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Bi-2212 round wire development and industrialization at OST

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Acknowledgements

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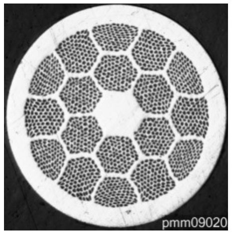
Outline

- **Status of round Bi-2212/Ag for high field applications**
- **Development of round Bi-2212/Ag wires**
  - Identify current limiting mechanisms
  - Improve wire J_E
    - ✓ Reduce C & H content
    - ✓ Increase bulk or filament density
    - ✓ Reduce ac loss
- **Fabrication of Bi-2212/Ag wire**
- **Summary**

Bi-2212 wire advantages for HF applications

- An isotropic conductor form

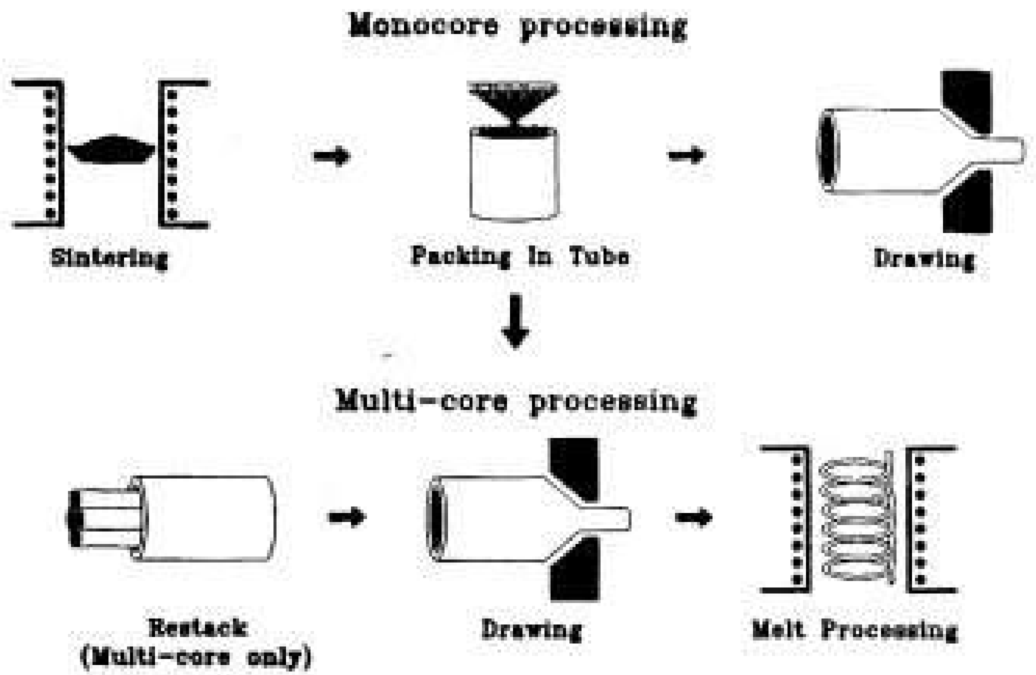


- High current under ultra high field
- Ability to twist, cable and transpose

- Resistance to quench, compatible insulation and materials utilization technology developed for Nb_3Sn
- Manufactured by traditional technology and easy to scale up

➢ Unique material for High Field magnet application.

Bi-2212 round wire developing over 10 years @ OST



➢ Bi-2212 round wire are fabricated by the traditional wire process with many configurations for different applications and easy to adapt Nb_3Sn well developed technology.

Bi-2212 wire configurations for different operating current demands

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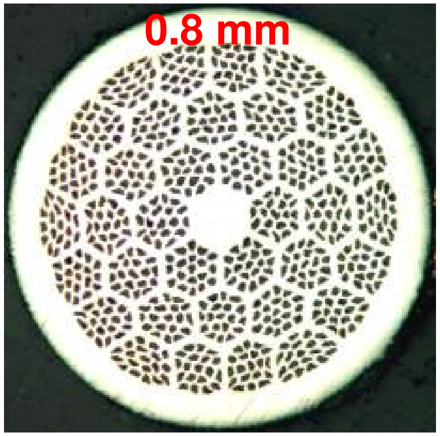
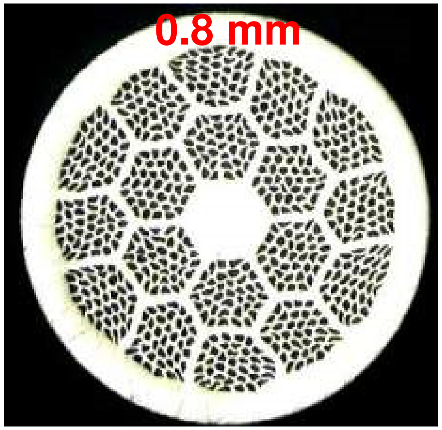
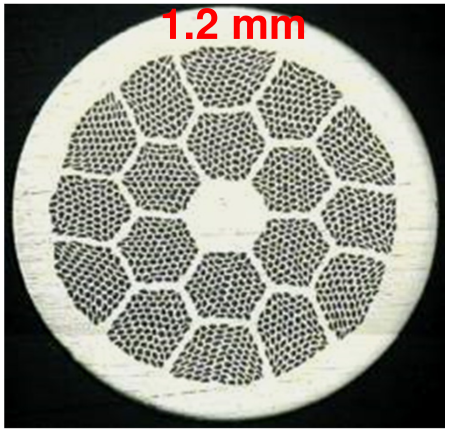
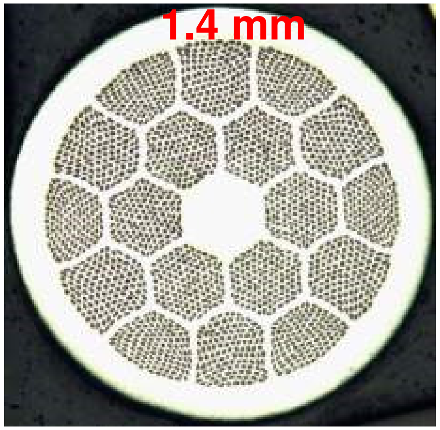
Wire configuration (sub filament number x sub bundle number)	Wire diameter range (mm) @Optimum J_E 4.2K & 15T
19 x 36	0.7 - 1.0
37 x 18	0.7 - 1.0
85 x 18	1.0 - 1.2
121 x 18	1.2 - 1.5





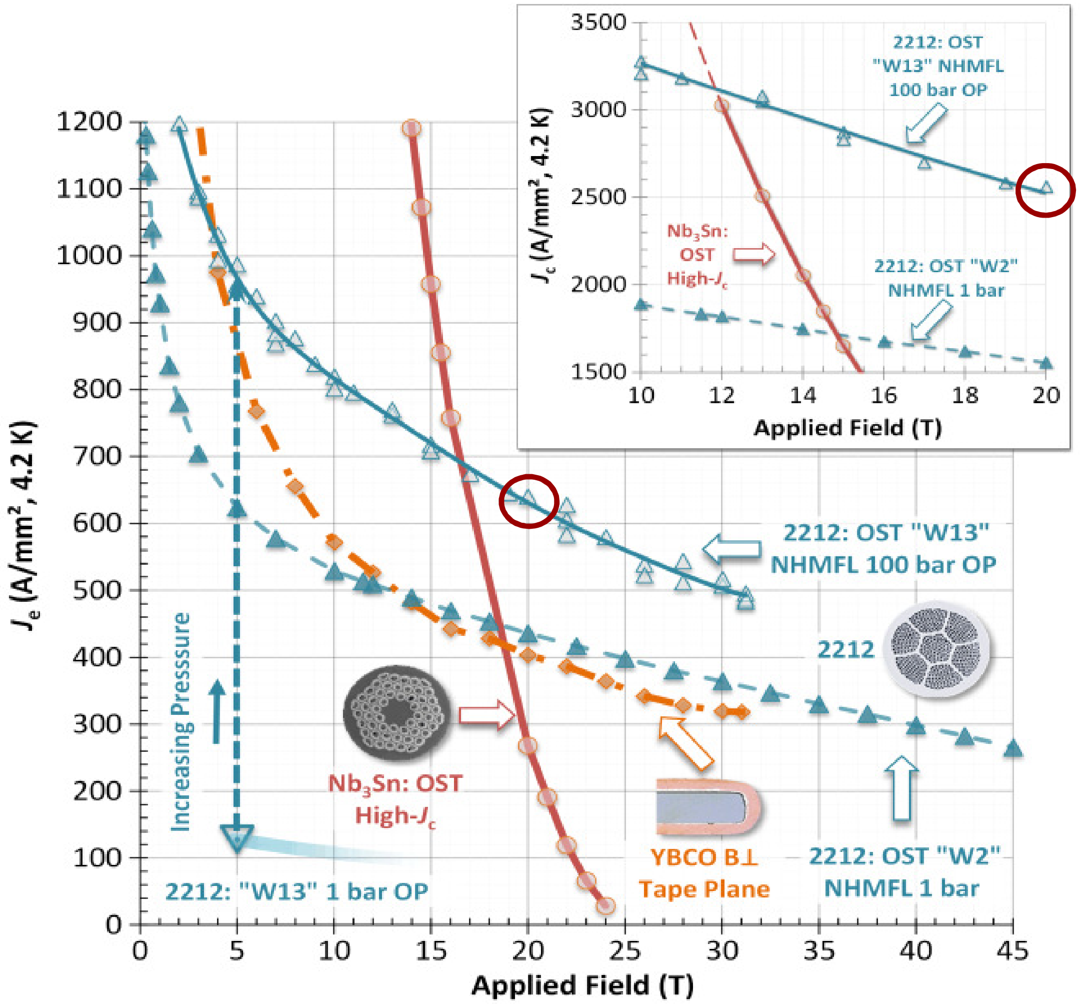




- Various wire configurations to fit different application requirements- cable (0.7-1.0 mm) and insert coil (1.0-1.5 mm)

Bi-2212 wire performance status

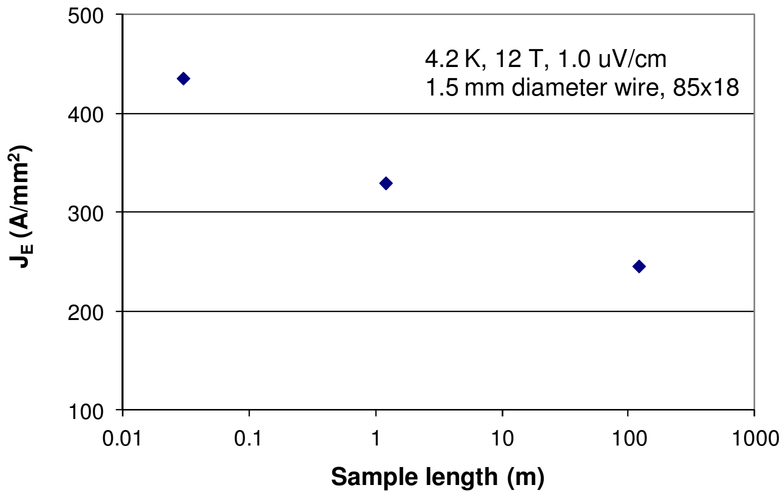
- Improved performance in short sample has met dipole magnet requirement
- Challenges on material for large-scale applications:
  - ✓ Achieving short sample J_E performance in long length
  - ✓ Increasing wire piece-length
  - ✓ Enhancing wire strength

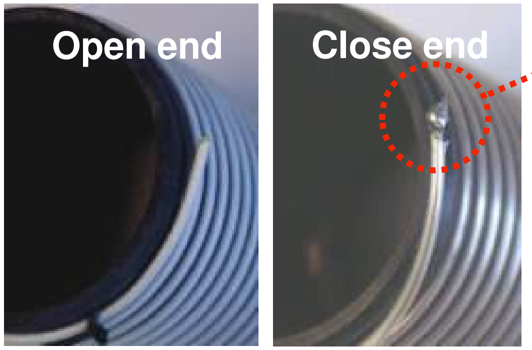


P. Lee, ASC/FSU

Bi-2212 wire Ic variation along the length

J_E vs sample length in as-drawn wire





"Close ends" simulates long length as in a coil

The impact of closing sample ends during heat treatment:

• Traps gas inside wire, builds up pressure, leads to higher wire porosity, more leakage and lower performance.

J_E reduction on samples with closed ends

	J_E (A/mm^2) at 15 T	
Wire diameter	Open ends	Close ends
0.8 mm	240	65
1.20 mm	330	280

➢ Reduction of C & H contents could be one of critical steps to improve long length wire performance.

C & H change during wire processing

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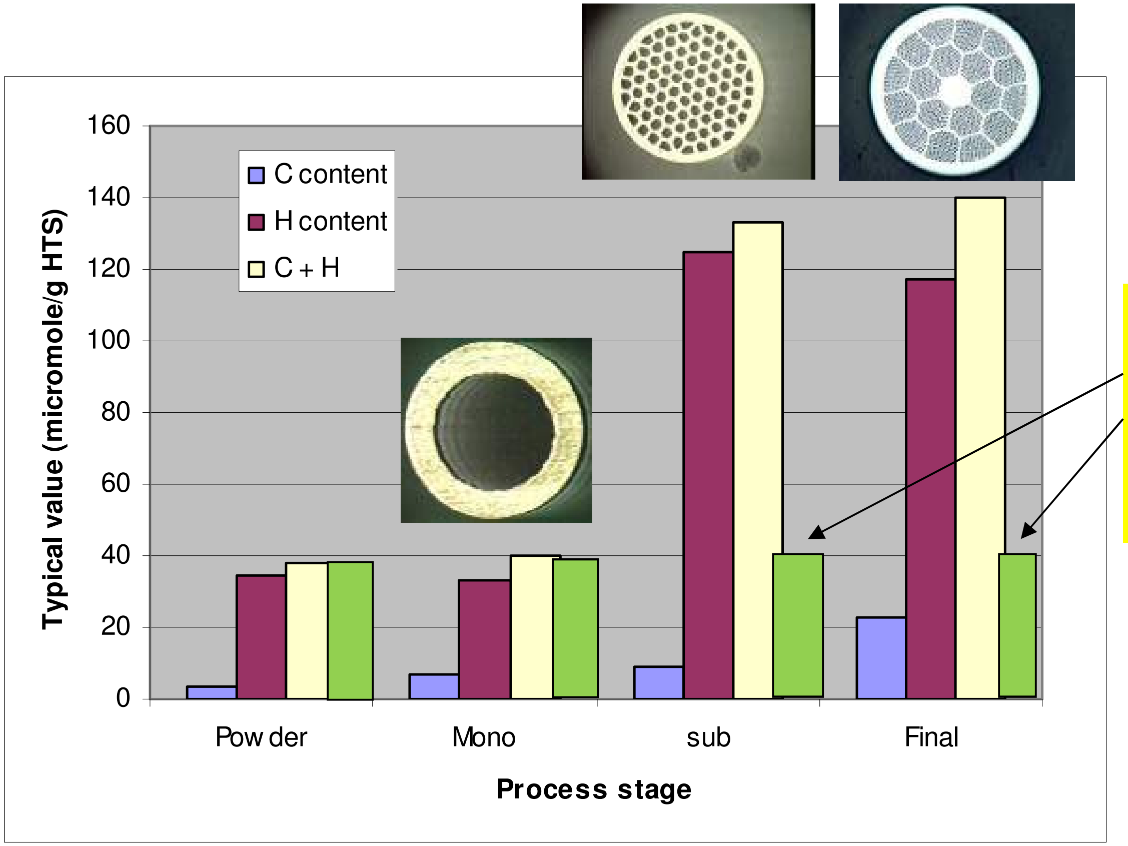

C+H by new process (to HTS elements)

C: 9 μmole/g &

H: 29 μmole/g

- H and C contents increase significantly after monofilament to element
- New process reduced C&H content by 70%.

J_E vs C & H content in as-drawn wires

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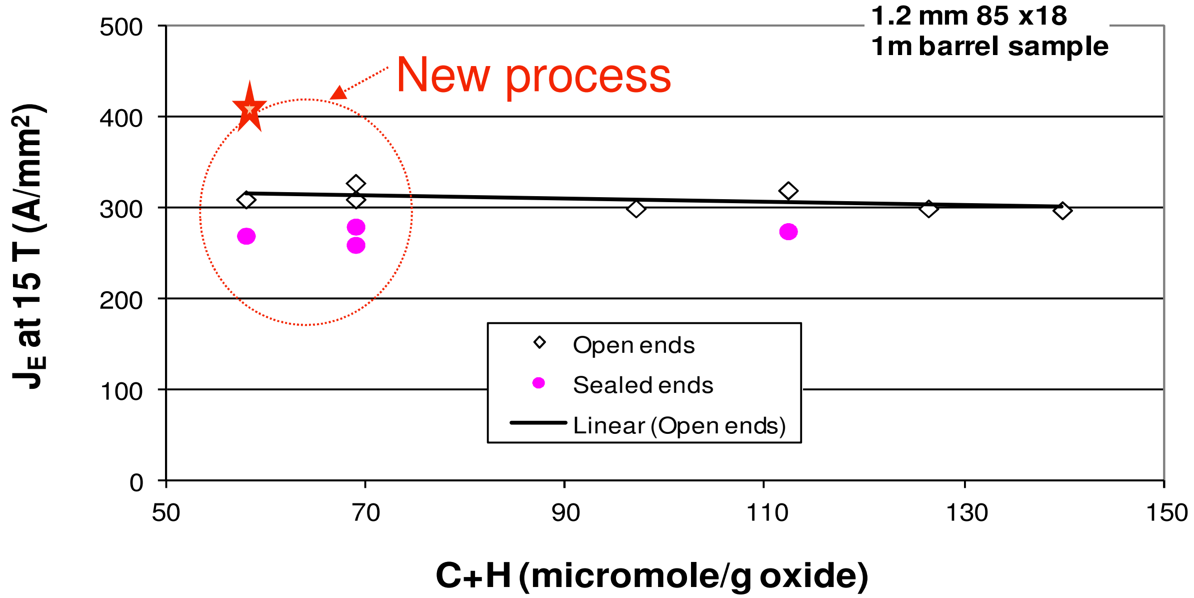

- The leakage in the densified wires with lower C/H is significantly reduced, no leakage observed in closed end 100 ksi CIPed barrels with Je > 400A/mm2 at 15T.
- No significant J_E improvement in as-drawn wires with lower C and H content.

Wire creep during heat treatment

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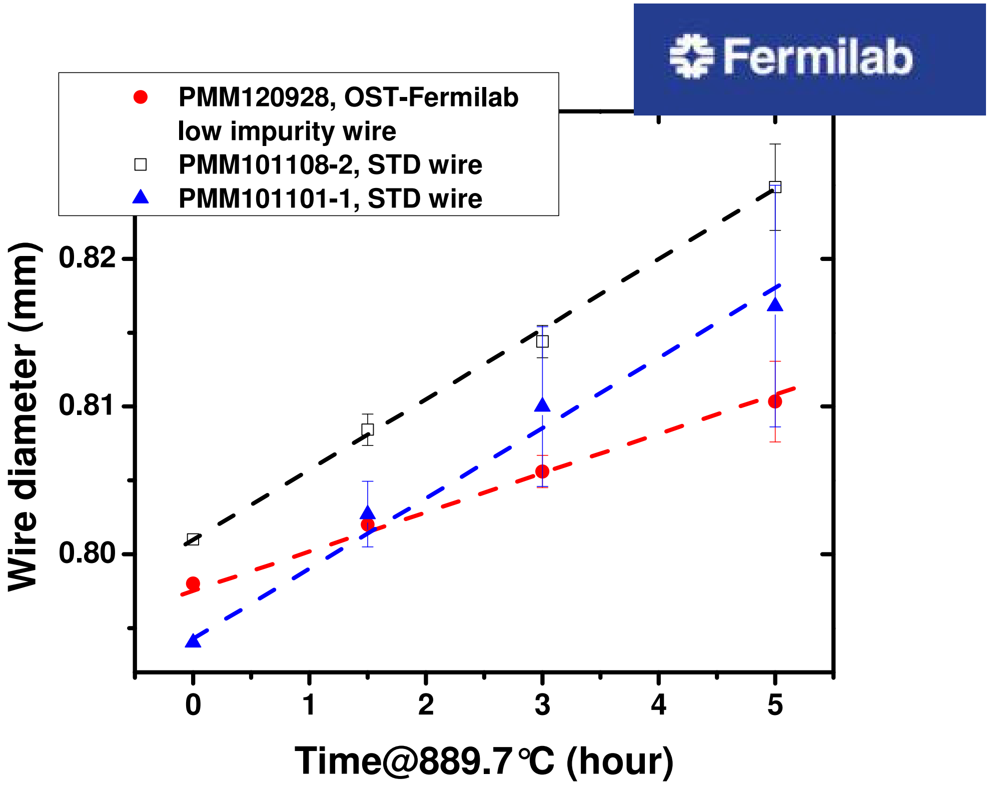
Standard wire: carbon (15 µmole/g)
hydrogen (132 µmole/g)

New wire: carbon (9 µmole/g)
hydrogen (29 µmole/g)

Huang, Miao (OST), Jiang (FSU), Shen (FNAL)



➢ Confirmed progress in reducing the gas impurities.

Mono-core wire densification by swaging

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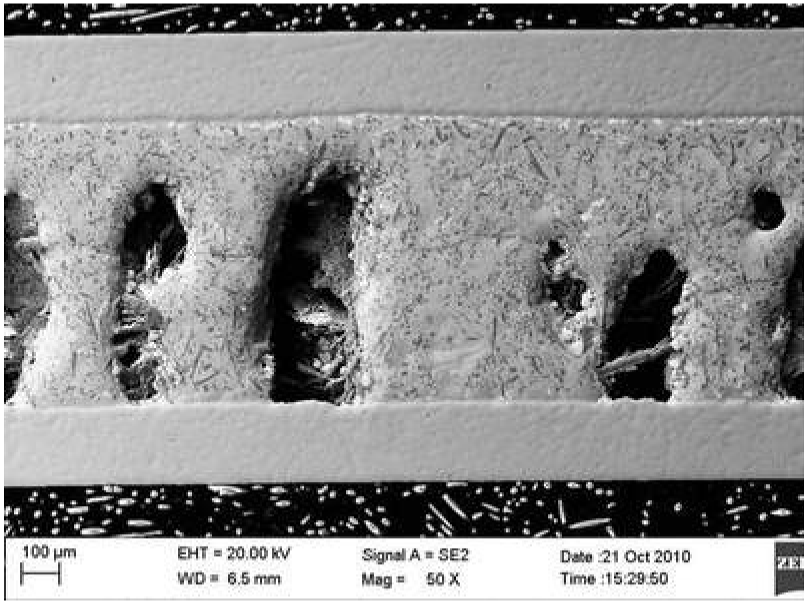
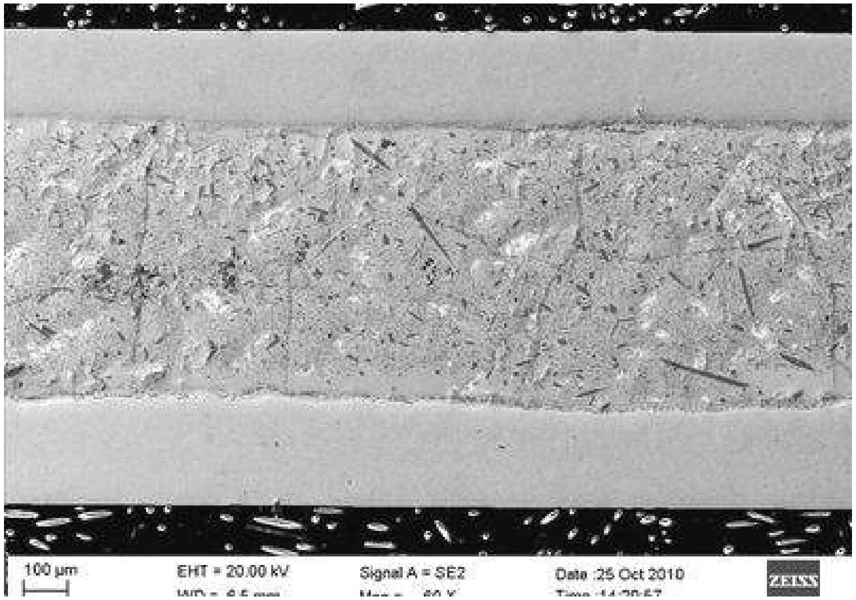
Quenched samples right after melt treatment at 890^{o}C

Pictures courtesy of ASC/FSU



Quenched from melt as-drawn mono filament, initial core density ~70%



Quenched from melt swaged mono filament, initial core density ~90%

- Large bubbles in as-drawn mono filament
- No obvious large gas bubbles in the swaged filament

Bi-2212 Wire J_E improvement by CIPing

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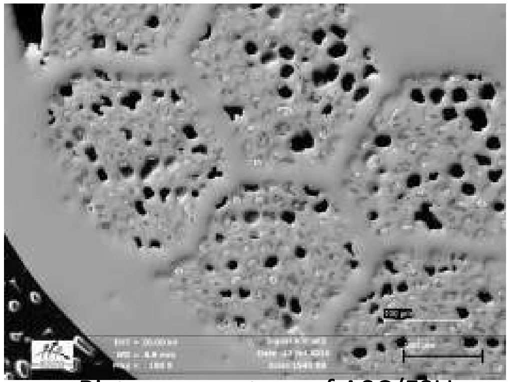
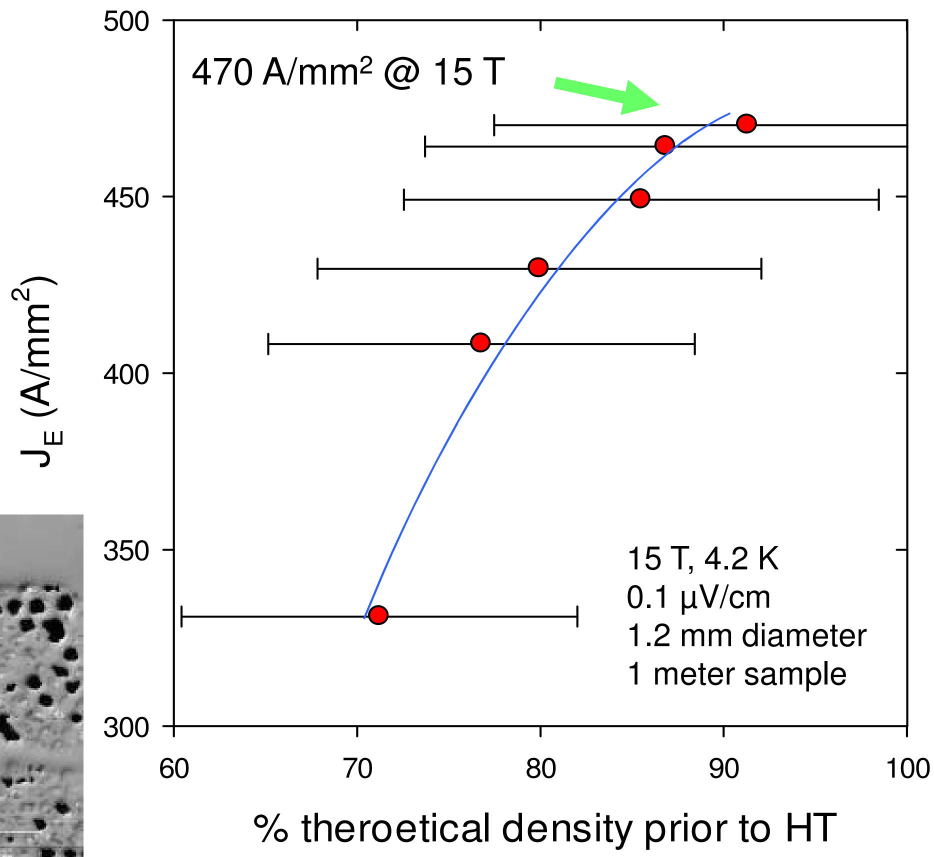
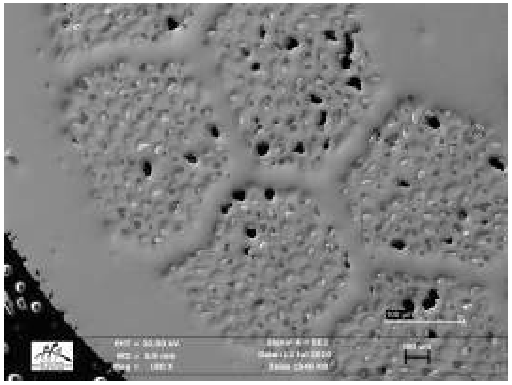
Quenched from melt
as-drawn wire



Pictures courtesy of ASC/FSU





Quenched from melt
650 MPa CIP wire

- Core densification results in double J_E values to ~470 A/mm² at 15 T

Bi-2212 wire J_E improvement by swaging

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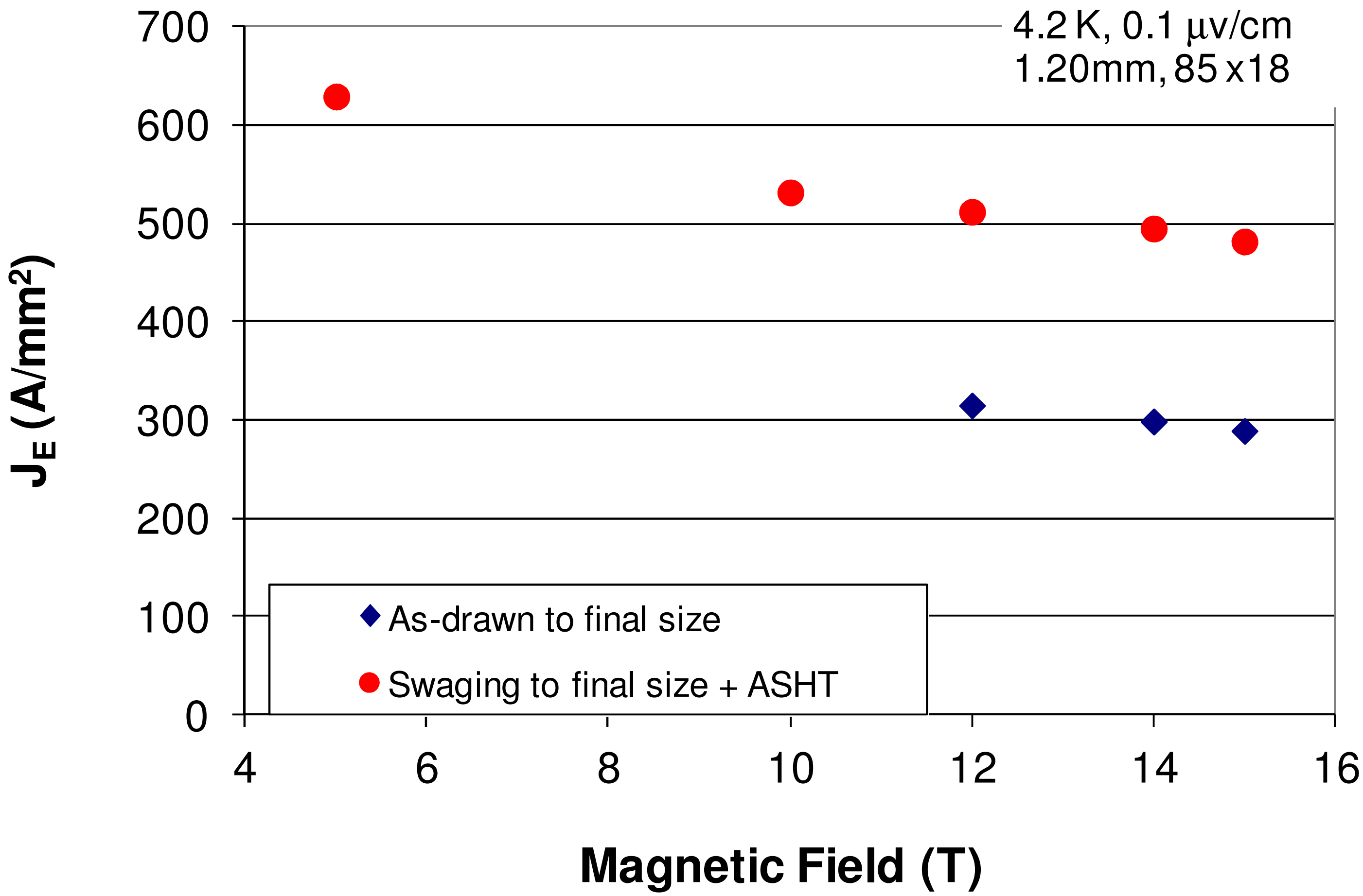

- The best J_E value is > 480 A/mm^2 at 15 T

State of art OST Bi-2212 wire J_E

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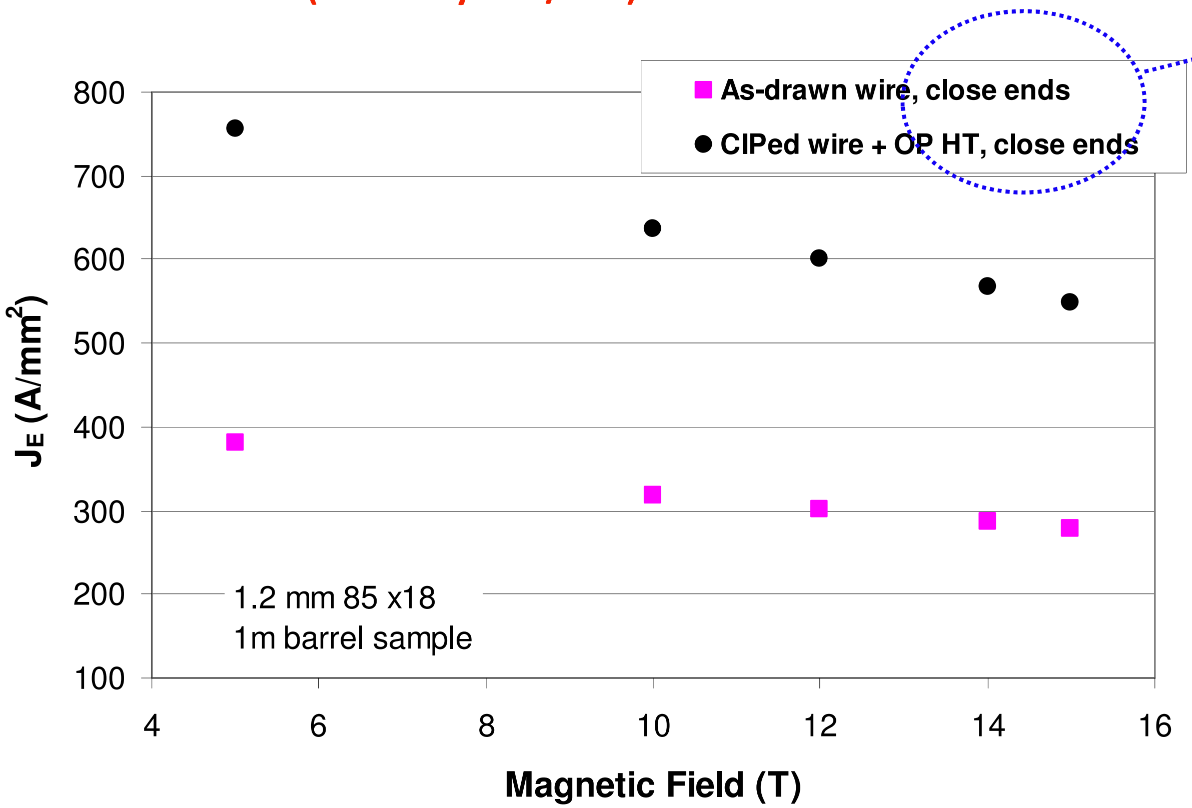
Over Pressure Heat Treatment (10 bar by ASC/FSU)



"Closed ends" simulates long length as in a coil

- "Over pressure HT" is to prevent the leakage
- "Core densification + over pressure HT" achieve a recorded J_E values to ~550 A/mm^2 at 15 T in *meter barrel* samples with *closed ends*

J_c of 2500 A/mm² at 20 T and 4.2 K by OP

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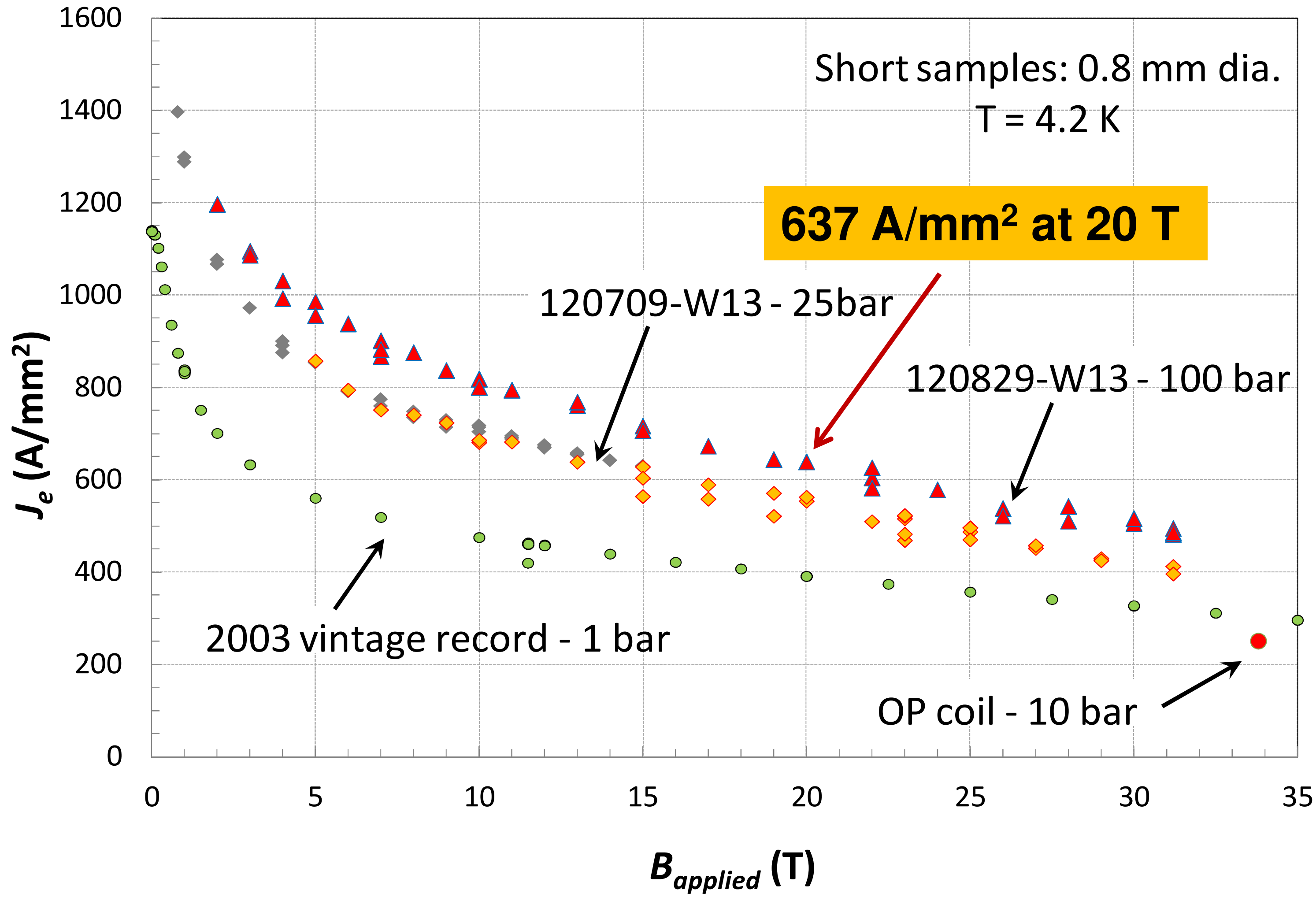

Courtesy by ASC/FSU Dr. Jiang, Prof. Hellstrom, Prof. Larbalestier et al

Continuous progress on OST wire J_E

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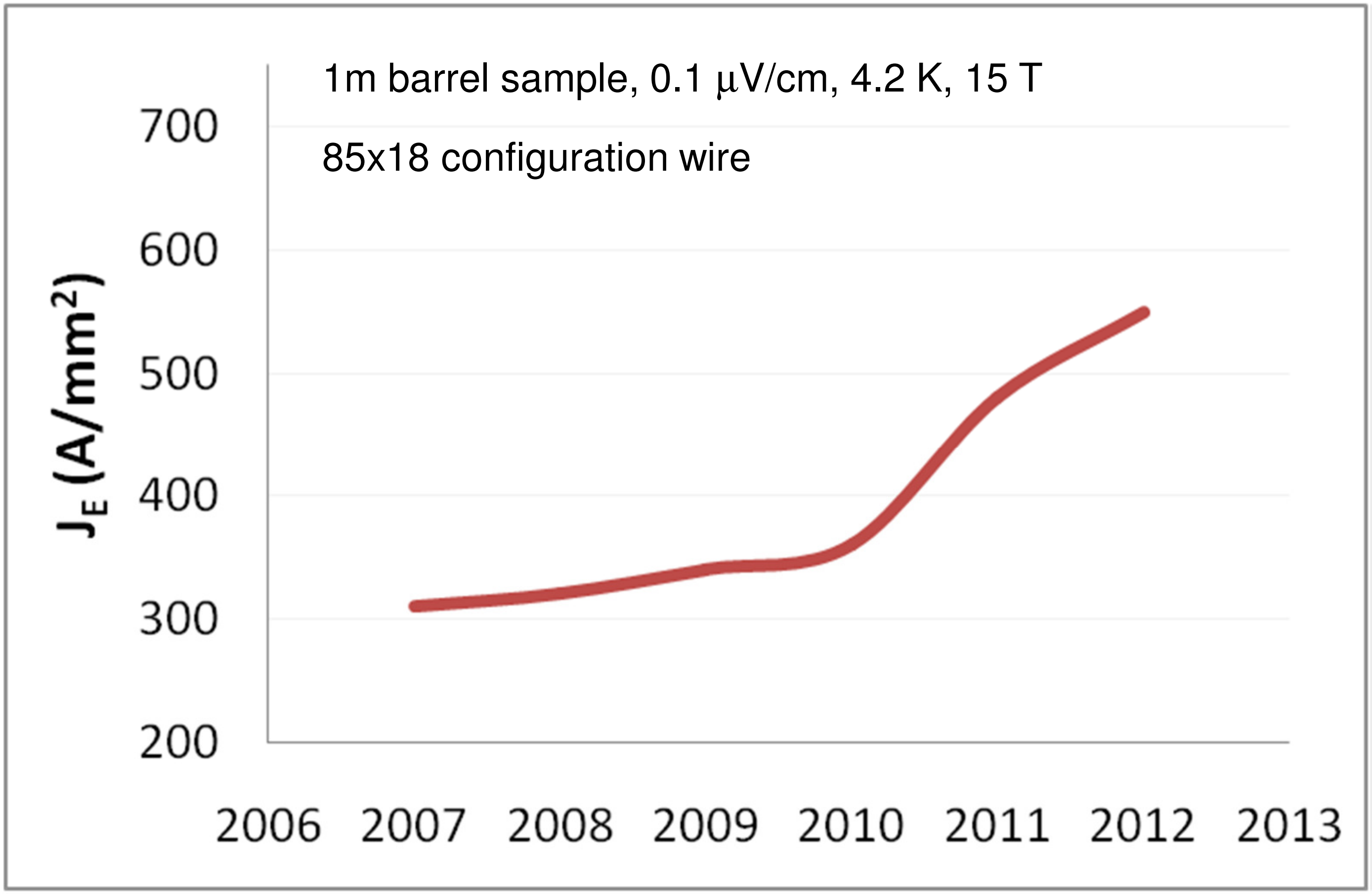

- Wire performance continues to improve with leakage under control

Reduce ac losses by wire twisting

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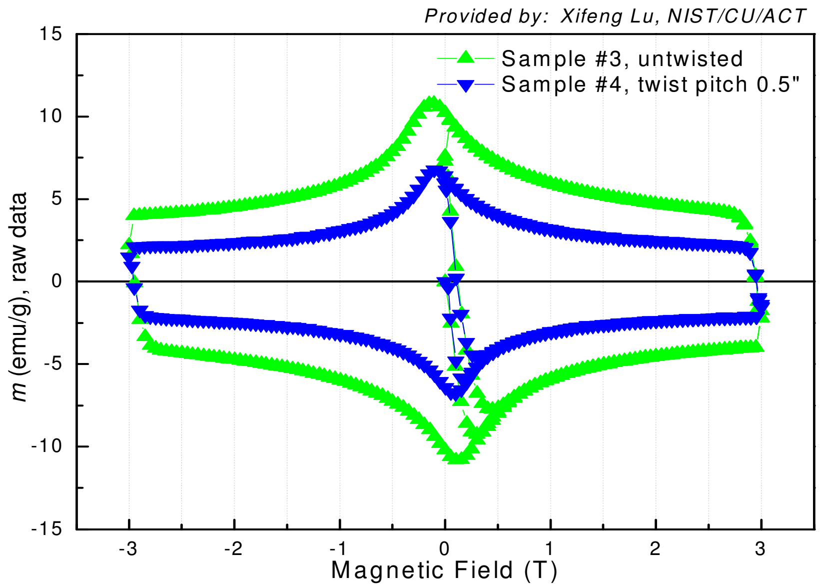

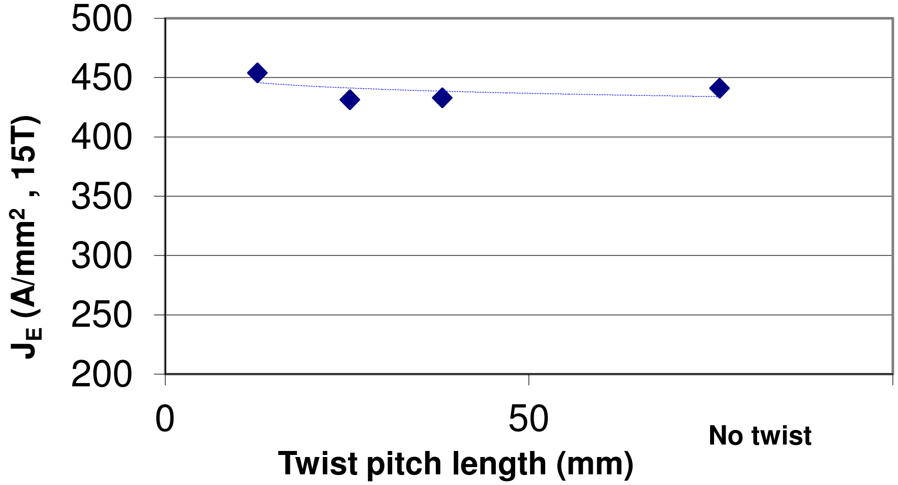

- Samples: 1.20mm 85x19 wires in the same spiral size and HT
- 50% ac loss reduction is achieved on wire with 12 mm twist pitch length
- Bi-2212 wire can be twisted to 12 mm in twist pitch length without J_E degradation.

Bi-2212 wire twisted evaluation in production scale

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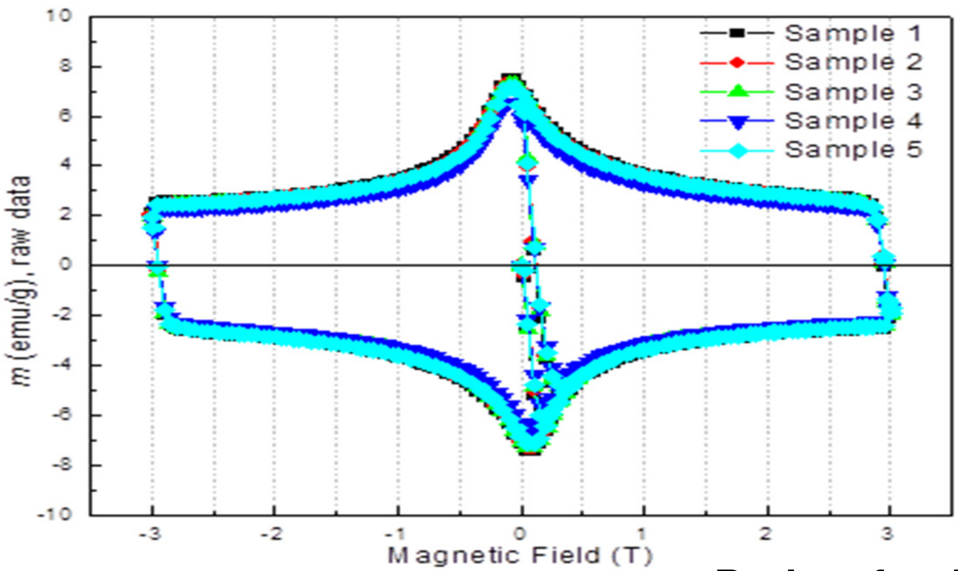

Project funded by US-CDP program

- 95 m of 1.2 mm wire twisted through production equipment:
  - ✓ Twist pitch length is 20 mm (+/- 1 mm)
  - ✓ Ic (A, 4.2K & 15T) variation within 2%
  - ✓ ac loss values consistence in whole length

• Twisting process is now applied up to km wire fabrication.

Bi-2212 round wire development in near future

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Property of importance	Delivered value today	In 2 years	In 5 years
Temperature range	4.2-20 K	4.2-20 K	4.2-20 K
Field range	20 -50 T	20 -50 T	20 -50 T
Conductor current density	J_E ~500 A/mm2 at 4.2 K 20 T	J_E ~700 A/mm2 at 4.2 K 20 T	J_E ~700 A/mm2 at 4.2 K 45 T
Conductor form and dimensional range	Round, > 0.5mm	Round, > 0.5mm	Round, > 0.5mm
Conductor length	200-1000 m	400-1000 m	> 3000 m
Conductor shape	round	round	round
Conductor strength	110 MPa	150-200 MPa	> 200 MPa
Conductor shape anisotropy (tape, round, bulk)	round	round	round
Superconducting isotropy	Yes	Yes	Yes
Stabilizer	Ag	Ag	Ag
Delivered selling price range $/kA.m, @4.2K&20T	330-550	200-400	100-150

Summary

1. Bi-2212 round wire fabrication is easy to scale up because it uses the traditional wire manufacturing technology.
2. Various wire configurations to fit different application requirements.
3. Twisted Bi-2212 wires significantly reduce ac loss without the critical current degradation and processed through production scale.
4. Core densification by swaging and cold isotactic pressing prior to heat treatment leads to less voids in the melt and doubles the wire performance.
5. Over pressure HT densified core, prevented wire leakage and achieved J_E values to >550 A/mm^2 at 4.2K & 15 T (in meter long sample and by OP pressure of 10 bar).
6. Lower C&H content in the wire leads to decrease the Ag sheath creeping and reduce risk of wire leakage.