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The structural evolution of (Gd,Y)Ba$_2$Cu$_3$O$_x$ tapes with Zr addition made by metal organic chemical vapor deposition

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Improved pinning achieved by BZO nanodefects in HTS tapes
Critical current of Zr-doped tapes is strongly influenced by Zr concentration. Why?

- Structural study of films with different Zr to understand the effect of Zr content on microstructure
- GADDS XRD: overall film texture, phases
- TEM: local defects
XRD study of films doped with different Zr content

With more Zr addition,

1. BZO intensity increases
2. Re$_2$O$_3$ intensity decreases
3. (00l) GdYBCO peaks broaden or GdYBCO quality degrades
4. The c axis of GdYBCO tilts away from the normal of LMO/MgO after 12.5%Zr
Comparison of BZO nanorod density

Low Zr: Nanorod spacing varies widely. There is still space for more nanorods.

High Zr: Dense arrangement of BZO nanorods.

Distance:
- 7.5% Zr: ~20-50 nm, average 35 nm
- 15% Zr: ~18 nm
- 20% Zr: ~19 nm
Size distribution of BZO nanorods in high Zr content films

15% Zr
Average size: 3.86 nm
Areal content: 4.45%

20% Zr
Average size: 4.25 nm
Areal content: 4.45%
In-plane defects in GdYBCO films all on (001) planes of GdYBCO

- **Stacking fault**
  - No effect on nanorods

- **In-plane BZO**
  - May or may not affect nanorods

- **Re2O3**
  - Effect on nanorods

- **BZO defects**
  - May connect and form big plates
  - May block the growth of BZO nanorods

- **BZO**
  - Effect on rods

BZO defects are a larger version of in-plane BZO defects.
In-plane growth defects with different Zr content

Thin and discontinuous in-plane defects in 7.5% Zr
Thick and continuous plates in 15% Zr
Plan-view image of 20%Zr film

1) Low-angle grain boundary
2) 2\textsuperscript{nd} phase with special orientation relationship with REBCO
3) 2\textsuperscript{nd} phase (Gd,Y)CuO\textsubscript{2}

BZO takes Ba and leads to formation of Ba-free 2\textsuperscript{nd} phase
BZO layer on LMO buffer and tilting of c-axis of GdYBCO away from [001] of LMO/MgO

BZO directly on LMO may induce the tilting of c axis and result in low-angle GB
Summary

1. Critical current at 77 K, zero field decreases with Zr addition beyond 7.5%Zr

2. With increasing Zr addition, XRD study shows that BZO content increases, RE₂O₃ content decreases, HTS film quality degrades and c-axis of GdYBCO tilts away from the c-axis of LMO

3. BZO nanorod size does not change significantly with increase of Zr, but spacing of nanorods decreases from 35 nm to 20 nm as the Zr content is increased from 7.5 to 15%

4. In-plane defects in high Zr films have a large influence on the growth of BZO nanorods

5. High Zr content films has Ba free oxides and high density of in-plane BZO. BZO can grow on LMO buffer in high Zr content films, which introduces of tilting of c-axis of BZO/GdYBCO film away from LMO/MgO, and may induce low angle boundaries