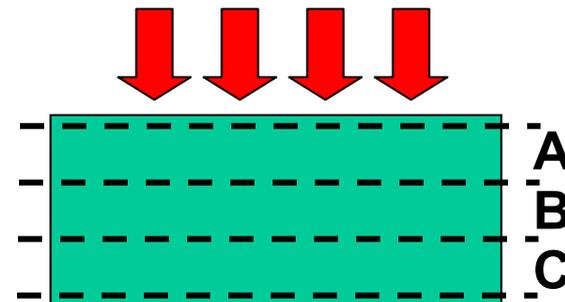
# More evidence of HF buildup in the chamber : Under identical processing conditions, YBCO conversion rate of 4 mm-wide film is much faster than full 1 cm-wide sample



# HF buildup at the sample surface coupled with high gas flow rates can result in inhomogeneous YBCO conversion



- A 0.9  $\mu\text{m}$ -thick YBCO sample was cut into three  $\sim 3$  mm-wide strips and  $I_c$  was re-measured:

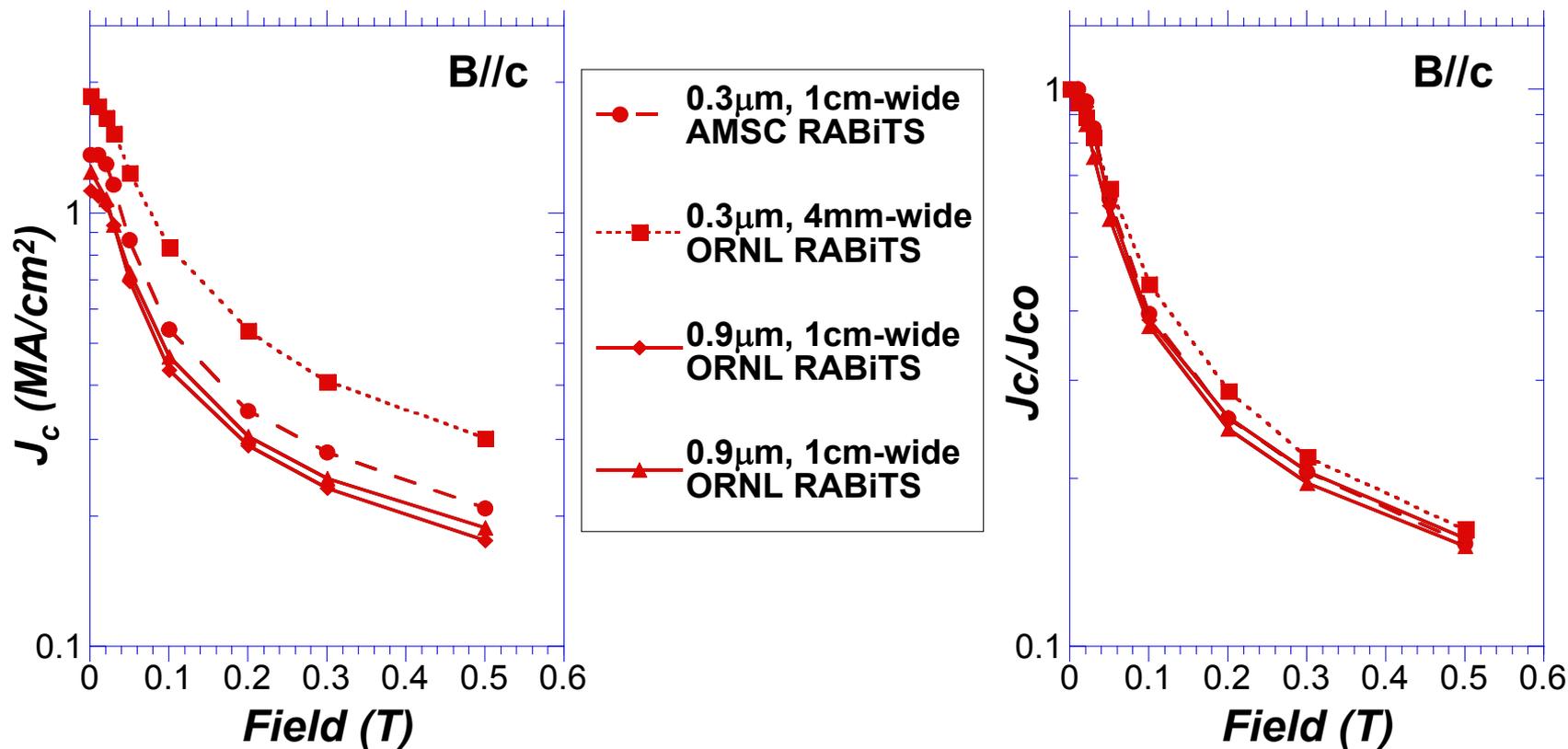


**Inhomogeneity can remain even when the sample is “optimally” processed.**

Sample	Width (cm)	$I_c$ (Å)	$I_c/\text{cm}$ (Å/cm)	$J_c$ (MA/cm <sup>2</sup> )
Full 1cm	1	110.0	110.0	1.22
A	0.301	33.53	111.4	1.24
B	0.305	29.02	95.1	1.06
C	0.301	26.68	88.6	0.98

**A 27% change from edge-to-edge!**

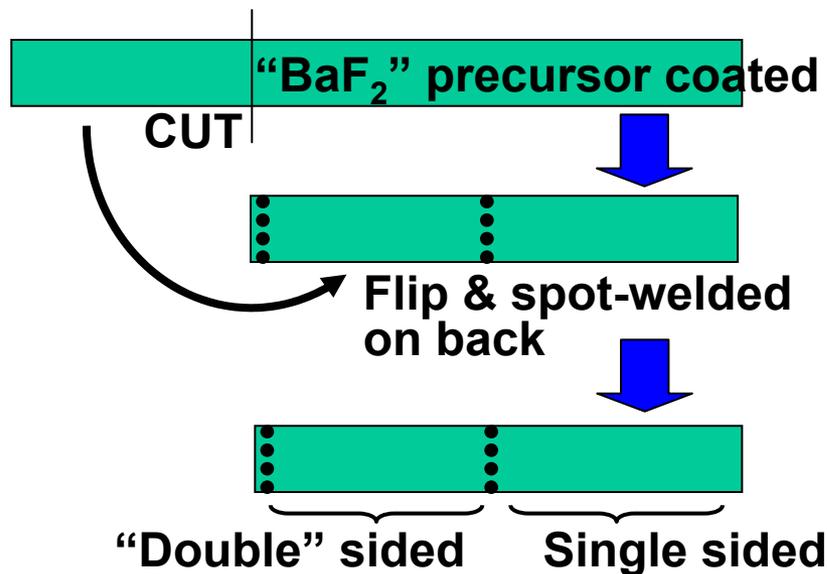
# Strong field dependency ( $B//c$ ) was found in samples processed in this atmospheric R2R furnace



- Instead of the typical 4-to-1 drop at 0.5 T, samples processed in this atmospheric R2R chamber range from 6-7 to-1!

# Doubled-sided YBCO coating can result in high current capacity with reduced processing time → If double-sided buffer deposition is feasible & economical

- Double-sided coating:
  - Double the  $I_c$ ,
  - Nearly double the  $J_E$  (not including any stabilizing layers),
  - **Can the same processing conditions be used?**  
**Will the processing time remain unchanged?**
- Simple test using atmospheric R2R furnace →  
HF buildup, most unfavorable conditions among our systems:

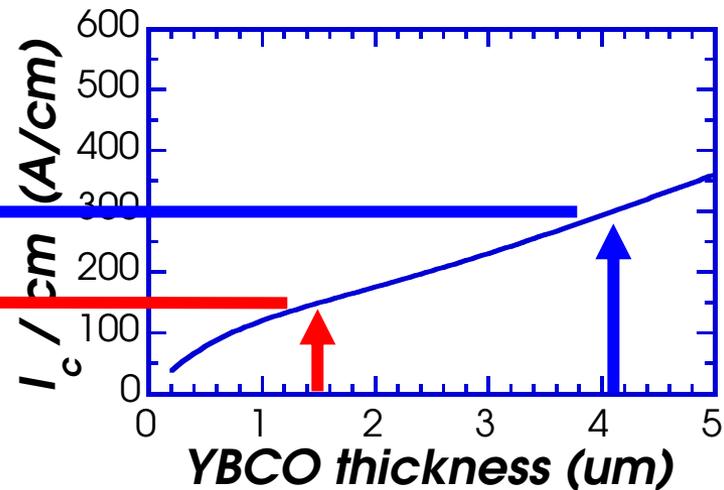
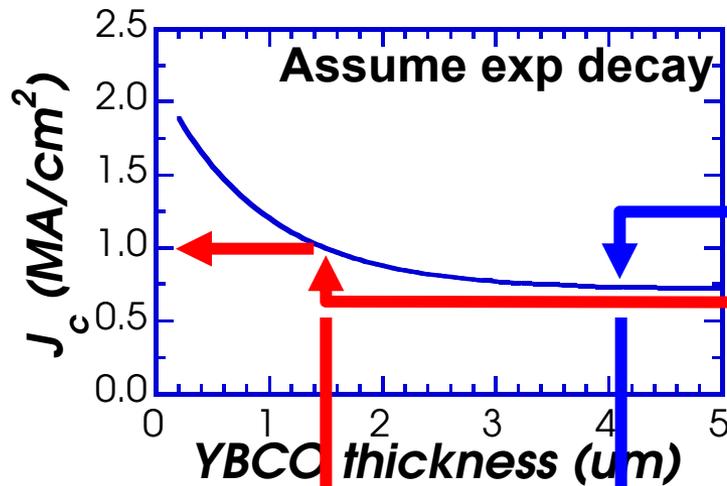


**0.9  $\mu\text{m}$  YBCO**  
**180 min, 0.83  $\text{\AA}/\text{s}$**

	$I_c$ (A)
Single sided	124
Double (top)	117
Double (bottom)	121

- Conversion time has not changed!
- 238 A/cm conductor!

# Double-sided CC can take advantage of the increase $J_c$ offered by thinner YBCO

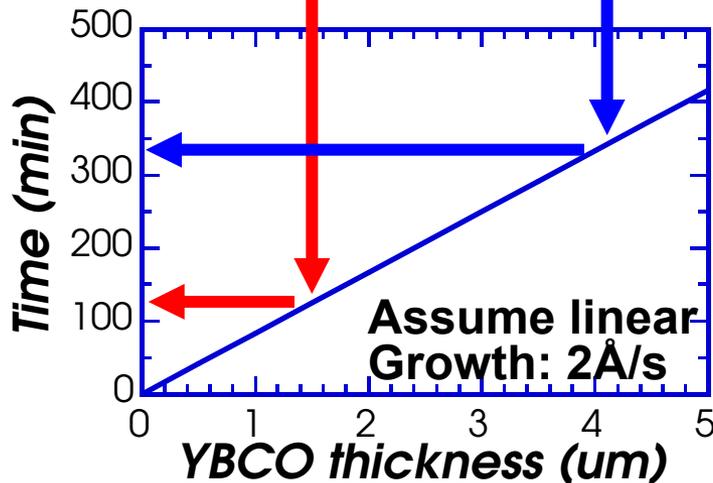


## Single-sided CC

To obtain 150 A: YBCO = 1.5 µm  
 $J_c = 1$  MA/cm<sup>2</sup>,  $t = 125$  min.

To obtain 300 A: YBCO = 4.1 µm  
 $J_c = 0.73$  MA/cm<sup>2</sup>,  $t = 342$  min.

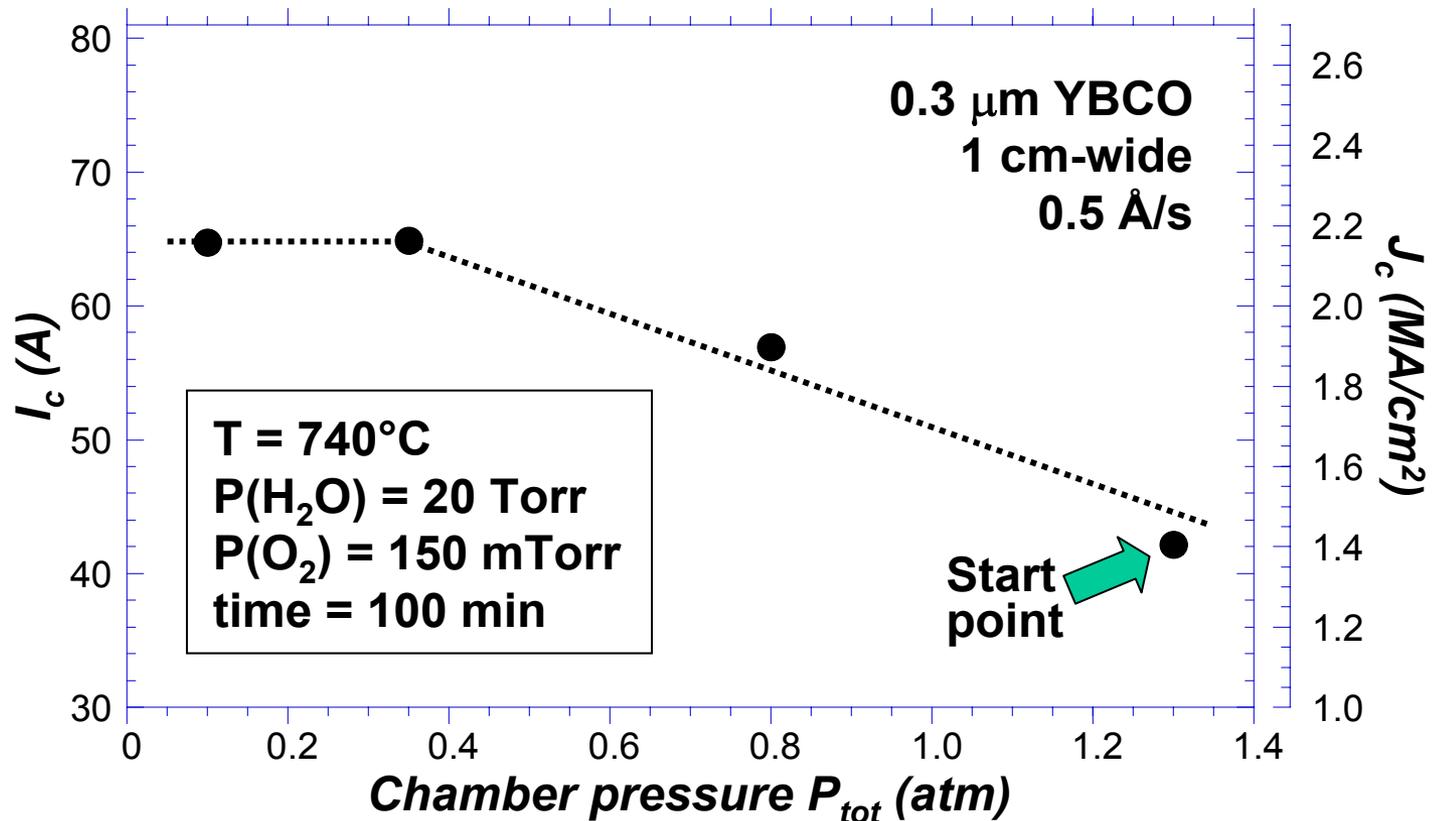
Almost triple the time!



**FY2003 Results:**  
**2. Reduced pressure conversion chamber**

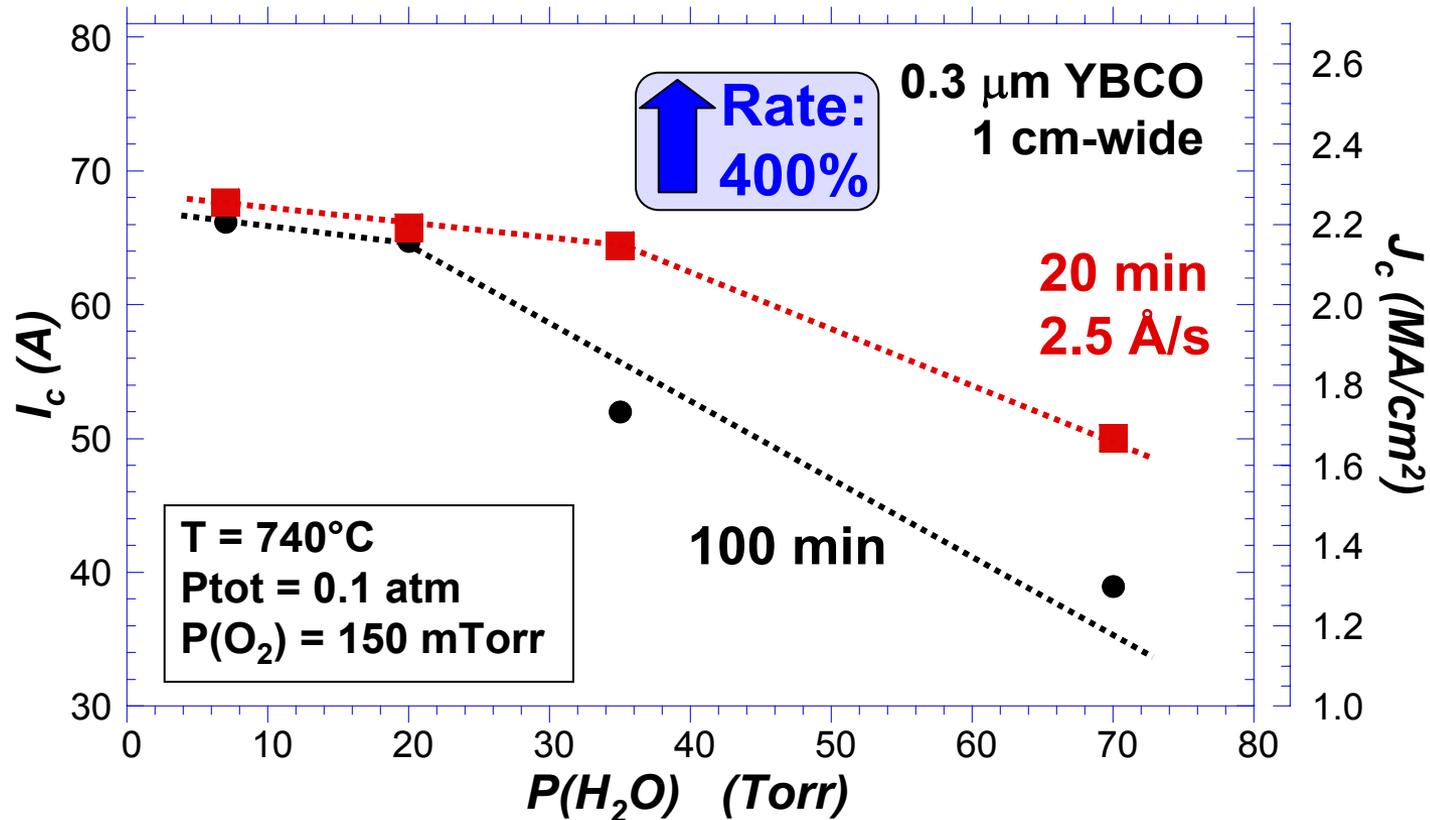
# Sample performance is improved by reducing the chamber pressure

- All 0.3  $\mu\text{m}$  films were cut from single length of PVD BaF<sub>2</sub> precursor on Ni-3%W RABiTS.
- **Starting point:** other parameters fixed based on best performance without pumping (1.3 atm,  $I_c = 42$  A, 100 min).



# At reduced pressures, lower $P(\text{H}_2\text{O})$ leads to better performance in these $0.3 \mu\text{m}$ CC

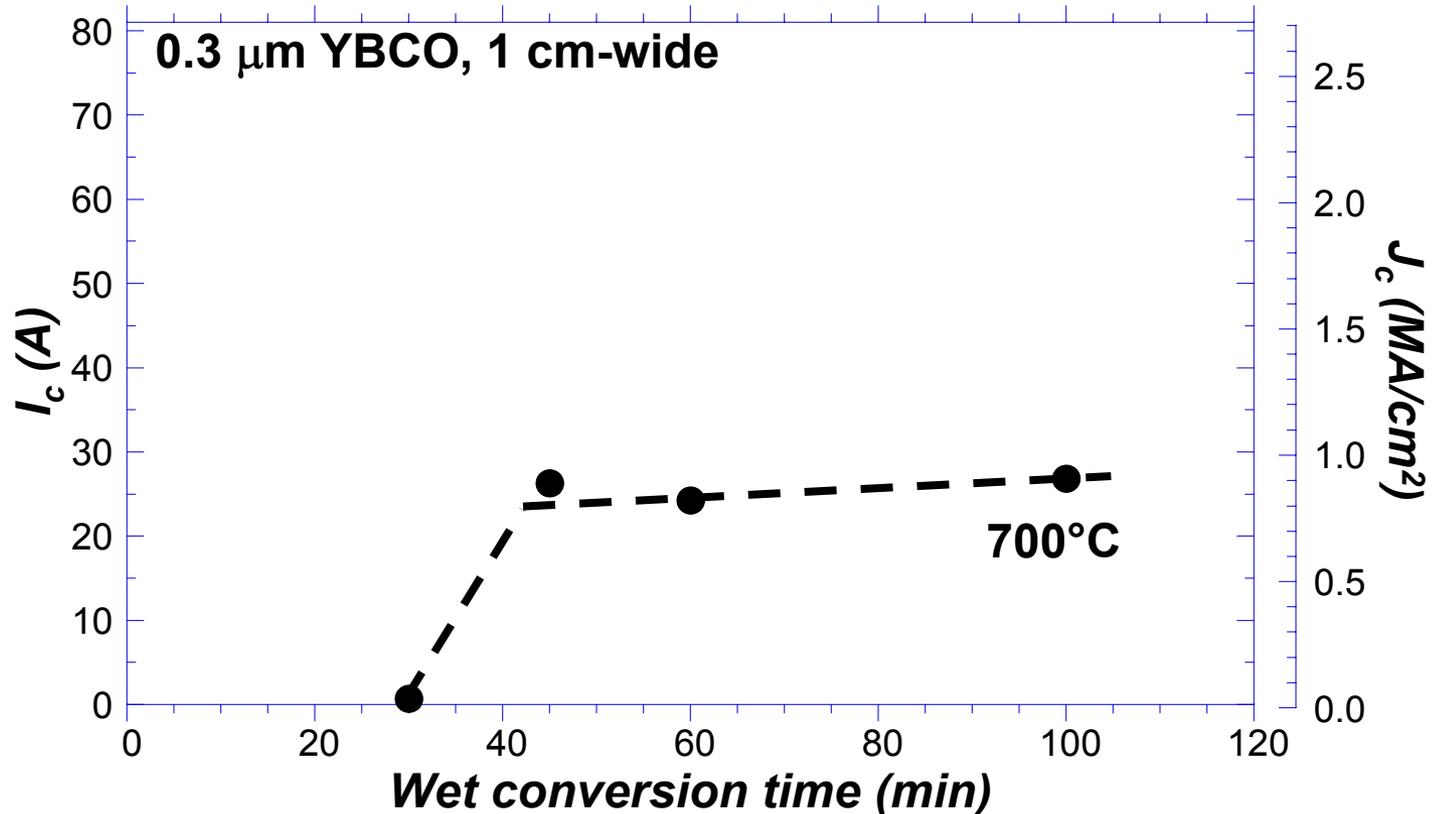
- Chamber pressure  $P_{\text{tot}}$  is fixed at 0.1 atm.



- Higher  $I_c$  with faster conversion rate compared to atmospheric conditions [this chamber (4X) , R2R atm (3X)].

# Optimum conversion time varies with processing temperature

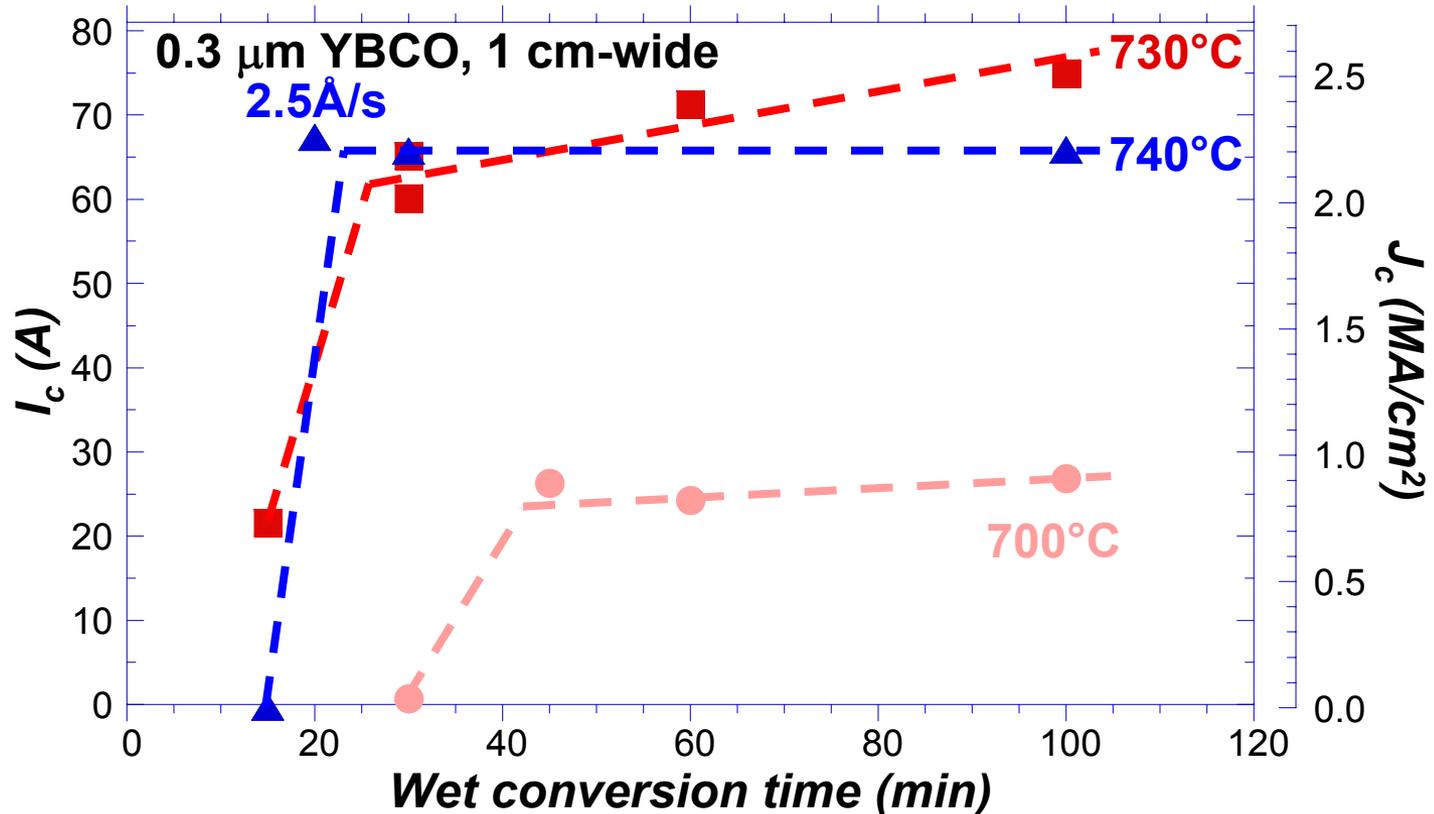
- Chamber pressure  $P_{\text{tot}}$  fixed at 0.1 atm,  $P(\text{H}_2\text{O})$  at  $\sim 7$  Torr and  $P(\text{O}_2)$  at 150 mTorr.



- Too low a temperature resulted in very slow conversion rate  $\rightarrow$  complete conversion not achieved after 100 min.

# Optimum conversion time varies with processing temperature

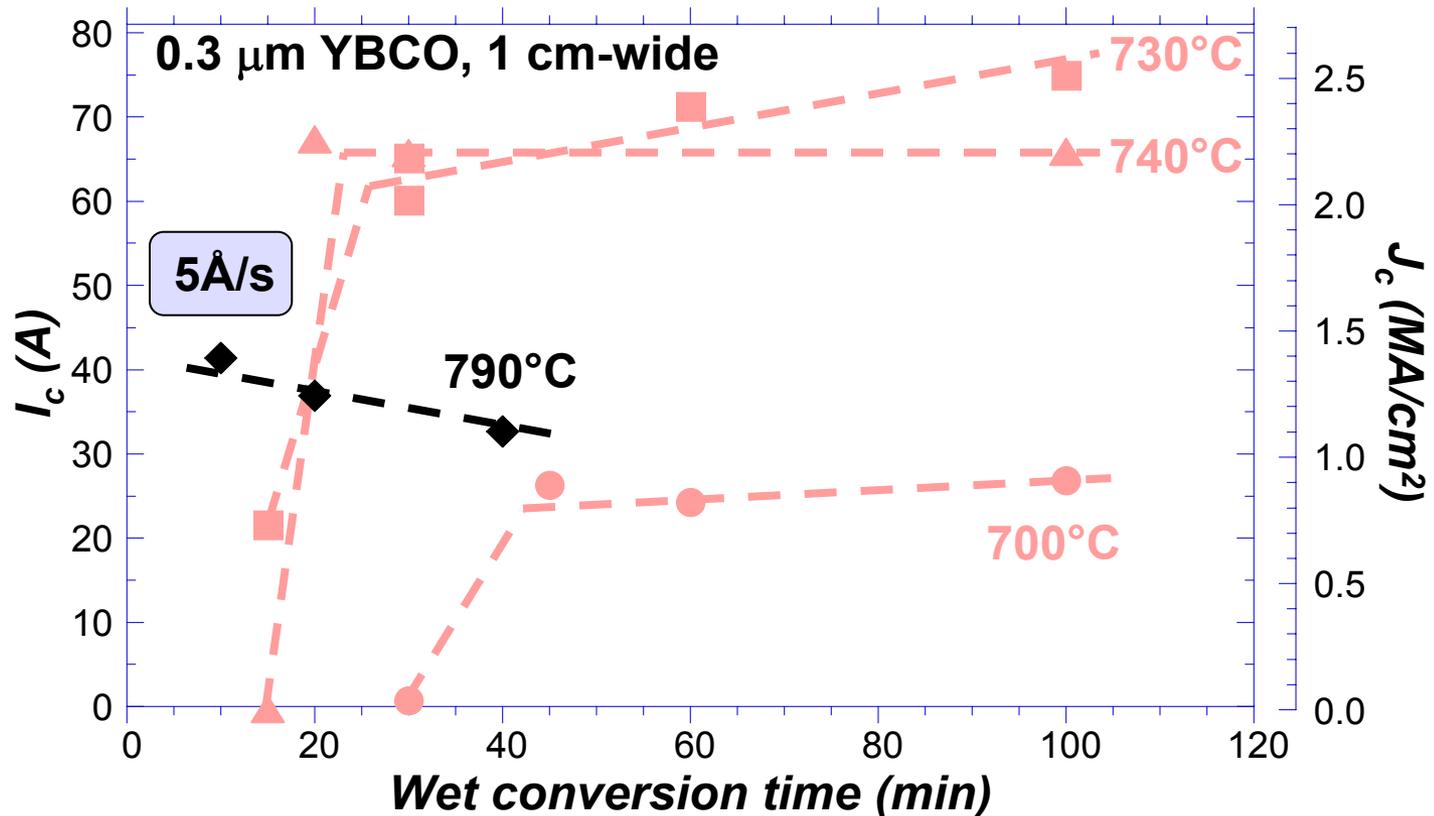
- Chamber pressure  $P_{\text{tot}}$  fixed at 0.1 atm,  $P(\text{H}_2\text{O})$  at  $\sim 7$  Torr and  $P(\text{O}_2)$  at 150 mTorr.



- High  $I_c$  achieved in relatively short time at intermediate temperatures.

# Optimum conversion time varies with processing temperature

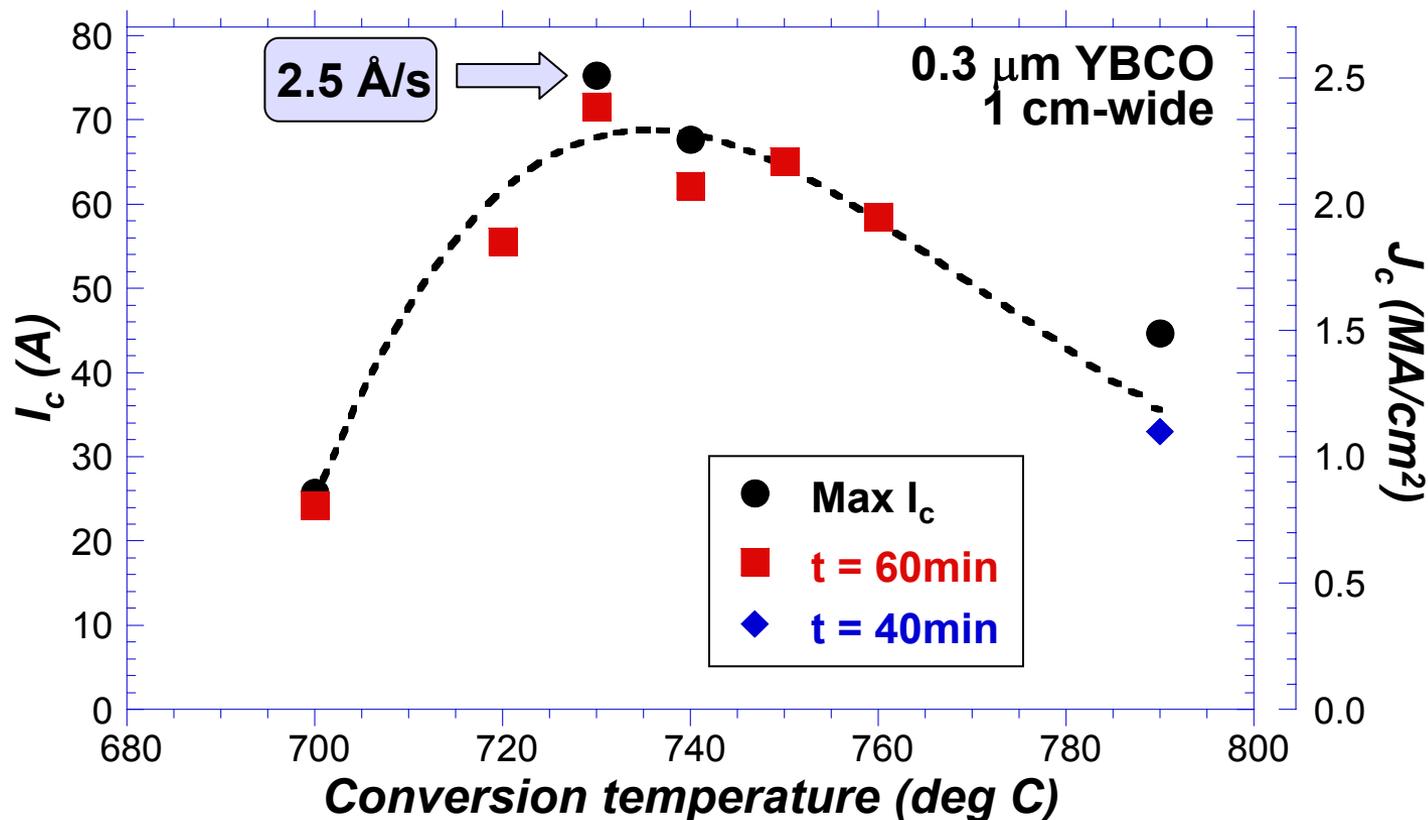
- Chamber pressure  $P_{\text{tot}}$  fixed at 0.1 atm,  $P(\text{H}_2\text{O})$  at  $\sim 7$  Torr and  $P(\text{O}_2)$  at 150 mTorr.



- Too high a temperature leads to more rapid formation of YBCO BUT with lower  $I_c$  & faster degradation.**

# Optimum processing temperature appears to range between 725°C and 745°C under these conditions

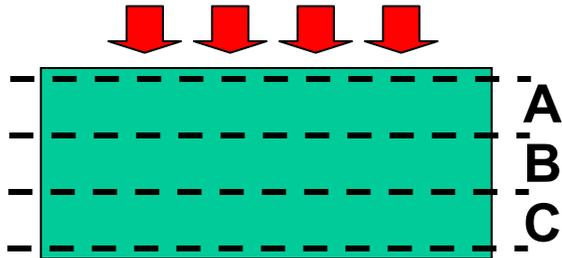
- Chamber pressure  $P_{\text{tot}}$  fixed at 0.1 atm,  $P(\text{H}_2\text{O})$  at ~7 Torr and  $P(\text{O}_2)$  at 150 mTorr.



# 0.9 $\mu\text{m}$ YBCO with high and homogeneous $J_c$ has also been obtained

- 0.9  $\mu\text{m}$  1 cm-wide on Ni-3%W RABiTS:

➤  $T=740^\circ\text{C}$ ,  $P_{\text{tot}} = 0.07 \text{ atm}$ ,  $P(\text{H}_2\text{O}) = <7 \text{ Torr} \rightarrow 11 \text{ Torr}$ ,  $P(\text{O}_2) = 150 \text{ mTorr}$ , **TIME = 60 min  $\rightarrow$  2.5  $\text{\AA}/\text{s}$  (3X compared to atm R2R).**

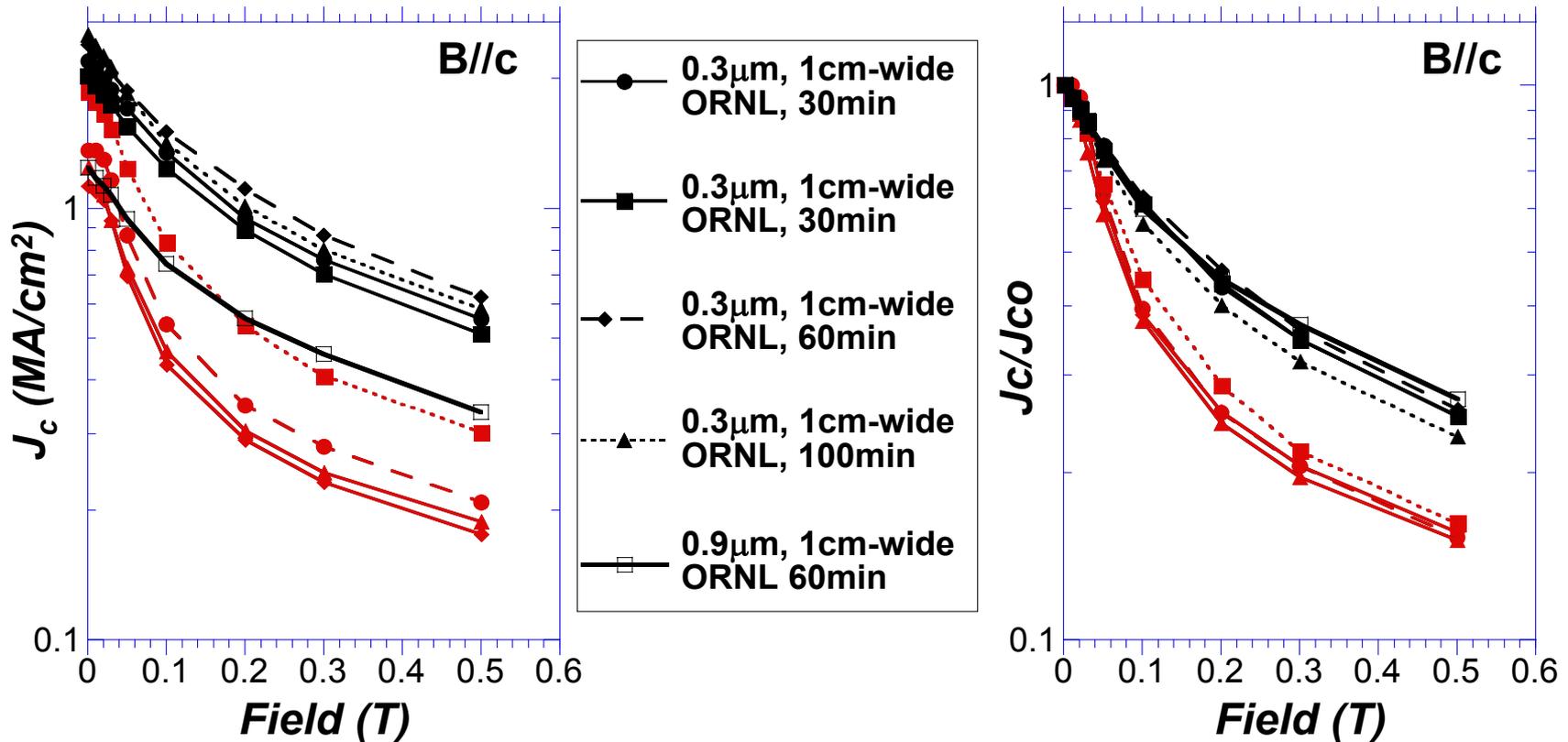


- The 0.9  $\mu\text{m}$ -thick YBCO sample was cut into three  $\sim 3 \text{ mm}$ -wide strips and  $I_c$  was re-measured:

Sample	Width (cm)	$I_c$ ( $\text{\AA}$ )	$I_c/\text{cm}$ ( $\text{\AA}/\text{cm}$ )	$J_c$ ( $\text{MA}/\text{cm}^2$ )
Full 1cm	1	110.5	110.5	1.23
A	0.296	34.05	115.0	1.28
B	0.297	33.29	112.0	1.24
C	0.322	34.83	108.1	1.20

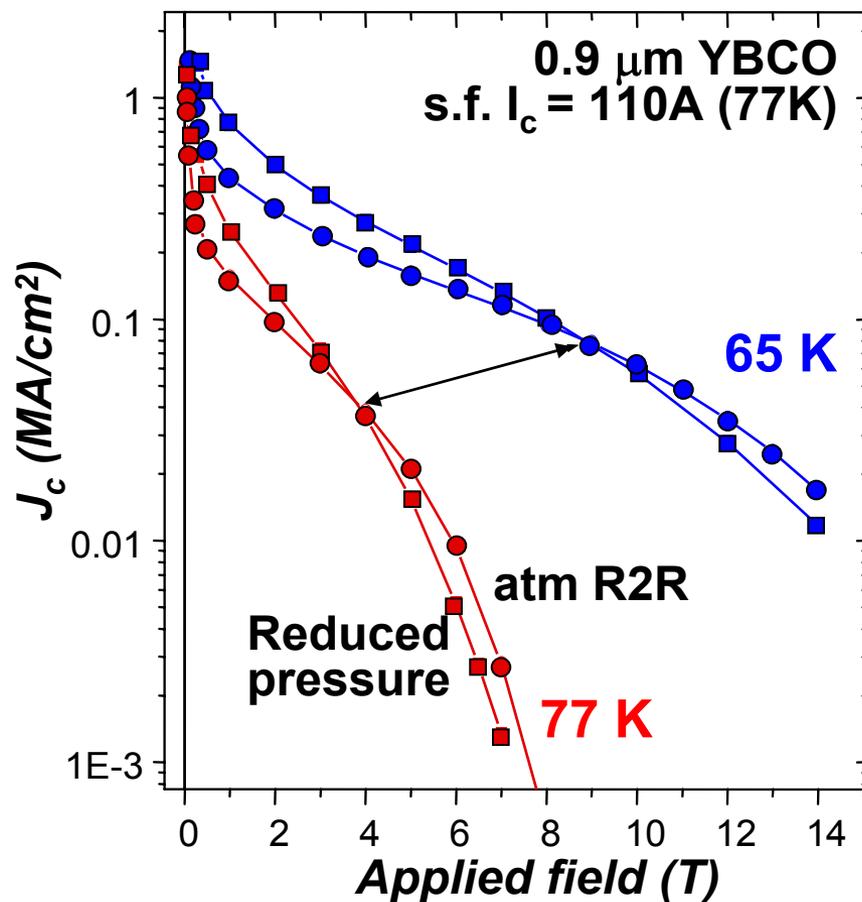
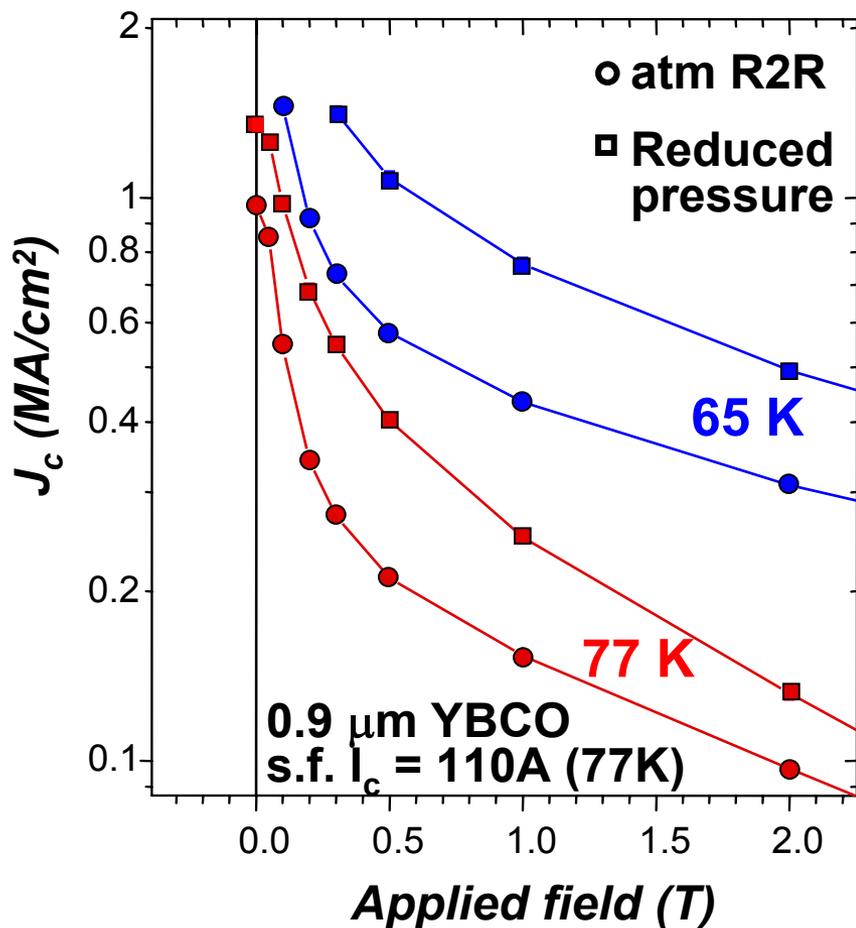
*Sample is homogeneous  
From edge-to-edge!*

# Samples converted in the reduced pressure chamber exhibit the typical weaker field dependency

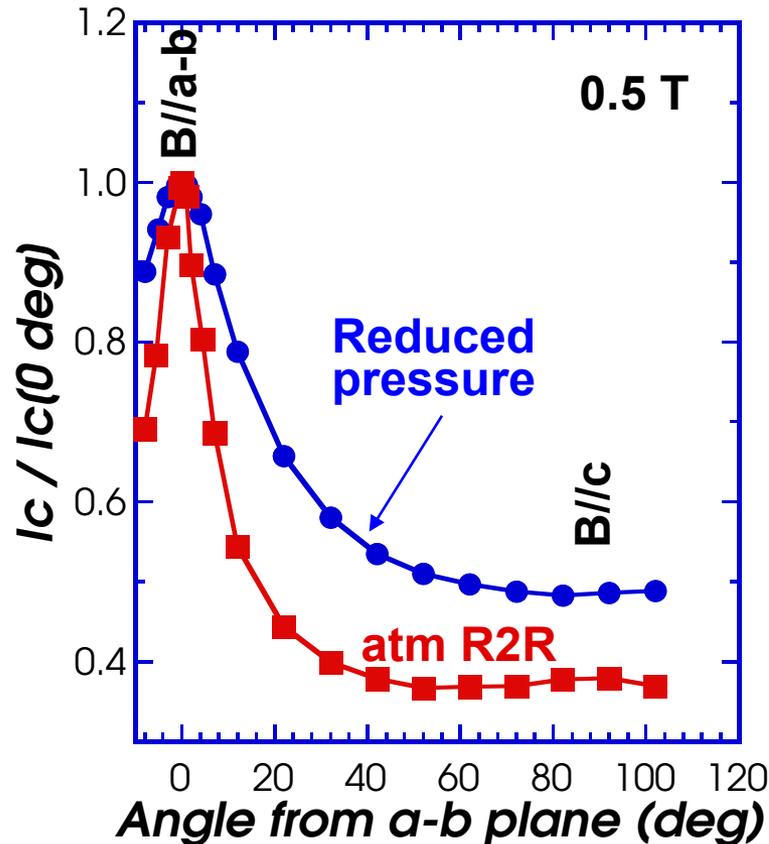


- Similar field dependency ( $\sim 4$  to 1 drop at 0.5 T regardless of processing time or film thickness) as “typical” films.

While the samples processed in atmospheric R2R furnace exhibit strong dependency at low fields, the field dependency is weaker at high fields (B//c)



# Knowing the differences in processing parameters that lead to different pinning may aid in the development of better CC



- Real difference in bulk pinning.
- Need to identify responsible pinning sites and relate to conversion parameters.
- Can we enhance these parameters to increase the pinning centers of “typical” CC?

# FY2003 Results Outline

- “Atmospheric” reel-to-reel furnace:
  - Moving e-beam (PVD) “BaF<sub>2</sub>” precursor.
- “Reduced pressure” chamber:
  - Short stationary e-beam (PVD) “BaF<sub>2</sub>” precursor.
- **“Low pressure” vacuum system:**
  - **Short stationary precursors: → e-beam (PVD) “BaF<sub>2</sub>”, solution TFA, PED “BaF<sub>2</sub>-YF<sub>3</sub>”.**
- **FY2003 performance.**
- **FY2004 plans.**
- **Research integration.**

# Low-Pressure Conversion of YBCO Precursor Films

- **Goal:**

- Develop more rapid precursor processing for high performance YBCO/RABiTS tape

- **Approach:**

- Use in-situ x-ray diffraction to study low-pressure conversion of several types of short, stationary YBCO precursors
- Identify trends in conversion rate & performance with process conditions:
  - a) that apply to each type of precursor
  - b) that apply to all types precursor
- Extend low-pressure processing results developed for short, stationary tape to continuously moving lengths

# Why use low-pressure for precursor conversion?

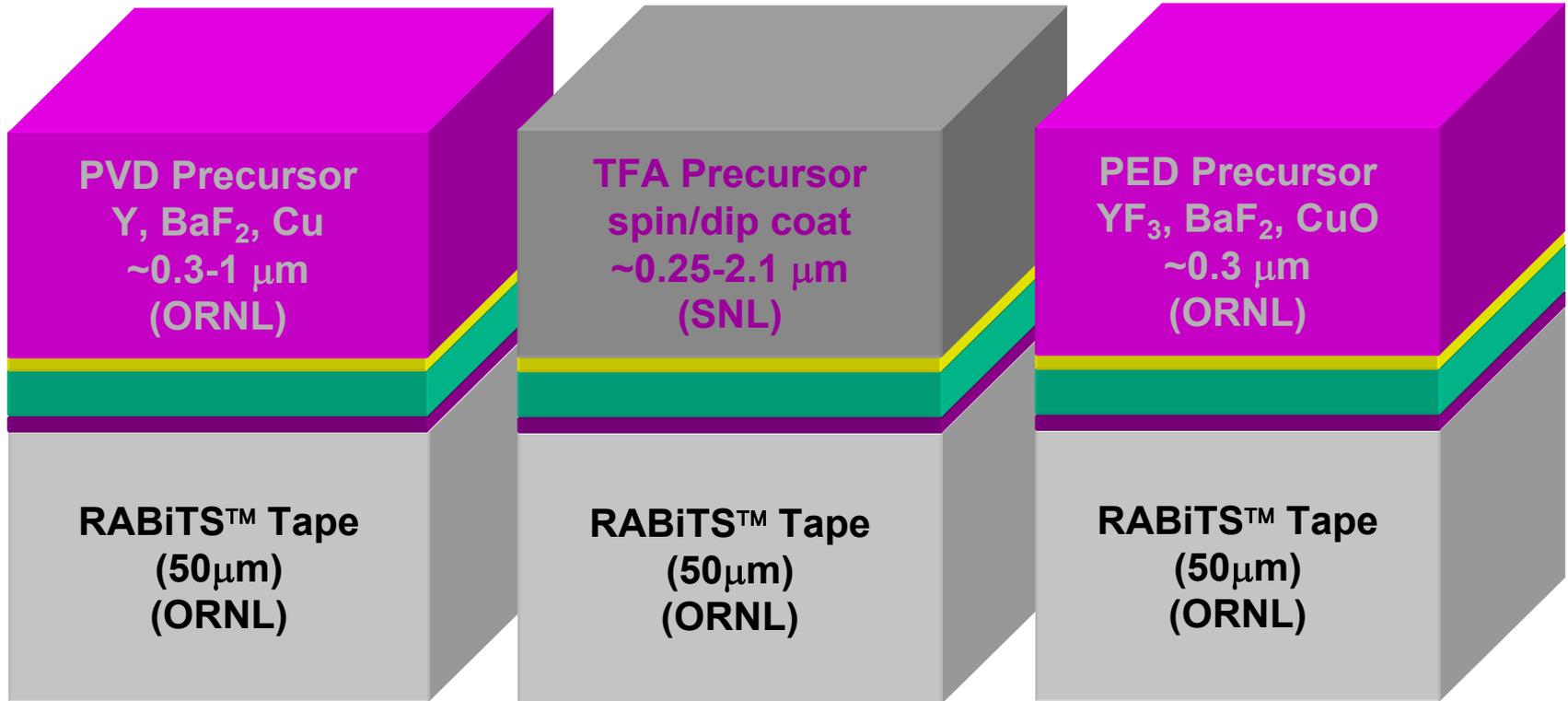
- **By simply eliminating the “carrier” gas (e.g., N<sub>2</sub>):**
  - Total pressure is decreased by ~4000x (760 Torr  $\Rightarrow$  200 mTorr)
  - Mean free paths ( $\lambda$ ) are increased by ~4000x ( ~0.4  $\mu$ m  $\Rightarrow$  ~1.5 mm)
- **Some direct consequences of lower pressure are:**
  - Flow is more molecular & nozzle jetting is reduced **(more uniform)** 😊
  - Diffusivities in gas are increased by ~4000x **(more rapid)** 😊
  - Total gas consumption is reduced by ~4000x **(more efficient)** 😊
  - Total heat consumption is reduced by ~4000x **(more efficient)** 😊
- **Because low-pressure conditions facilitate more uniform, rapid, and efficient precursor conversion.**

# Precursors were deposited by e-beam co-evaporation (PVD), solution (TFA), and pulsed electron deposition (PED) methods.

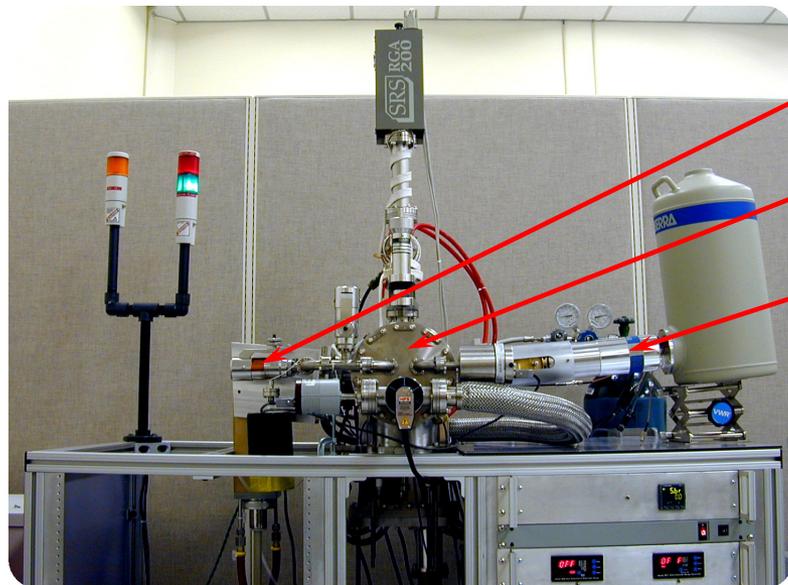
109 PVD samples

40 TFA samples

2 PED samples



# *In-situ* x-ray diffraction has been used to follow crystalline phase development during precursor conversion.



X-ray Source

Reaction Chamber ( $5 \times 10^{-8}$  Torr base)

X-ray Detector

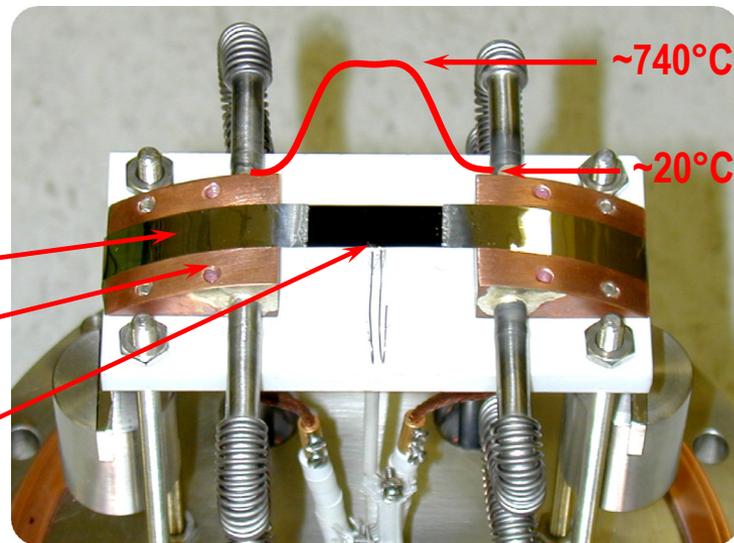
## Low-Pressure Conversion System

Nickel Leader

Water Cooled Cu Electrode

Precursor Sample (1x3 cm)

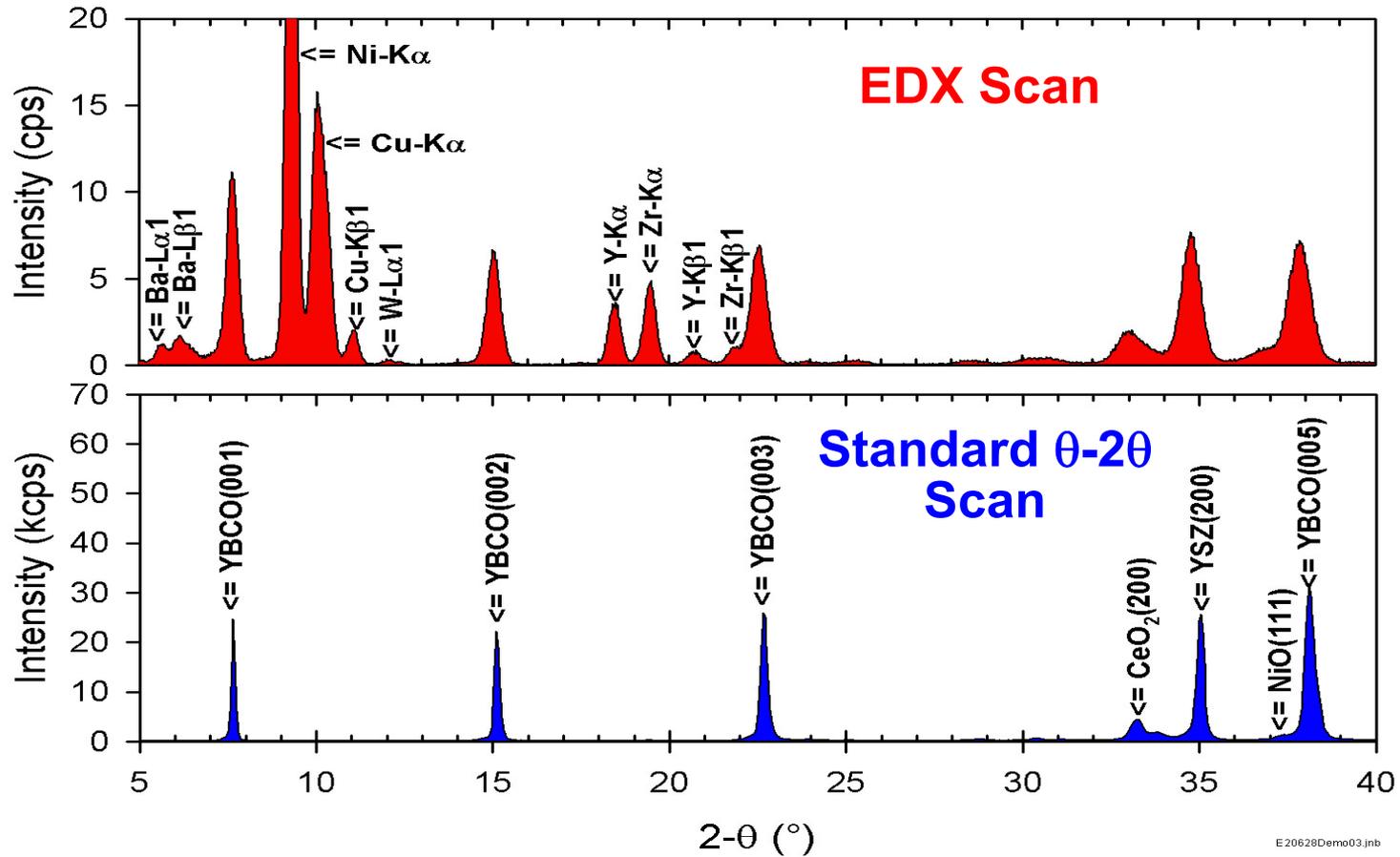
## Sample Holder



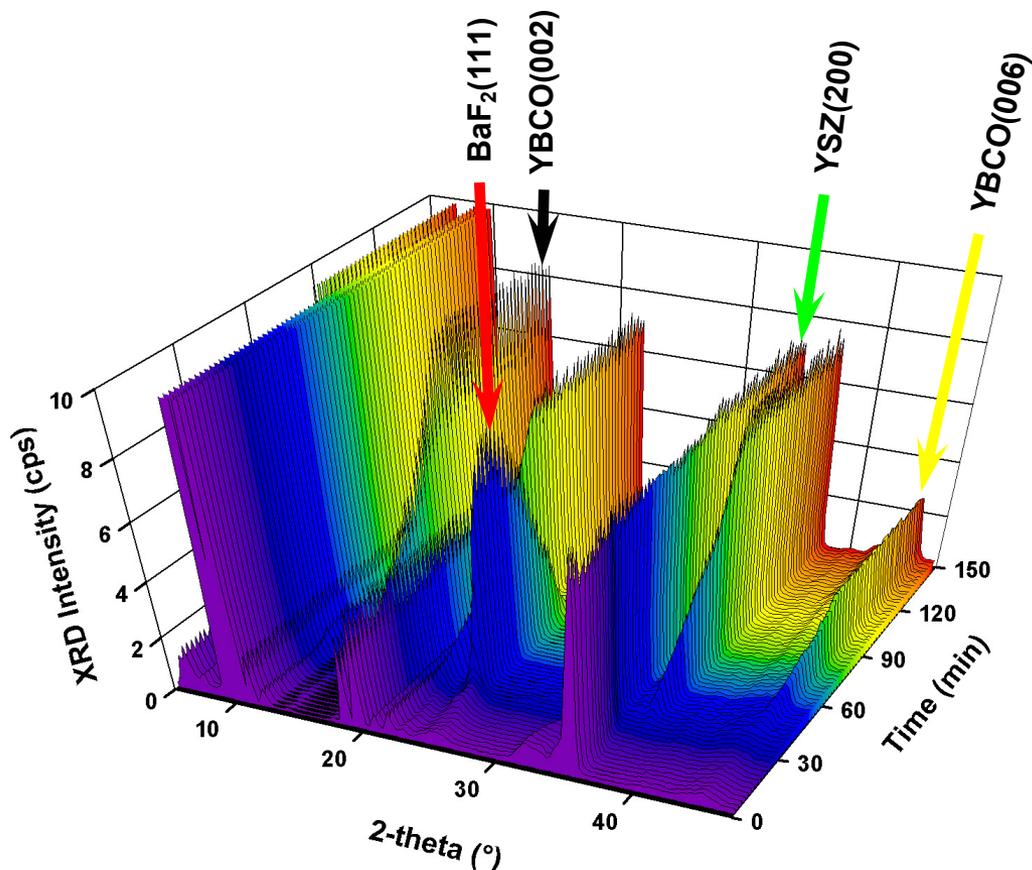
$\sim 740^\circ\text{C}$

$\sim 20^\circ\text{C}$

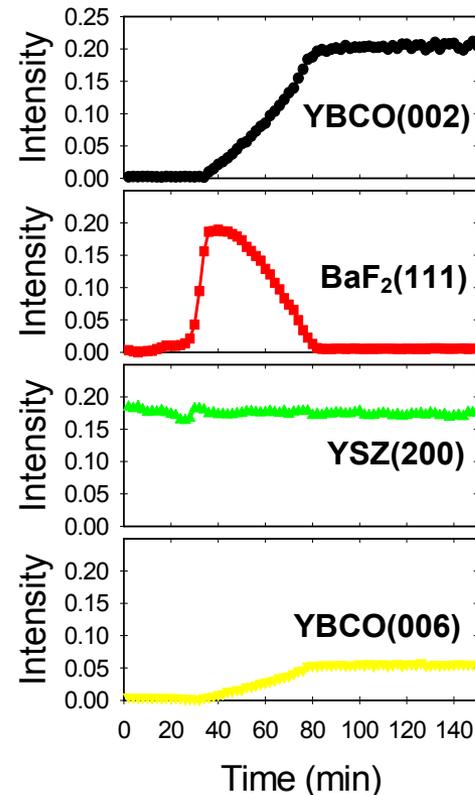
X-ray data is collected using an energy dispersive detector at rates up to ~4 scans/min.



# From a family of scans, peak scans are generated for specific crystalline phases.



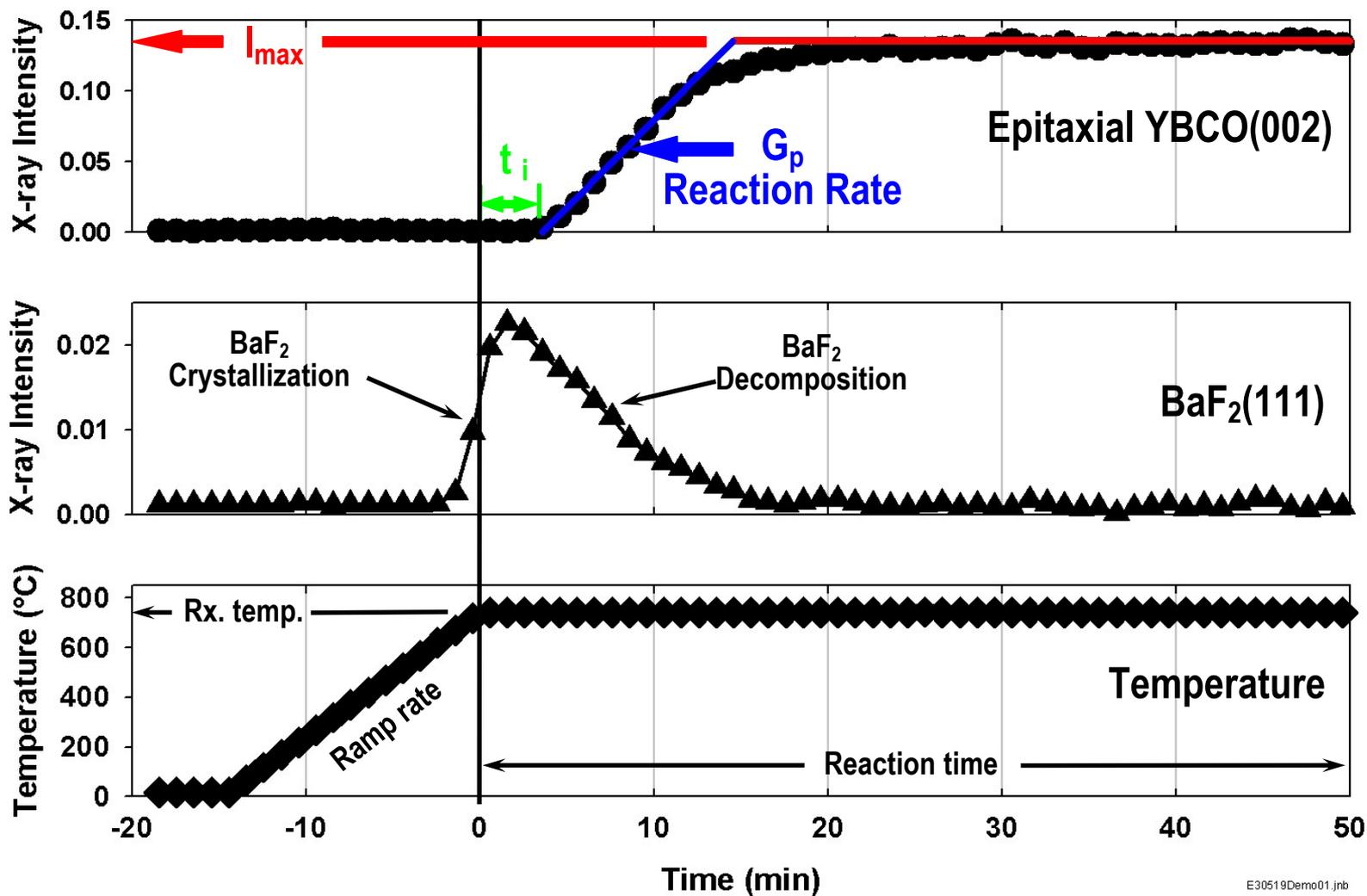
Family of Scans



Peak Scans



# From peak scans, details of conversion kinetics are determined.

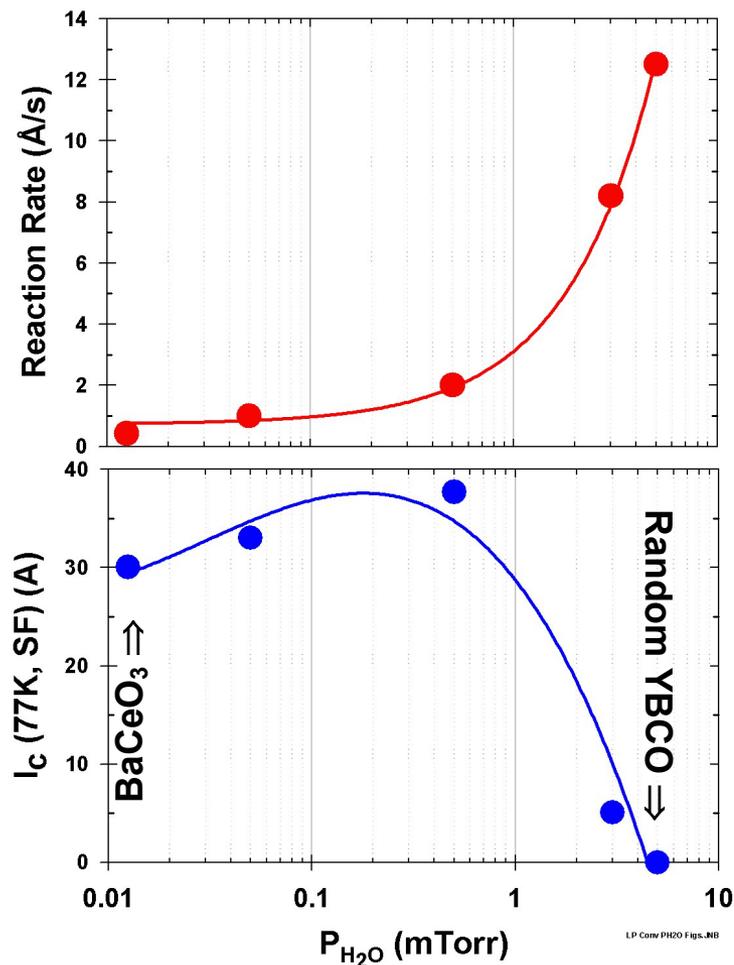
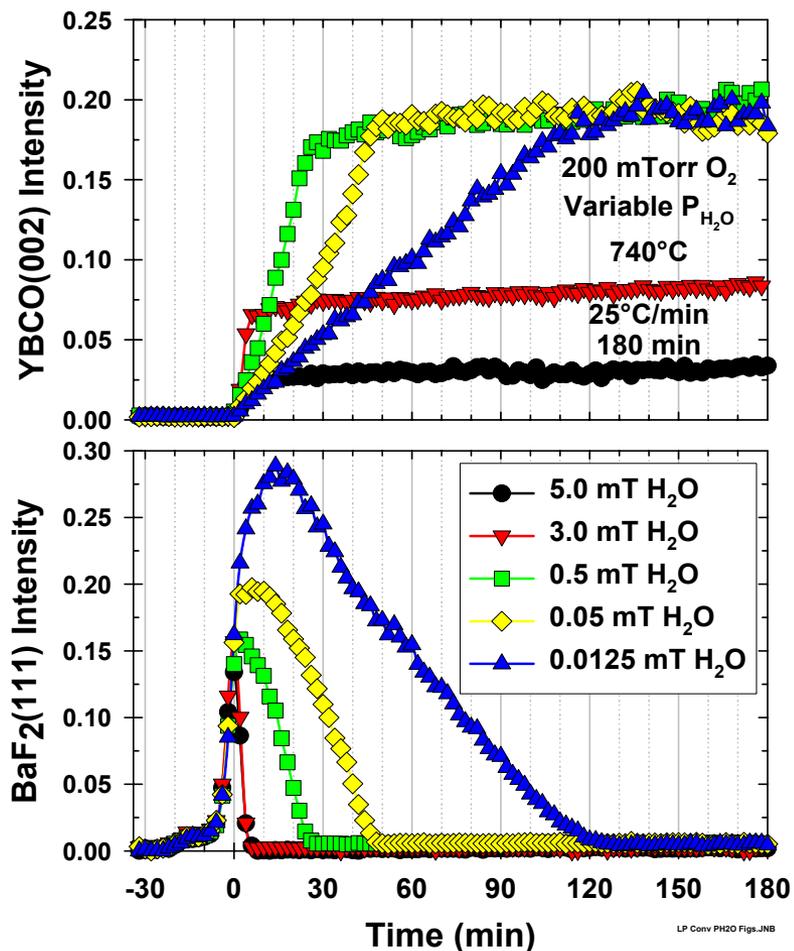


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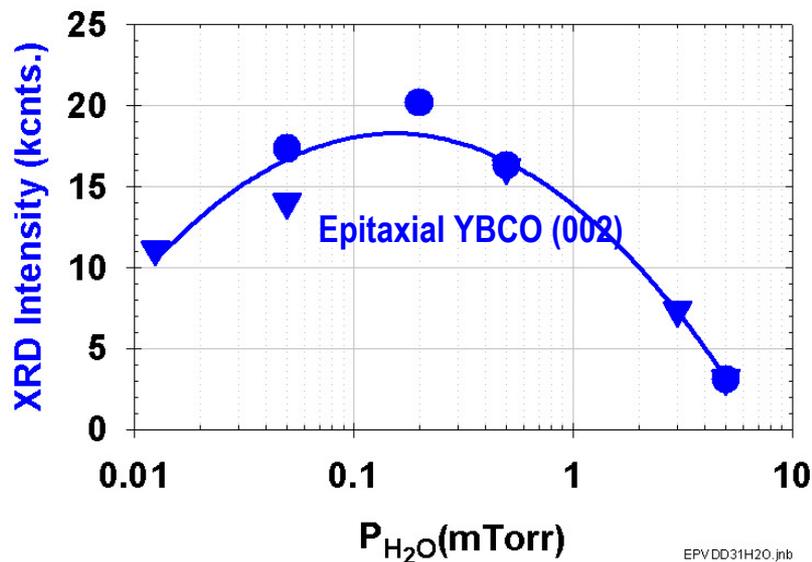
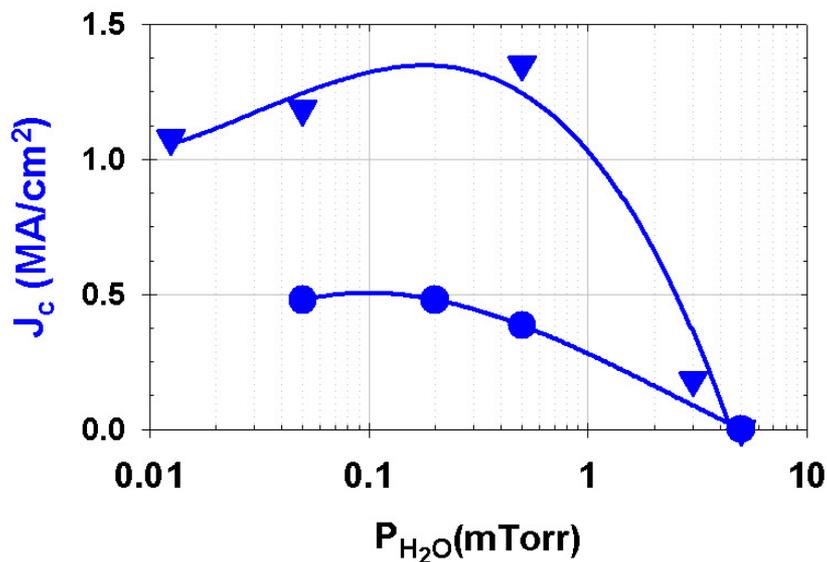
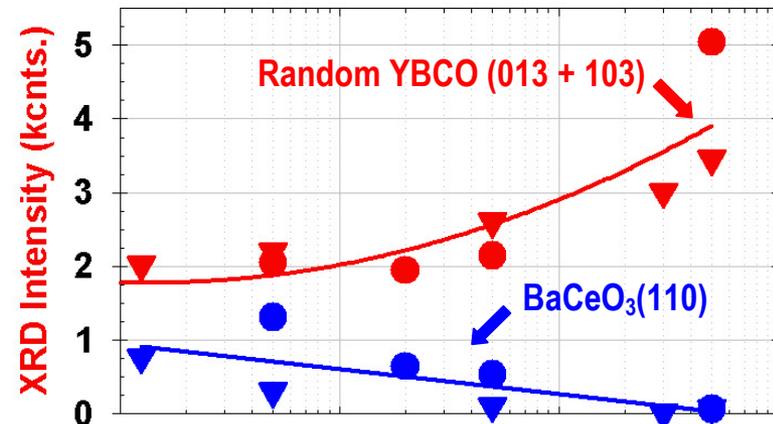
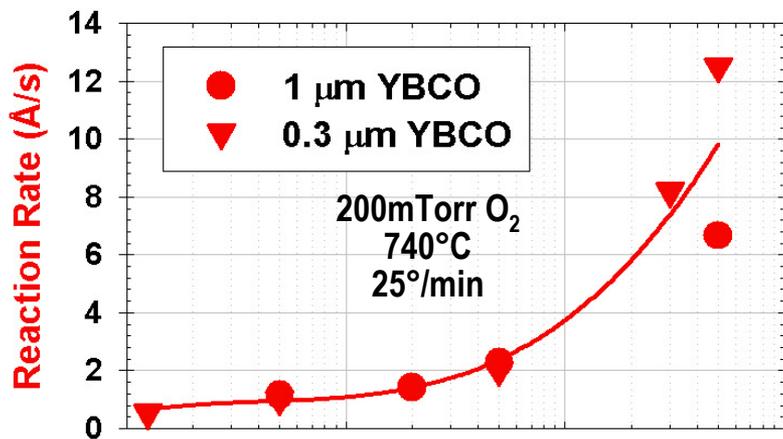
# Low-pressure conversions of precursor have been conducted for a range of process parameters.

- Oxygen partial pressures ( $P_{O_2}$ ) ..... 1  $\Leftrightarrow$  1000 mTorr
- **Water partial pressure ( $P_{H_2O}$ ) ..... 0.01  $\Leftrightarrow$  300 mTorr**
- Reaction temperature ..... 620  $\Leftrightarrow$  820 °C
- Ramp rate ..... 0.5  $\Leftrightarrow$  1000°C/min
- Reaction time ..... 2  $\Leftrightarrow$  480 min

# The reaction rate ( $G_p$ ) for thin PVD precursor ( $\sim 0.3 \mu\text{m}$ ) increases with $P_{\text{H}_2\text{O}}$ .

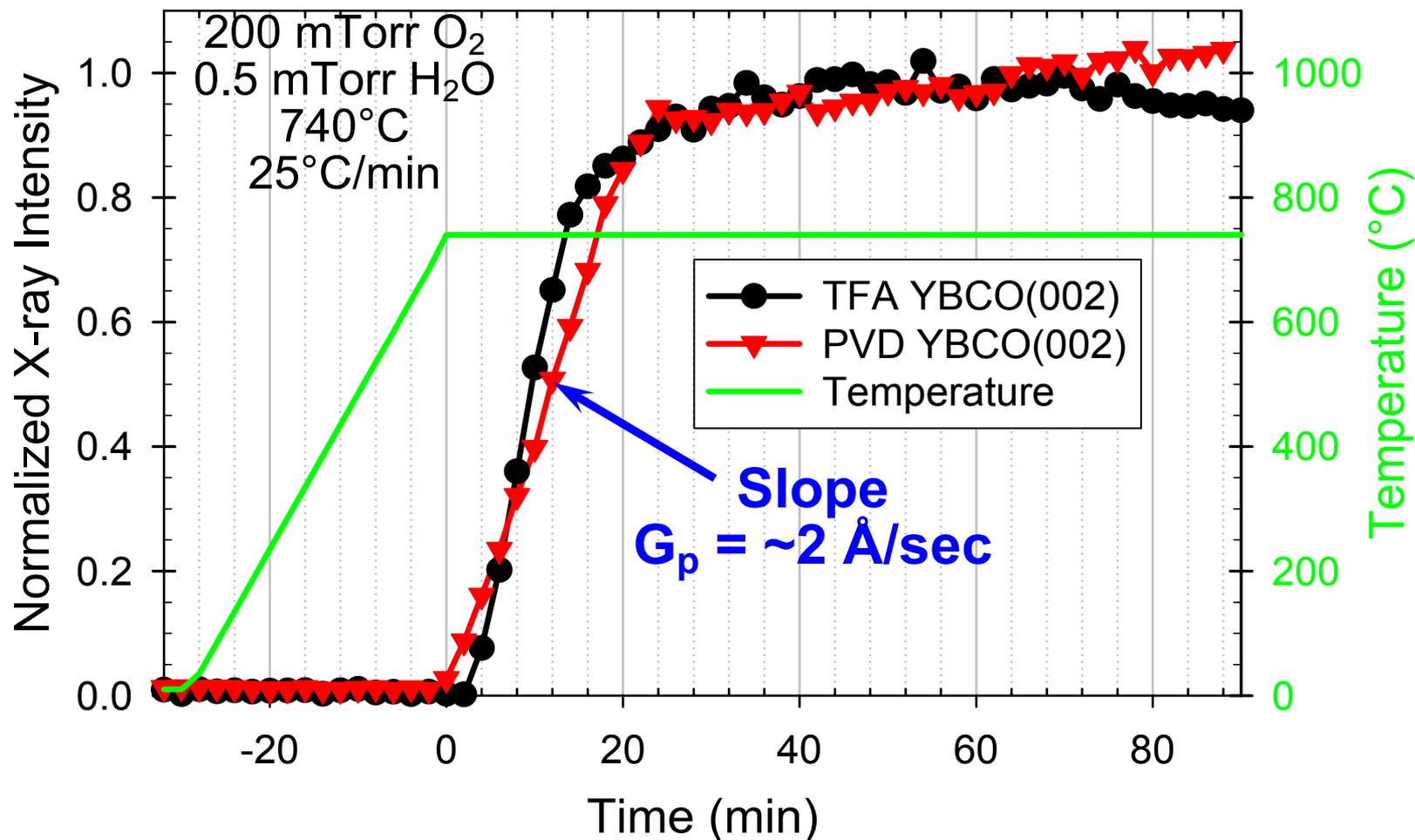


# Trends with $P_{H_2O}$ are similar for both thick ( $\sim 1\mu\text{m}$ ) and thin ( $\sim 0.3\mu\text{m}$ ) PVD precursor.

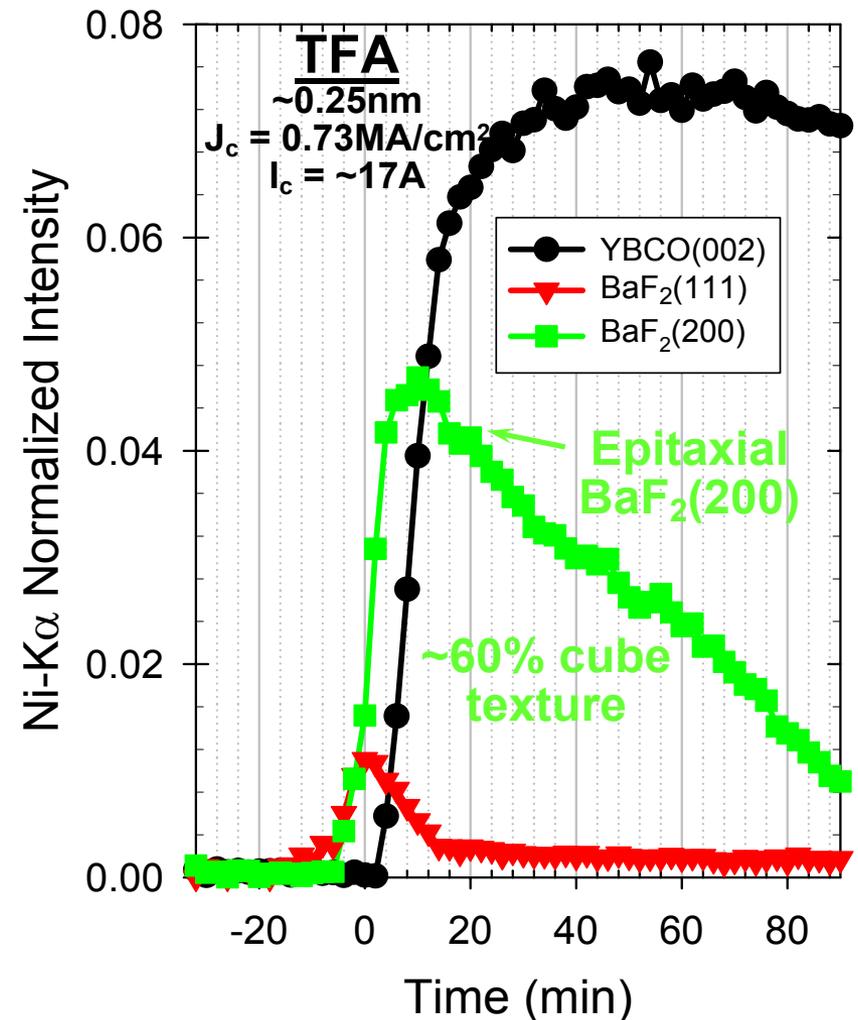
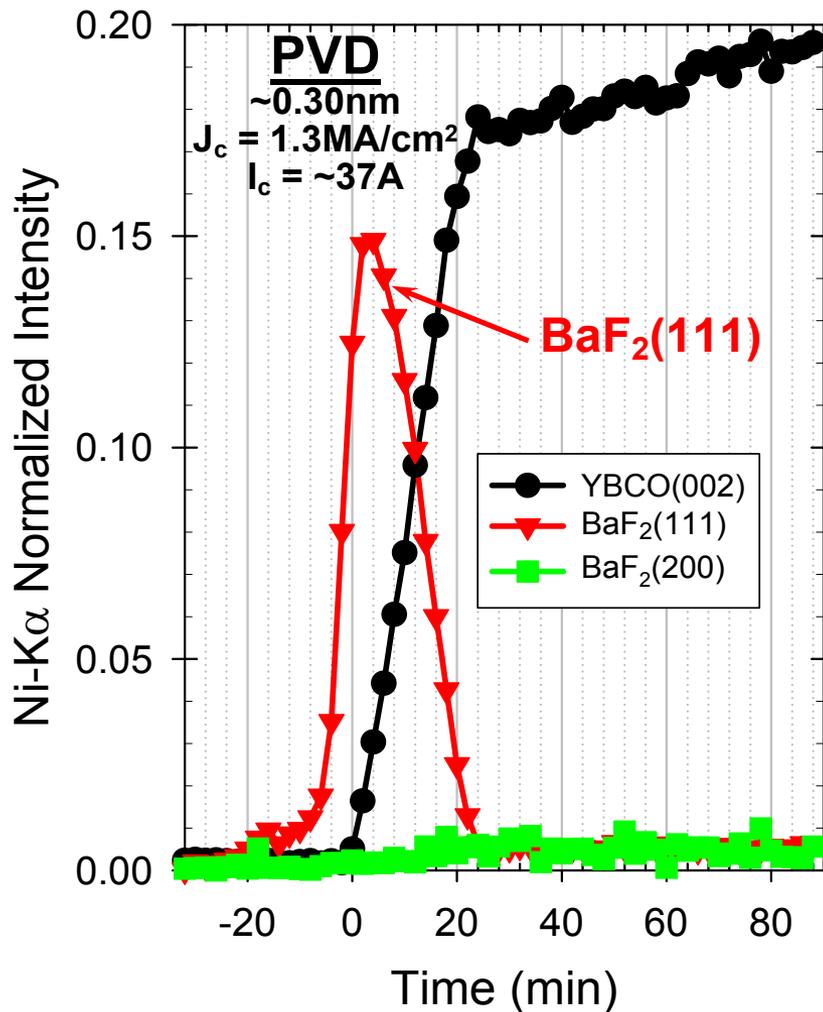


EPVDD31H2O.jnb

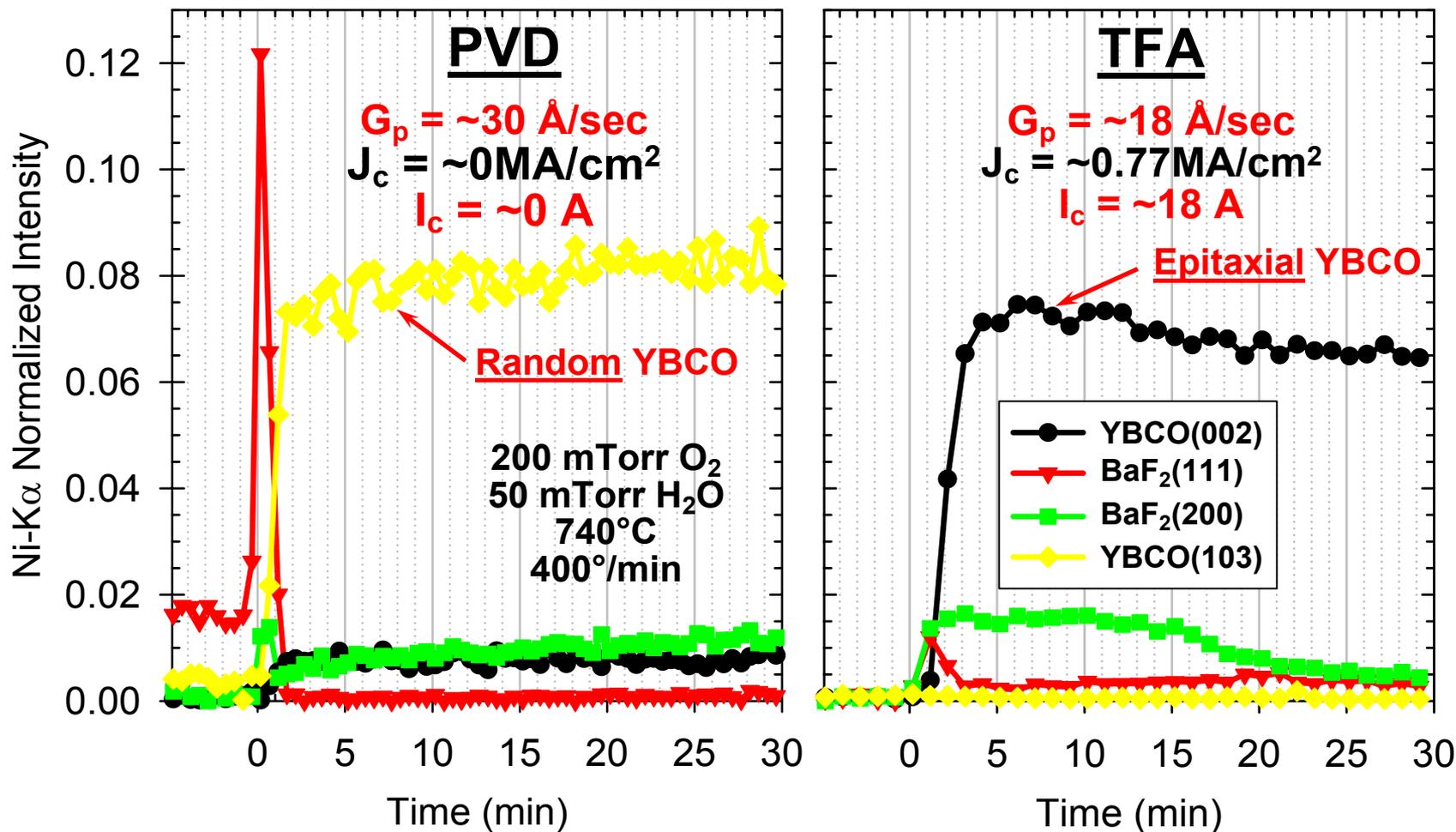
For conversion conditions optimized for thin PVD precursor,  $G_p$  is similar for TFA and PVD precursors.



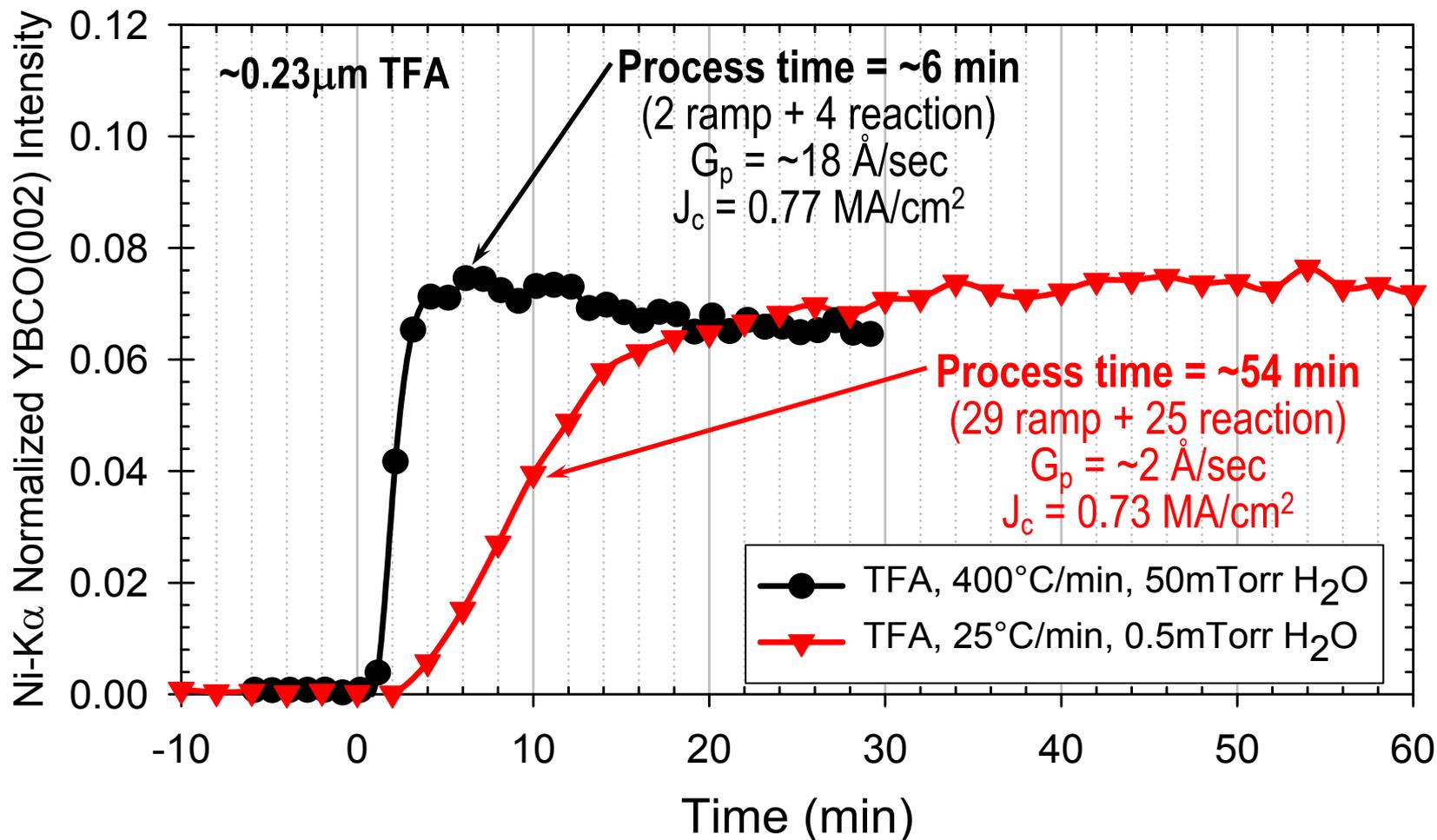
# However, crystalline phase development is distinctly different for PVD and TFA precursors.



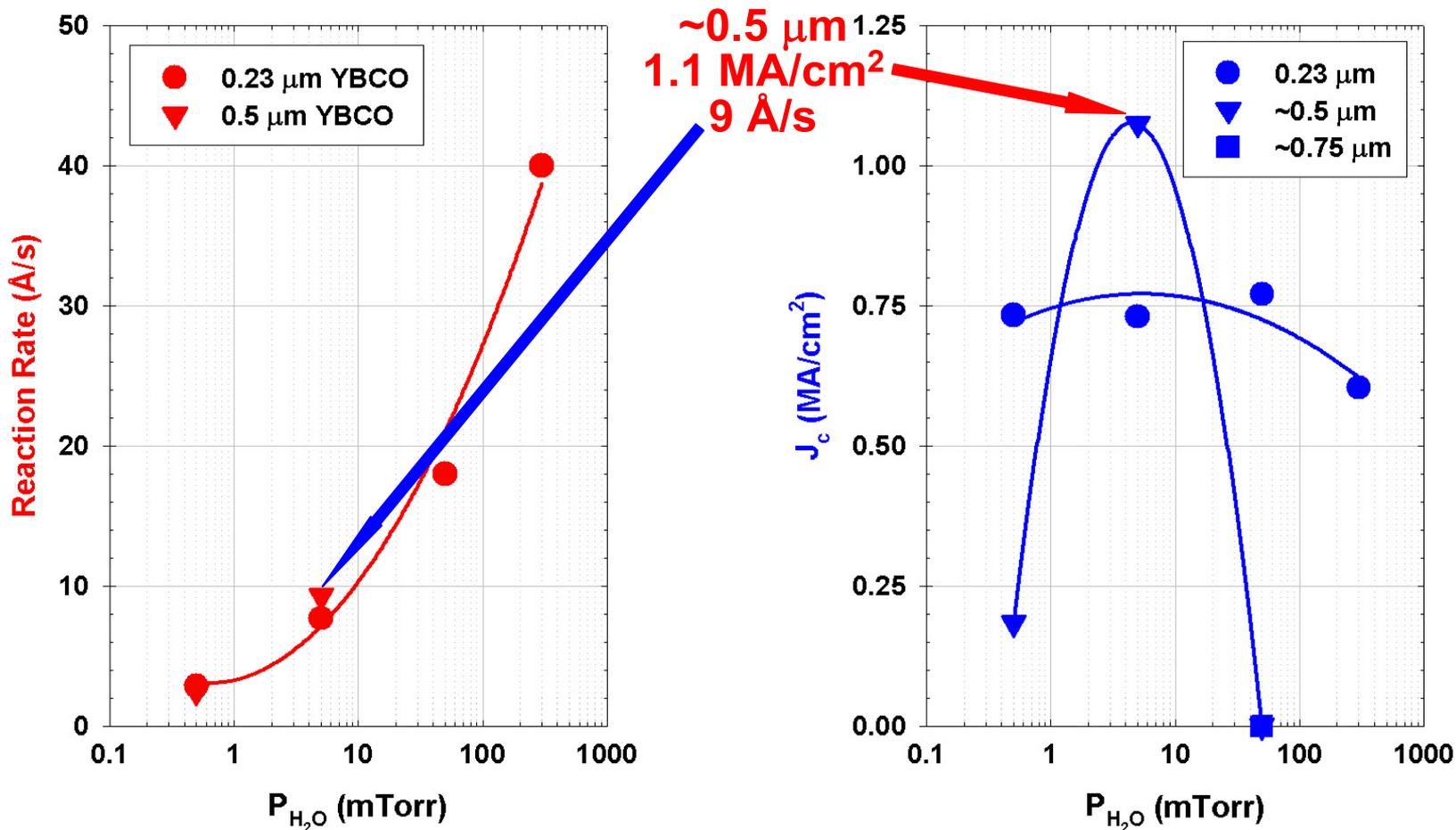
By using higher  $P_{H_2O}$  & higher ramp rate, higher  $G_p$ 's for both PVD and TFA precursors are obtained.



# Shorter process times (~9x) are possible for TFA precursor using higher $P_{H_2O}$ & ramp rate.



# Rapid conversion to high performance YBCO has also been achieved for thicker TFA precursor.



ETFAThick01.jnb

# Pulsed electron deposition (PED) has been successfully used to deposit YBCO precursor.

## If TFA looks good, why consider PVD processes?

- precursor cracking is observed for thick ( $> \sim 2 \mu\text{m}$ ) TFA
- no thickness limit is expected for PVD processes

## If e-beam co-evaporation is working, why consider PED?

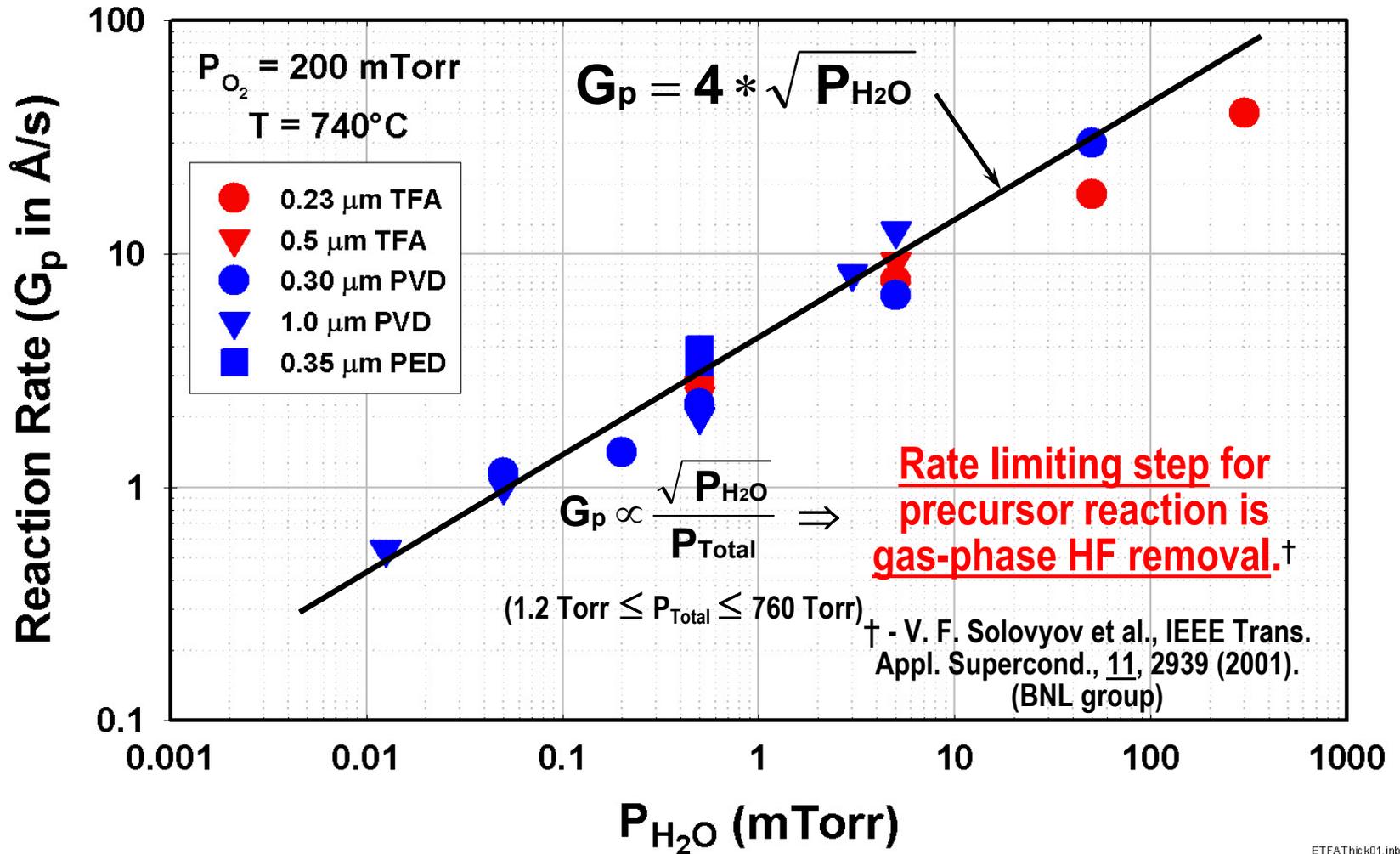
- greater stability of composition (no flux feedback)
- better target utilization (more directional plume)
- lower power process (less substrate heating)

## Two YBCO precursors have been prepared on RABiTS by PED:

- target:  $\text{YF}_3 / \text{BaF}_2 / \text{CuO}$  mixture
- deposition rate:  $5.0 \text{ \AA}/\text{sec}$  ( $\sim 1 \text{ Hz}$ )
- composition:  $\text{Y}:\text{Ba}:\text{Cu} = 1.00 : 2.15 : 2.46$  (ICP)
- $G_p = 3.5 \text{ \AA}/\text{s}$
  
- $I_c = 14.0 \text{ A}$ ;  $J_c = 0.50 \text{ MA}/\text{cm}^2$  ( $\sim 0.3 \mu\text{m}$ , low-pres)
- $I_c = 40.6 \text{ A}$ ;  $J_c = 0.81 \text{ MA}/\text{cm}^2$  ( $\sim 0.5 \mu\text{m}$ , atmospheric)

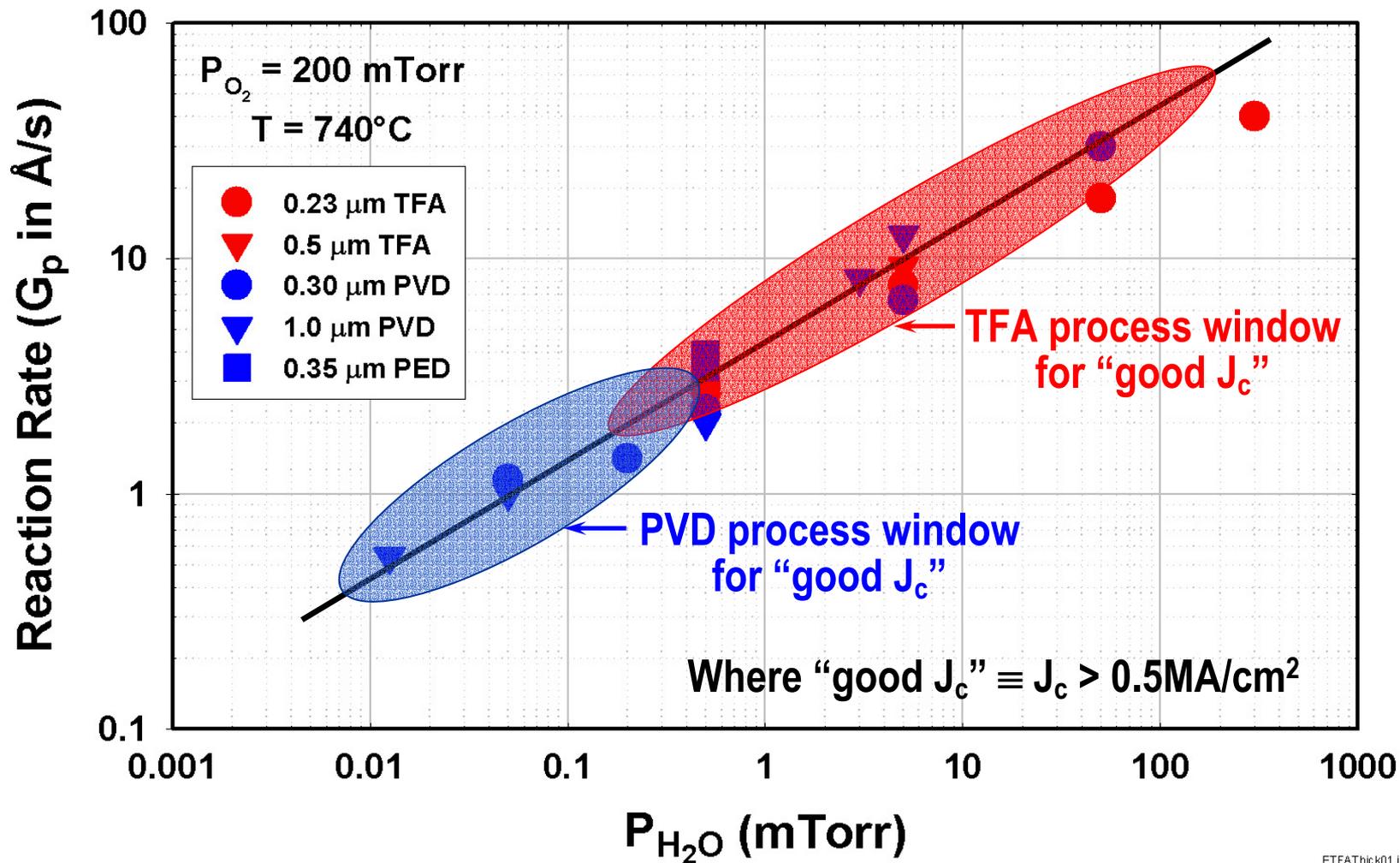


# The rate at which precursor reacts is independent of both precursor type and precursor thickness.



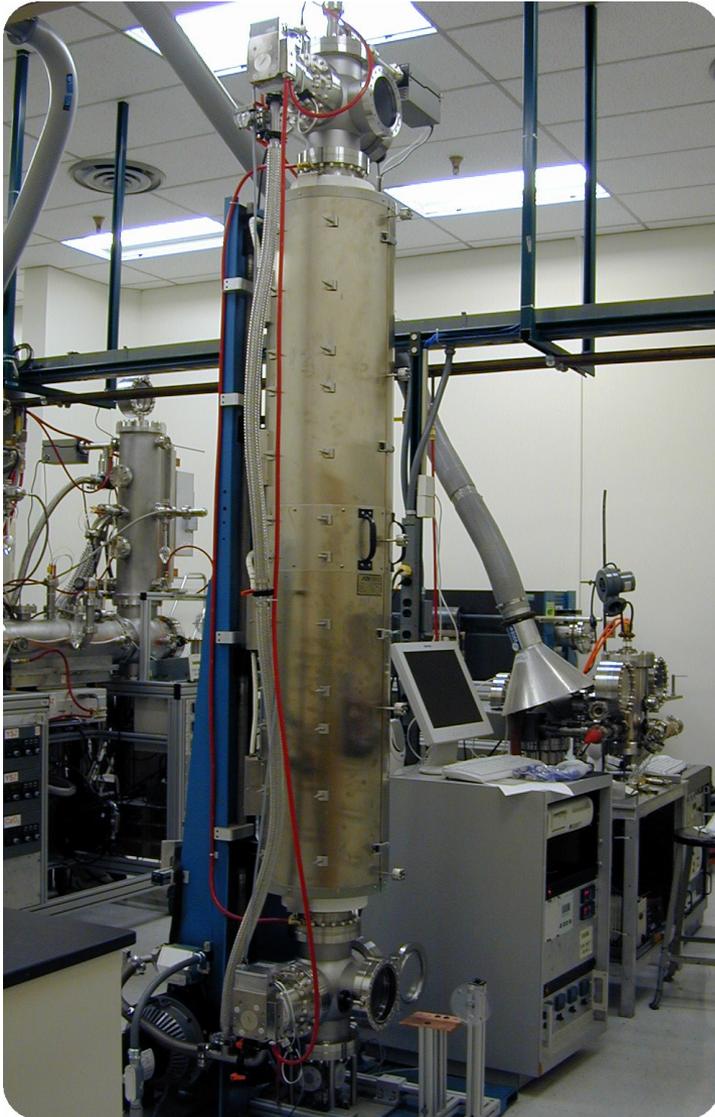
ETFATHic k01.jnb

However, the critical current is dependent on both the precursor type and precursor thickness.



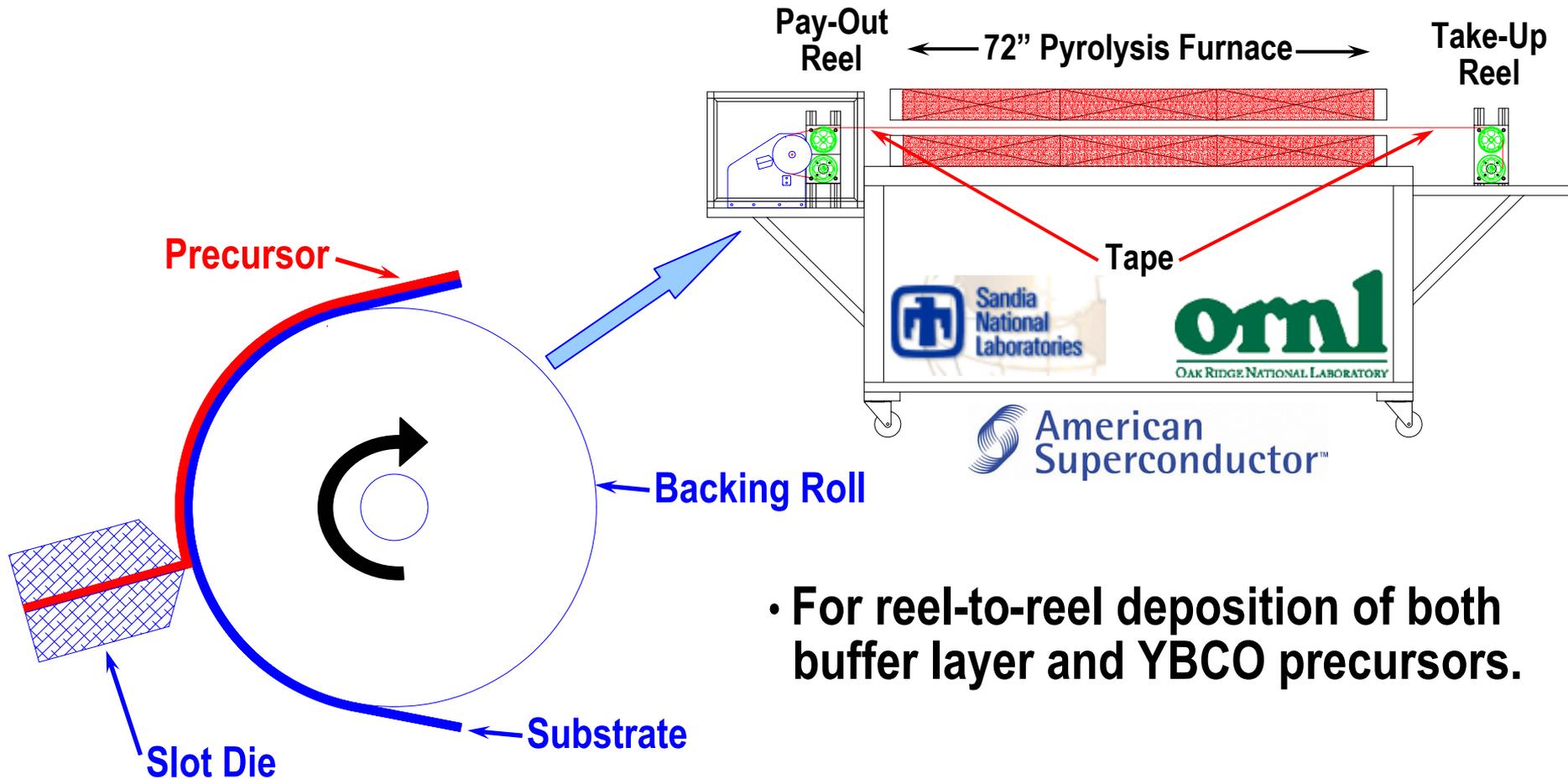
ETFATHick01.jnb

# Efforts to extend low-pressure processing to continuous lengths include a vertical R2R vacuum furnace.



- 4-zone, 2-meter furnace
- $P_{\text{base}} \approx 1 \times 10^{-6}$  Torr
- $P_{\text{total}} \leq 1$  Torr
- Capacity  $\approx 40$  meters
- Throughput :
  - $\sim 10$  m/hr (0.5 $\mu\text{m}$  TFA)
  - $\sim 2$  m/hr (0.5 $\mu\text{m}$  PVD)

# A slot die coating system is being constructed for continuous deposition of solution precursors.



- For reel-to-reel deposition of both buffer layer and YBCO precursors.

# FY2003 Performance Summary

- ✓ Objective 1: Explore YBCO conversion characteristics over the pressure range allowable by our conversion systems.
- **For the Atmospheric (A-P) R2R Furnace:**
  - HF buildup within chamber and along surface lead to slow conversion rate.
  - B-field dependence of  $I_c$  is stronger than expected.
- **For the Reduced-Pressure (R-P) system:**
  - Reaction rate increases with decreasing  $P_{tot}$ .
  - $I_c$  increases with decreasing  $P_{tot}$  &  $P_{H_2O}$ .
  - Temperature range for best  $I_c$  is 725°C to 745°C.
  - Rxn rate of 5 Å/s for 0.3 μm YBCO at high temp →  $J_c = 1.4 \text{ MA/cm}^2$ .
- **For the Low-Pressure (L-P) system:**
  - Reaction rate is  $\propto (P_{H_2O})^{1/2}$ .
  - Gas-phase HF diffusion limits reaction rate.

# FY2003 Performance Summary (cont.)

✓ Objective 2: Study the effect of precursor thickness on conversion parameters in different pressure ranges.

- **For thicker films, processing conditions need to be modified in A-P & R-P systems:**
  - **Low initial  $P_{H_2O}$  to nucleate c-axis YBCO with complete coverage,**
  - **Followed by more aggressive growth conditions to increase rate.**
- **“Double-sided” YBCO coating does not affect the conversion rate nor  $I_c$  even in the A-P furnace.**

✓ Objective 3: Examine the effects of conversion pressure on sample homogeneity.

- **For the A-P furnace, HF buildup and high flow rate lead to inhomogeneity.**
- **For the R-P system, no inhomogeneity is seen.**

# FY2003 Performance Summary (cont.)

✓ Objective 4: Compare the conversion characteristics of different precursors.

- **For the L-P system:**

- The precursor reaction rate is independent of precursor type (PVD, TFA, PED) and precursor thickness (0.25-1  $\mu\text{m}$ ).
- The maximum reaction rate for high performance YBCO is higher for TFA precursor than for PVD precursor.
- The minimum precursor processing time for  $\sim 1 \text{ MA/cm}^2$  YBCO is lower for thin TFA precursor (6 min) than for thin PVD precursor (54 min).
- The crystalline phase development during conversion is different for TFA and PVD precursors.

# FY2003 Performance Summary (cont.)

System	Pressure	Precursor	Thickness ( $\mu\text{m}$ )	Rx. Rate (A/sec)	Best J ( $\text{MA}/\text{cm}^2$ )	Best $I_c/\text{cm}$ (A/cm-w)
<b>Atmospheric</b>	1.5 atm	PVD	0.3	1.52	2.14	64.2
	1.5 atm	PVD	0.9	0.83	1.53	138
	1.5 atm	PVD	1.5	0.83	1.07	160
<b>Reduced-P</b>	0.1 atm	PVD	0.3	2.5	2.5	75
	0.1 atm	PVD	0.9	2.5	1.22	110
<b>Low-Pres.</b>	200 mT	PVD	0.3	2.0	1.39	42
	200 mT	PVD	1.0	2.0	0.65	65
	200 mT	TFA	0.25	18.0	0.77	19
	200 mT	TFA	0.5	9.0	1.1	54

# FY2003 Performance Summary (cont.)

System	Pressure	Precursor	Thickness ( $\mu\text{m}$ )	Rx. Rate (A/sec)	Best J ( $\text{MA}/\text{cm}^2$ )	Best $I_c/\text{cm}$ (A/cm-w)
Atmospheric	1.5 atm	PVD	0.3	1.52	2.14	64.2
	1.5 atm	PVD	0.9	0.83	1.53	138
	1.5 atm	PVD	1.5	0.83	1.07	160
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	200 mT	TFA	0.25	18.0	0.77	19
	200 mT	TFA	0.5	9.0	1.1	54

# FY2004 Plans

- Identify differences in TFA and PVD precursors responsible for different reaction rates:
  - Increase the reaction rates of PVD and/or TFA precursors.
- Add and develop both reduced- and low-pressure R2R capabilities for precursor conversion to determine maximum reaction rates for PVD and TFA precursors:
  - Minimum requirements →  $>1 \mu\text{m}$  at  $>1 \text{ MA/cm}^2$ .
- Investigate using R2R PED for YBCO precursors.
- Develop R2R slot die coater for solution precursors (w/ SNL).
- Process “truly” double-sided short samples under different pressures ( $I_c = 400\text{A/cm-width}$ ).
- Identify the pinning centers and processing parameters responsible for the different field dependencies.

# Research Integration

- **AMSC**
  - ORNL characterization of AMSC YBCO tapes (XRD & transport)
  - ORNL information briefing to AMSC staff
  - ORNL on-site technical visitations & design consultation by AMSC staff
- **SNL**
  - Exchange of buffered tapes, precursor solutions, & pyrolyzed films
  - ORNL on-site visitation by SNL staff
- **ANL**
  - Coordinated research on YBCO formation and reaction mechanism.
- **NREL**
  - ORNL YBCO films to NREL for studies of Cu stabilizing layers
  - NREL buffer to ORNL for YBCO processing
- **Case Western**
  - ORNL YBCO tape for evaluation in liver probe
- **Neocera**
  - PED YBCO precursor deposition equipment
- **MCT/Oxford**
  - YBCO processed on MCT/Ox RABiTS
- **MetOx**
  - ORNL on-site briefing to MetOx staff
- **ORNL**
  - YBCO tape to ORNL Systems Group for stability & AC losses studies
  
- **Publications**
  - Three submitted

# *Ex Situ* Processing of YBCO Precursors

## Oak Ridge National Laboratory

T. Aytug, H.M. Christen, S.W. Cook, A.A. Gapud, L. Heatherly,  
C.E. Hippner, S. Kang, D.M. Kroeger, D.F. Lee, K.J. Leonard,  
F.A. List, P.M. Martin, M. Paranthaman, S. Sathyamurthy,  
E.D. Specht, Y. Xu, J. Yoo, H. Zhai

## Sandia National Laboratory

P.G. Clem, J.T. Dawley

ORNL Funding: \$750,000 (2.5 FTE 2 Post-Docs)

# Can industry achieve the production milestone of 50 m/h/cm-width at $I_c > 200$ A/cm (s.f. 77K)?

**For a SINGLE 10 meter-long furnace**

Precursor	Type	RXN rate (Å/s)	Thickness (μm)	Furnace Length (m)	sample Width (cm)	Production rate (m/h/cm-width)
PVD	single	2.5	3	10	17	51
PVD	double	2.5	1	10	10	90
Solution	single	10	3	10	10	120
Solution	double	10	1	10	10	360
Solution*	single	10	1	10	10	360
Solution*	double	10	0.5	10	10	720

\* ASMC-type precursor, substrate, process...