Title: Solution deposition planarization for ion beam texturing of long-length flexible substrates

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Solution deposition planarization for ion beam texturing of long-length flexible substrates

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We present the results of a study of solution deposition planarization (SDP) for preparing smooth flexible substrates in long lengths. Roll to roll fabrication of electronic and power devices with single-crystal properties are desired for inexpensive production. Using the SDP process we have achieved 0.5 nm RMS roughness from a starting roughness of over 20 nm on 5 μm areas. We model the surface roughness reduction as governed by the amount of film shrinkage during solution deposition, number of coatings, solution composition and a residual roughness based on film thickness. This process is extremely well suited for ion-beam texturing of MgO. By utilizing solution deposition of a-Y_2O_3 to planarize the substrate we create the required surface for in-plane MgO texturing using assisted ion-beam deposition. We have achieved in-plane texture FWHM of 4° on the SDP substrates. Using an appropriate simple layer architecture for superconducting coated conductors we attained critical currents in excess of 3 MA/cm^2 at 75 K for 1-1.2 μm thick $YBa_2Cu_3O_y$ films.

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Solution Deposition Planarization for Ion-Beam Texturing of Long-Length Flexible Substrates

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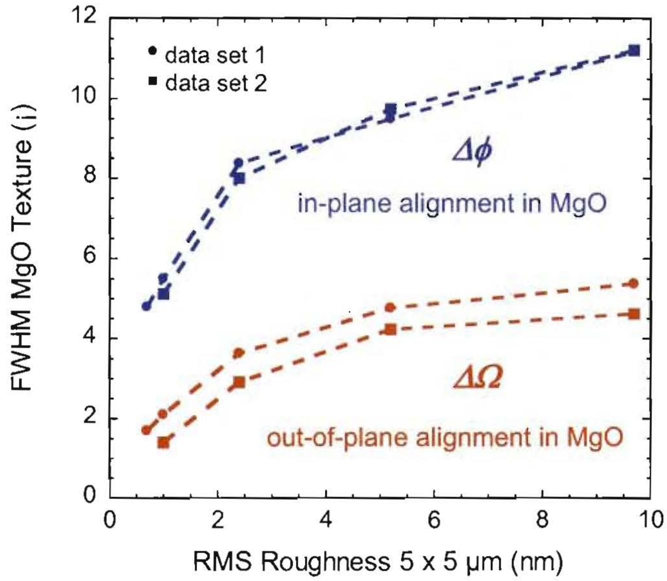
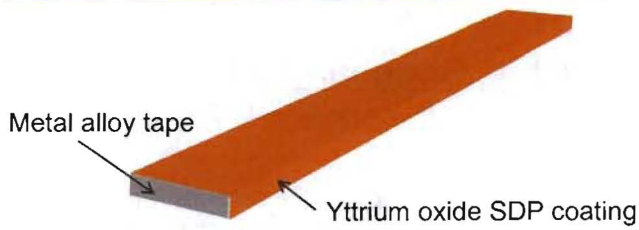
IBAD-MgO texture depends on the starting substrate roughness



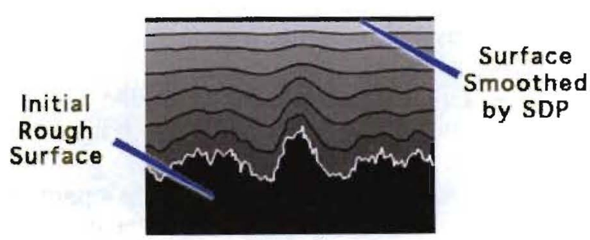
- IBAD texture degrades rapidly with increasing roughness, as judged by mosaic spreads in texture (full-width at half maximum, FWHM)
- Need smooth substrate surfaces with 0.5–2 nm root-mean-square, RMS, roughness (5 x 5 µm)

Solution Deposition Planarization provides an alternative technology for preparing smooth substrates

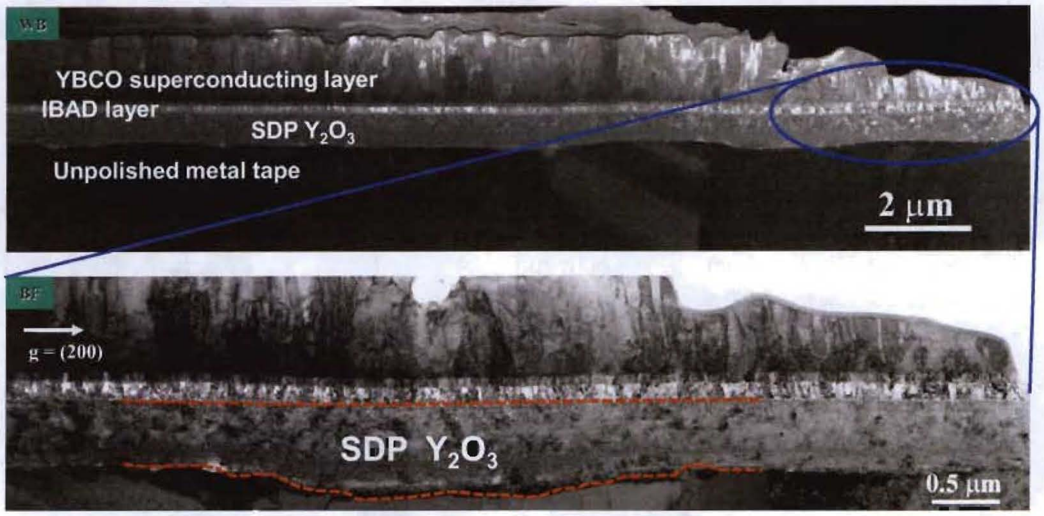
- Solution deposition Planarization (SDP) uses one or more coatings of an amorphous oxide by Chemical Solution Deposition (CSD) to planarize the surface
- For a meniscus-type solution coating, such as dip-coating of the substrate, surface tension of the liquid forces a smooth surface on the coating
- Multiple coats of SDP can reduce roughness down to any desired value, as low as 0.5 nm RMS



Metal tape is sheathed in a benign oxide coating

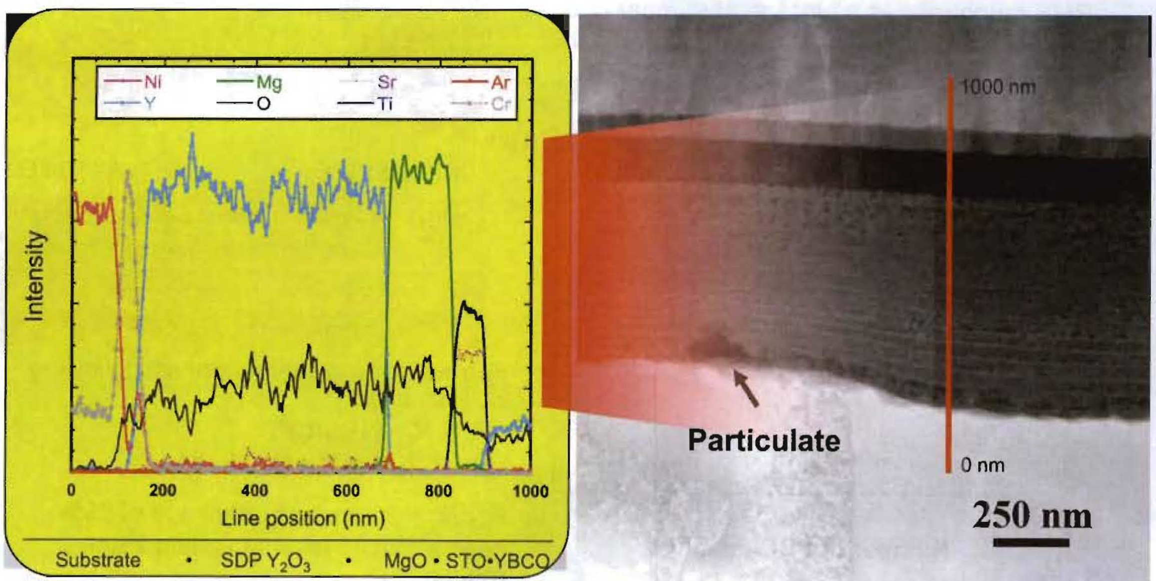


TEM Cross sectional analysis shows planarization of the unpolished metal tape



Transmission electron microscope (TEM) images

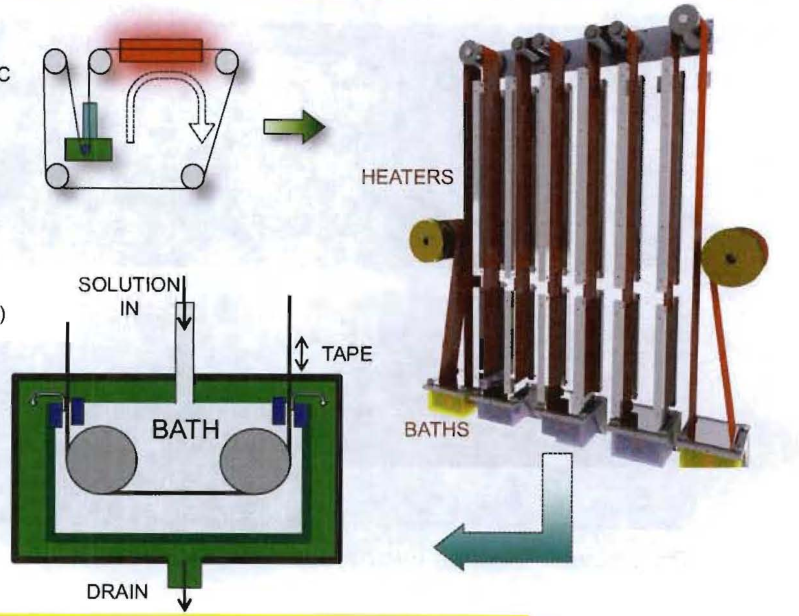
TEM section shows that SDP overcoat is effective in blocking out defects in substrate



Note sharp interfaces in the compositional profiles

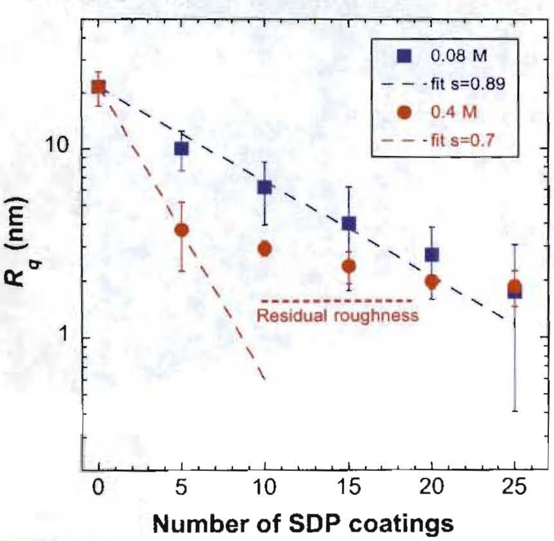
Dip coating equipment development

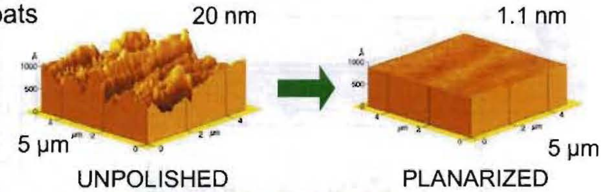
- Process developed on benchtop loop coater using dip coating and 500 – 600°C quartz tube furnace (below)
- In 2010 we designed and built a larger system which:
  - increases throughput
  - increases web width (1→10 cm)
  - increases tape length (5→100 m)
  - coats bi-directionally
  - continuously filters solution
  - purges liquid surface particles
  - automates the process



Planarization as a function of shrinkage and coating thickness

RMS roughness as a function of number of coats





Initial substrate RMS roughness	No. of passes required for final 1–2 nm RMS
3 – 4 nm	3 – 4
20 – 30 nm	10 – 15

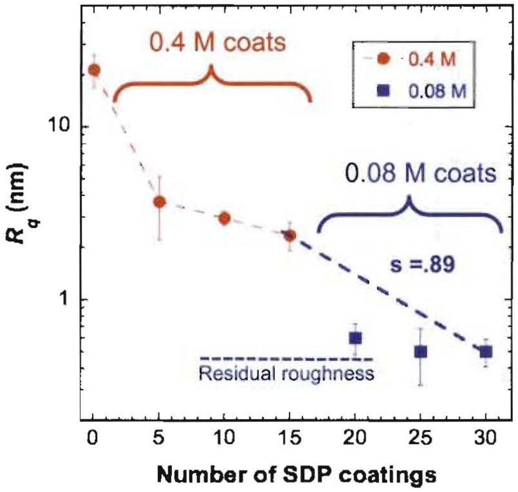
Formula for residual roughness following SDP coating:

$$R_n = R_0 \cdot (1 - t_1/t_0)^n$$

$s = 1 - t_1/t_0$, s is the shrinkage

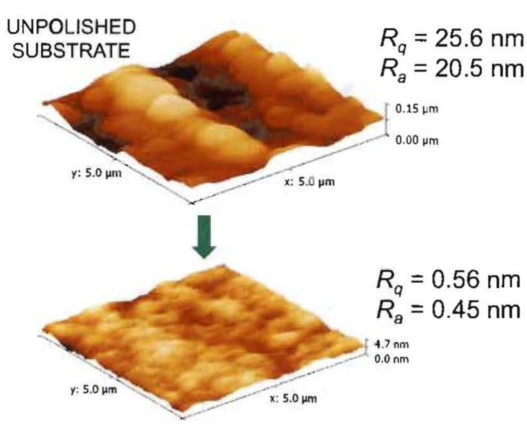
For R_0 = 30 nm and shrinkage of 85% need about 15 layers to attain 2 nm roughness

By using multi-molarity SDP coatings we were able to achieve less than 1 nm RMS roughness



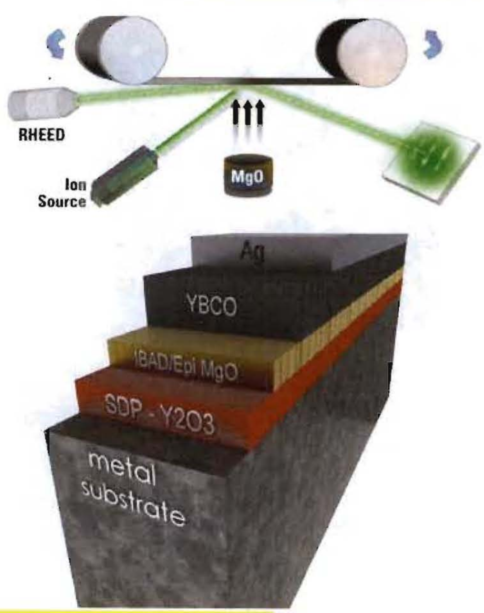
Unpolished RMS (5x5 µm): 26 nm

After15-20 SDP coatings (5x5 µm): **0.5 nm**

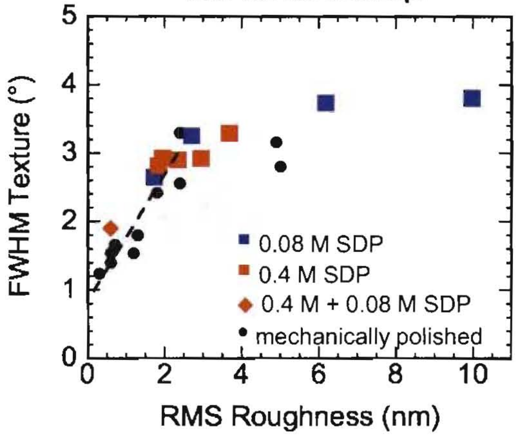


IBAD provides a single-crystal-like template for supercoducting coatings in long lengths

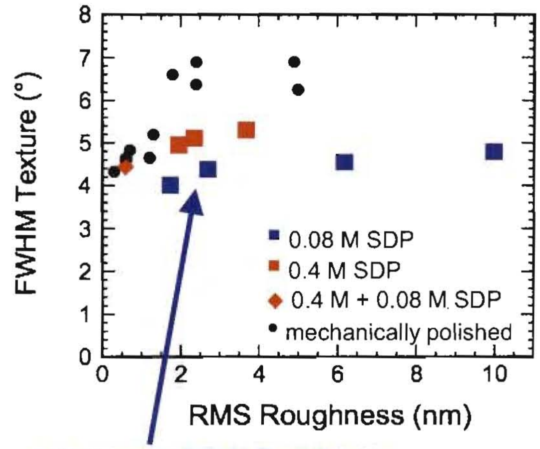
- Superconductor crystalline structure must be **highly aligned** (less than 5° mosaic spreads) for the superconductors to carry high currents
- The crystalline-aligned template is achieved with an ion-beam assisted deposition of an oxide coating
- **HOWEVER, for the best quality template smoothest starting surfaces are required (roughness less than 2 nm)**



Multi-molarity coatings result in improvements for MgO grain alignment

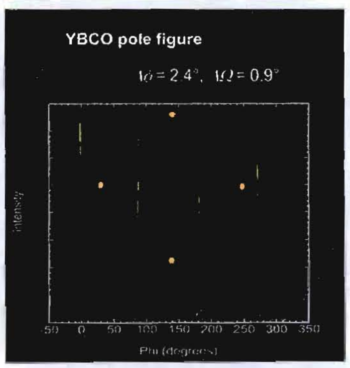


Out-of-plane texture follows a 'universal' dependence on roughness

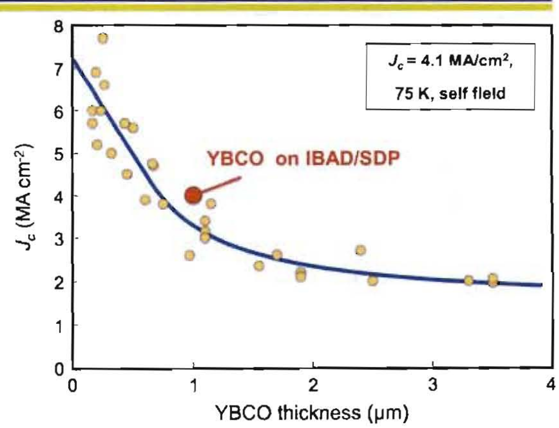


Low molarity finishing coat helps achieve low in-plane texture

High critical current, J_c, achieved by Reactive Co-Evaporation of $YBa_2Cu_3O_7$ (YBCO) on IBAD/SDP



- YBCO deposited by RCE on MgO template grown on SDP Y-Al-O
- Y-Al-O retains amorphous structure after YBCO deposition
- YBCO deposited on 30 nm MgO
- MgO texture: $\Delta\phi = 4.6°$, $\Delta\Omega = 1.5°$
- 1.0 μm YBCO film



- Figure above shows a plot of the best undoped YBCO samples grown by pulsed laser deposition (PLD) on single crystal substrates
- The red dot shows a YBCO film grown on IBAD template on an SDP prepared substrate

PLD data from Foltyn et al., *Nature Materials* **6**, 631 (2007)

Conclusions

- SDP enables lower cost, rough substrates to be used, such as stainless steels
- SDP eliminates the need for a PVD bed layer and is stable to at least 750˚C
- SDP minimizes toxic wastes, by eliminating use of acids used in electropolishing
- SDP yields comparable YBCO results to the best PLD deposited samples on single crystal substrates