Transformational Opportunities of YBCO/REBCO for Magnet Technology

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SuperPower 10th birthday celebration

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YBCO properties: Aixia Xu, Fumitake Kametani, Jan Jaroszynski, Youri Viouchkov

YBCO coil R+D and test: Ulf Trociewitz, Huub Weijers, Patrick Noyes, Bill Shepherd, Ken Pickard, Denis Markiewicz and colleagues

YBCO conductor by SuperPower (Venkat Selvamanickam, Yi-Yuan Xie, Drew Hazelton and many colleagues)
Basic Themes

- Can magnet applications of REBCO (RE = Y, Gd, Sm..) PULL demand for coated conductors?
- What is the strategic context?
- What has been done?
- What might be done within the next 1-5 years?
National Academy report: COHMAG-Opportunities in High Magnetic Field Science – 2004

Grand magnet challenges:
- 30T NMR (All SC)
- 60T Hybrid (R + SC)
- 100T Long Pulse (R)

Means:
- ....the involved communities [users and magnet builders] should cooperate to establish a consortium whose objective would be to address the fundamental materials science and engineering problems that will have to be solved........ COHMAG report 2004

All require materials in conductor forms that were not available in 2004

They now are!
HTS greatly extends the capability at 4K

Slide 4

Courtesy Peter Lee www.asc.magnet.fsu.edu
YBCO Coated conductor by SuperPower – very strong Hastelloy substrate

- Phenomenal Jc in the YBCO - \(~20 \times 10^6\) A/cm\(^2\) at 25T
  - YBCO is \(~1\)% of cross-section
  - 50% is high strength superalloy

YBCO Coated conductor by SuperPower –

- 2 µm Ag
- 1 µm HTS
- \(~30\) nm LMO
- \(~30\) nm Homo-epi MgO
- \(~10\) nm IBAD MgO

< 0.1 mm

Hastelloy C-276 substrate
Cu/Ag/YBCO/Hastelloy
Cu-plated all-sides

T = 76 K

Tensile Stress (MPa)

Tensile Strain (%)

< 0.1 mm
National Magnet Lab is a User Facility

- Provides the world’s highest DC magnetic fields
  - 45T in hybrid, 32 mm warm bore
  - Purely resistive magnets: 35T in 32 mm warm bore, 31T in 50 mm bore and 19T in 195 mm warm bore

- 20 MW resistive magnets: ~$1000/hr in electricity
  - Long-time, full-field experiments are very expensive
  - Quantum oscillation, quantum Hall effect, low noise, large signal averaging experiments could run 7 days a week……….
2007 Test of 12 pancake SuperPower CC-coil in NHMFL Large Bore Resistive Magnet

New world record of 26.8 T (in 19 T background)
Flange OD is 127 mm, 450 m of tape, peak stress 215 MPa

Hazelton et al. July 2007
2008: MagLab YBCO Coil achieves almost 34 T

- **2008 MagLab coil** – 33.8 T in 31 T (Denis Markiewicz and Ken Pickard)
  - Test by Huub Weijers and Patrick Noyes
  - Short sample tests by Aixia Xu and Jan Jarosynski
  - Conductor by SuperPower with tapes of high Ic

Coil ID 25 mm, OD 36.5 mm, height 46.6 mm

- 38 turns, 36 m of 4 mm wide tape

2.78 T in 31 T background at 325 A and peak hoop stress of 466 MPa
32 T User Magnet Proposed to NSF in 2009

Total field 32 T
Field inner YBCO coils 17 T
Field outer LTS coils 15 T
Cold inner bore 32 mm
Uniformity 5x10^{-4} 1cm DSV
Current 186 A
Inductance 436 H
Stored Energy 7.54 MJ

Good news – “fully” (~50%) funded at $2 million starting 10/09
YBCO Test Coils – recent update

SuperPower I.
Bmax = 26.8 T  
ΔB = 7.8 T

SuperPower II.
Bmax = 27 T  
ΔB = 7 T

NHMFL I.
Bmax = 33.8 T  
ΔB = 2.8 T

NHMFL II.
Bmax = 20.4 T  
ΔB = 0.4 T
Successful YBCO Test Coils vs. 32 T YBCO Coils

- SuperPower I.
- NHMFL I.
- SuperPower II.
- NHMFL II.
- 32 T YBCO Coils
ZEEMANS Beam Line for SNS at ORNL

70 m long neutron beam line to ~30 T magnet center

ZEEMANS uses YBCO to replace a 10 MW resistive magnet – proposal now under review (Broholm (JHU), Granroth (ORNL), and Bird (NHMFL) PIs)
YBCO and cryocoolers can serve a broad, lower-field user magnet market

\[ J_c \text{ more than } 1 \text{ MA/cm}^2 \text{ over a very wide range, } J_E \sim 1\% J_c \]

9T magnets at 55K are within reach, even using the lower c-axis Jc as the gate, not the much higher \( J_c^{ab} \)

\[ H_{irr} \text{ of Nb}_3\text{Sn} – \text{ but at 58 K, not 2K} \]
The Muon Collider Design Study at Fermilab

50 T solenoids are a crucial feature......
A long term case for HTS magnet technology

**Magnet-pull focus**
- NMR HTS coil
- 40 T small HTS coil (31 T background)
- Finding the limits (stress, energy density, quench….)
- High current cables (e.g. Zeemans)

**Conductor-pull focus**
- YBCO coated conductors are evolving rapidly driven by 40-77K, 0-3 T use – what about 4 K, 20-40 T properties?
- Bi-2212 is round wire and multifilament – but has intrinsically poor vortex pinning due to large electronic anisotropy

2212 and YBCO have 3 times the critical fields of Nb₃Sn but their conductor technology is still primitive….

What we really want are the vortex pinning properties of YBCO and the grain boundary properties of 2212

Why not…………..?