A New Generation Nb_3Sn wire, and the Prospects for its Use in Particle Accelerators

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- OST
- OKAS
- SBIR Program Participants
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Presentation Outline

- Accelerator magnet applications for Nb_3Sn
  --LHC Luminosity Upgrade
  --LHC Energy Upgrade
- Conductor Development Program Status and Plans
  --Performance improvements (Jc and D_{eff})
  --Cost reductions
  --New conductors

Possible LHC upgrades would require large quantities of Nb_3Sn wire

- 20 tons for the interaction region quadrupole upgrade (timeframe--2010)
- As much as 500 tons for an energy upgrade to 14 TeV (timeframe--?)
- Conductor R&D and production scaleup are requried to meet the performance and quantity requirements.

Goals and Target Specifications have been developed in collaboration with the CDG

- Goal: Provide cost-effective, high-performance superconductor required for luminosity upgrades and for the next generation high-energy physics colliders.
- Target specifications for the HEP conductor include:

--Jc (noncopper,12T,4.2 K): 3000 A/mm^2 (1500 @ 15 T)

--Effective filament size: 40 microns or less

--Piece length: Greater than 10,000 m in wire diam. of 0.3-1.0 mm

--Heat treatment times: Less than 200 hr; target is 50 hr for wind and react

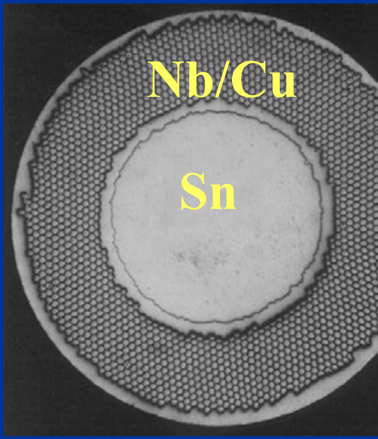
--Wire cost: Less than \$1.50/kA-m (12 T,4.2 K)

Steps toward improvements in Jc

1. Optimize use of available space

   --OST and OKAS focus during first 2 years R&D

   --a Jc increase from 2000 to 3000 A/mm^2 (12 T, 4.2 K) has been achieved



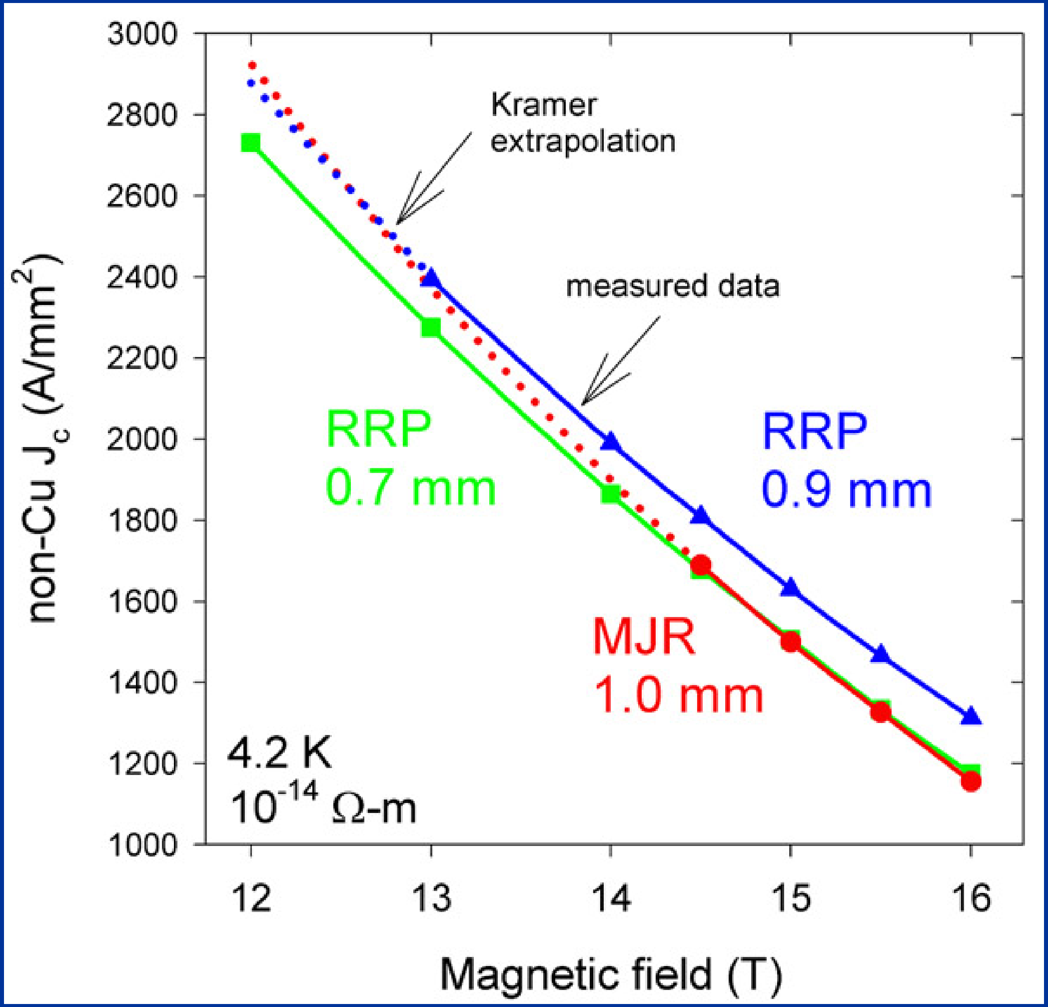
2. Optimize heat treatment

   --high Nb, Sn composites require different heat treatments (OST-MJR Jc increased from 2600 to 2900 A/mm^2)

   --Lab/Univ support includes microstructure evolution studies and improved Ic testing

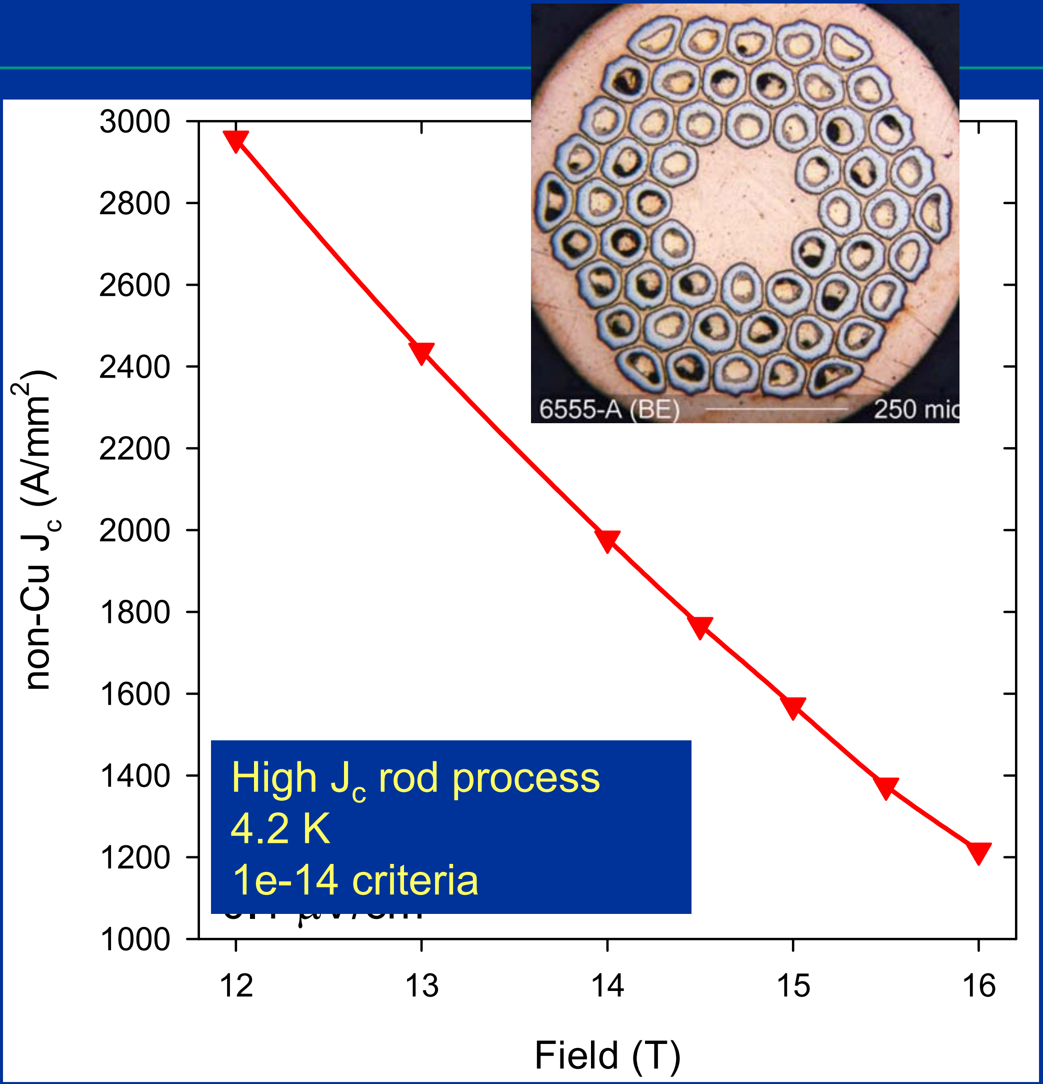
3. Refine grain size in Nb_3Sn

OST has achieved world record Jc values for Nb_3Sn made by two processes (LTSW Nov'02)



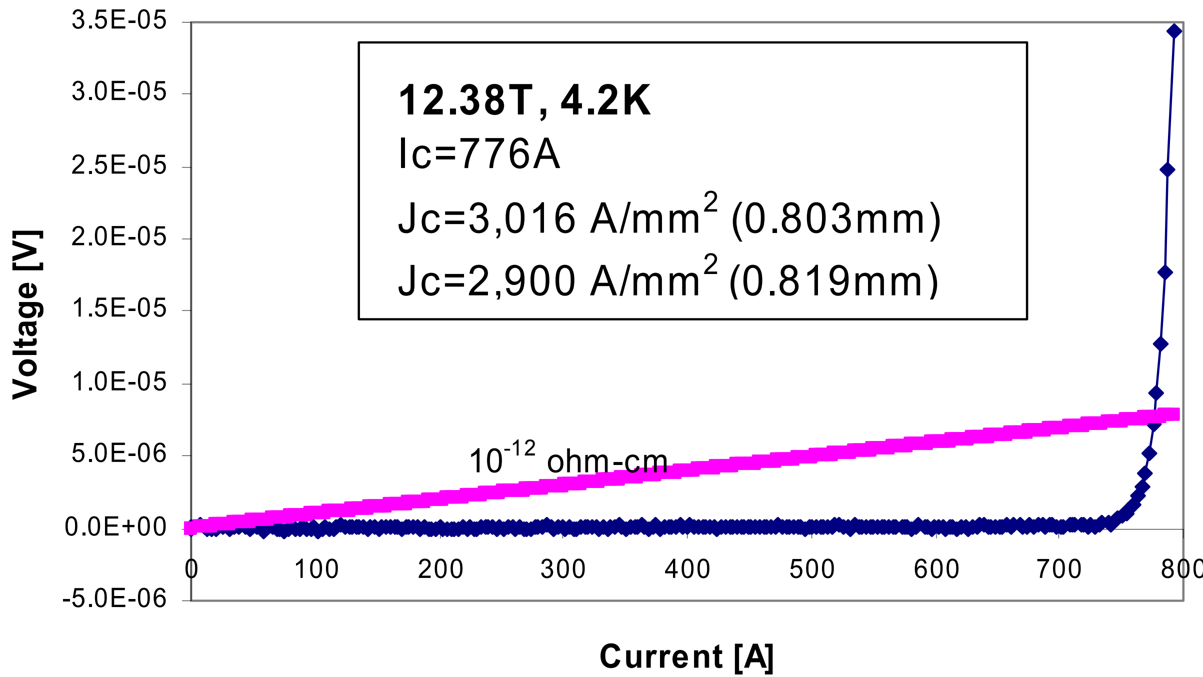
Rod process has replaced MJR at OST

- J_c performance as good or better than MJR
- Much better piece length than MJR
- Use of rods and extrusion instead of sheets and all-cold drawing makes yield more predictable
- J_c (12 T, 4.2) ~3000 A/mm^2 (one short sample over 3000 A/mm^2 at OST)



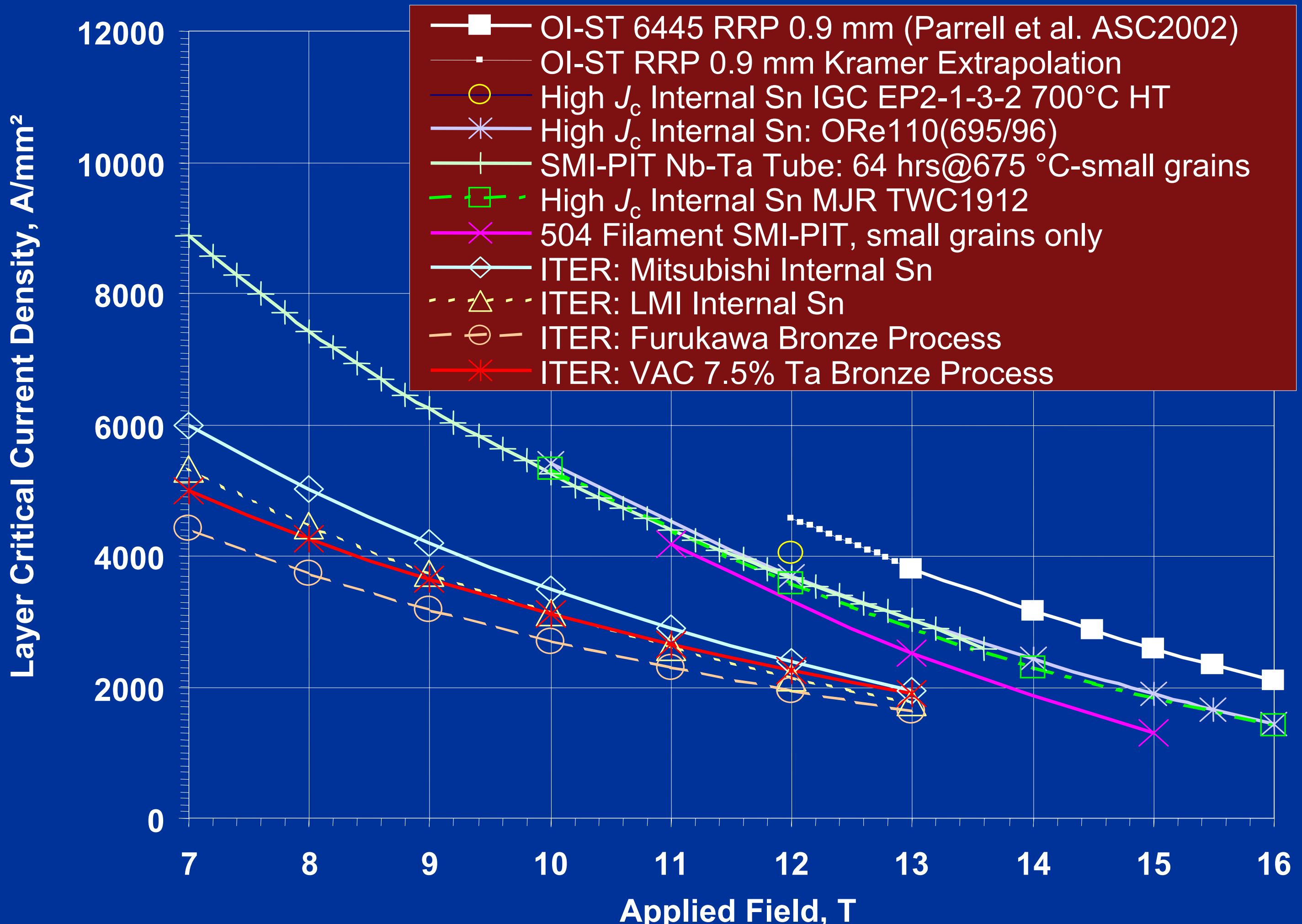
OST RRP Wire--HT and Test at LBNL

- OST B6555, 49%Cu
- HT 650 C, 200hr
- RRR=15
- D_{eff}~100 μm
- Stable to 58 μV/m



OI-ST 3000 A/mm² Strand: New J_{csc}

--From P. Lee, PAC'03



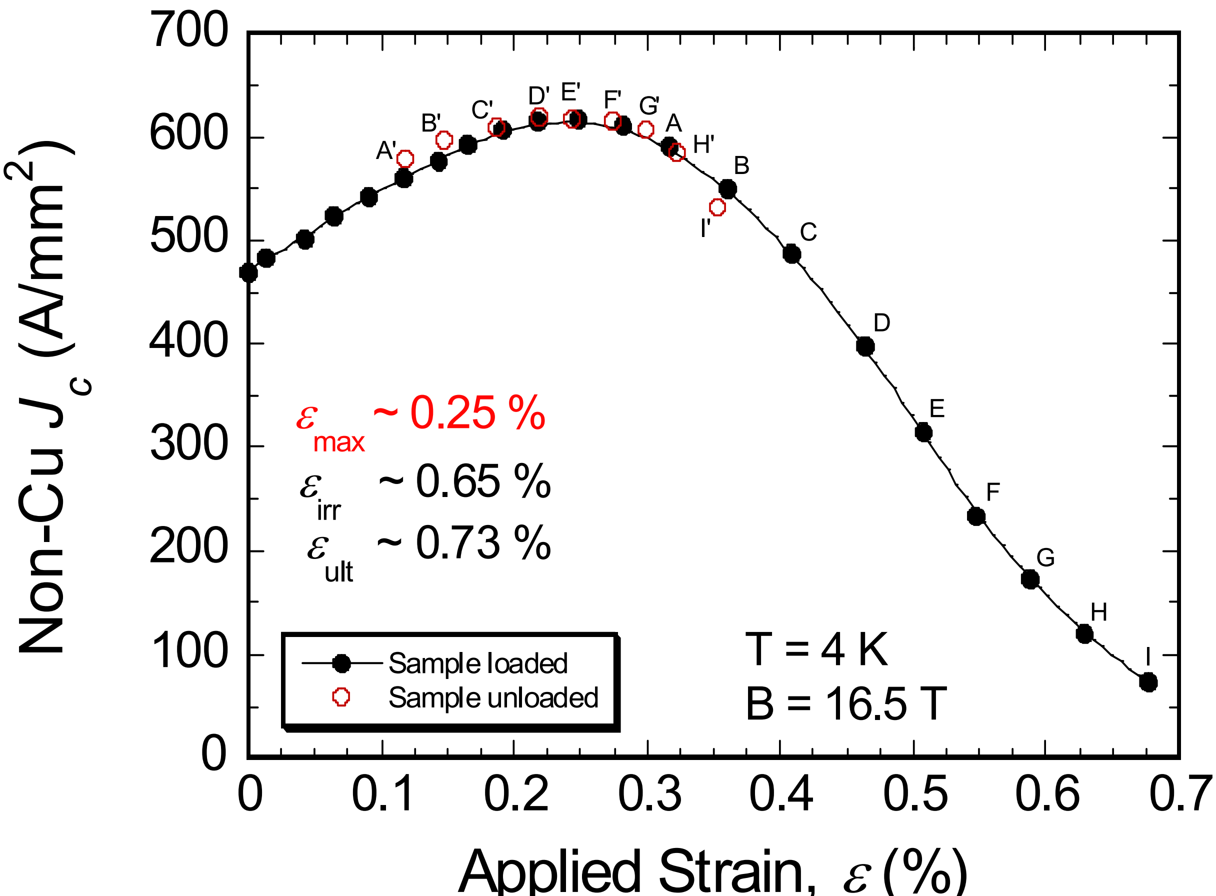
Non-Cu:A15 ratio from image analysis of high resolution FESEM images of 4 sub-elements

OI-ST RRP 3000 A/mm² (12T, 4.2K)

OST Nb_3Sn wire #6581 (higher Nb_3Sn %): Axial strain effect at 4 K & 16.5 T--data from Ekin and Cheggour, NIST

ϕ 0.5 mm; Cu-plated to ratio 3:1

($\phi \sim$ 0.77 mm)



OST has completed production quantities of high Jc wires for use in Dipole HD-1

- MJR process (50 kg delivered Aug 2002, meets specification)

  --Jc (12T, 4.2K) > 2250 A/mm^2

  --RRR(copper residual resistivity ratio) > 2

  --Yield: > 72 % piece lengths > 250 m

  --D_{eff} < 100 microns
- RRP process (50 kg delivered Jan 2003, exceeds Jc spec.)

  --Jc > 2750 A/mm^2; best value > 3000 A/mm^2

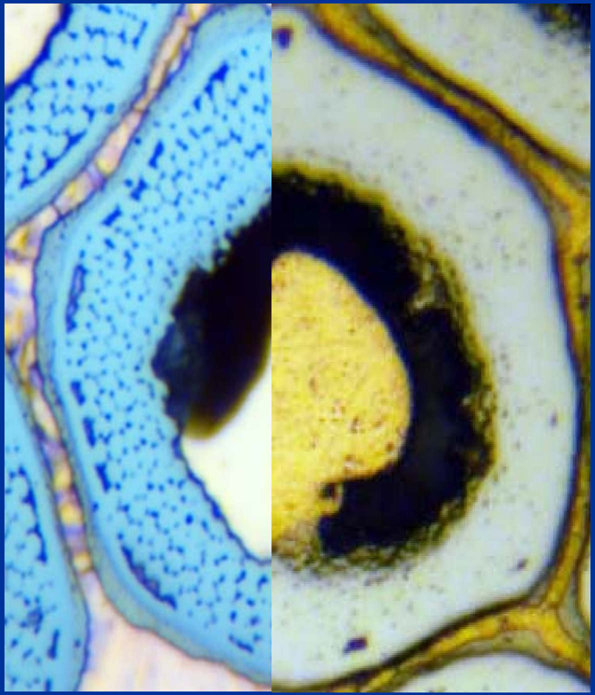
  --RRR > 15

  --Yield: 86 % piece lengths > 250 m

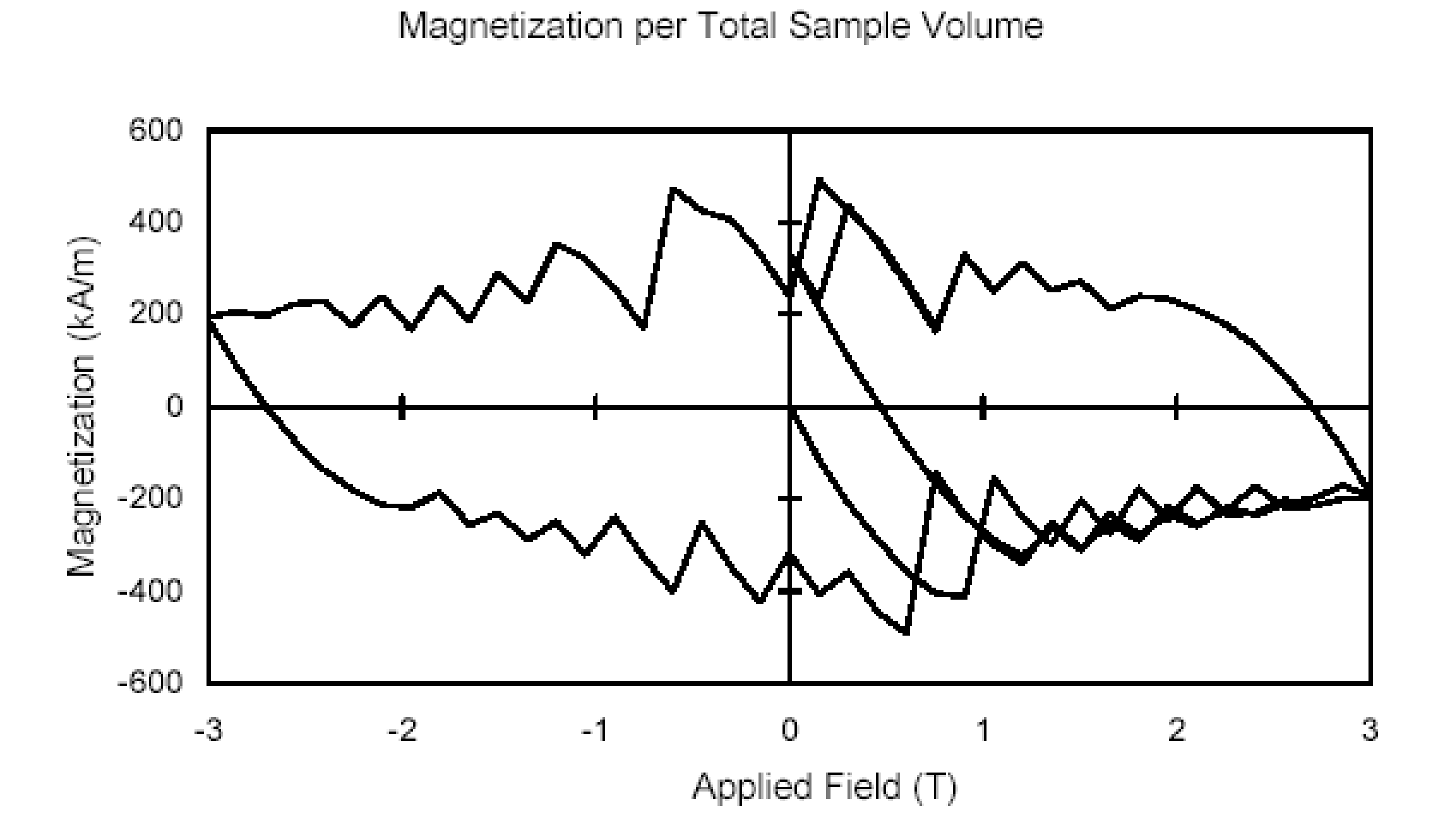
  --D_{eff} < 100 microns

Comparison of low, moderate and high Jc subelements

- •Low--filaments are discreet and not interconnected; diffusion barrier is Ta
- •Moderate--Filaments are discreet, but interconnected, diffusion barrier is Ta or Nb
- •High--filaments have coalesced to form a monolithic structure, diffusion barrier is Nb



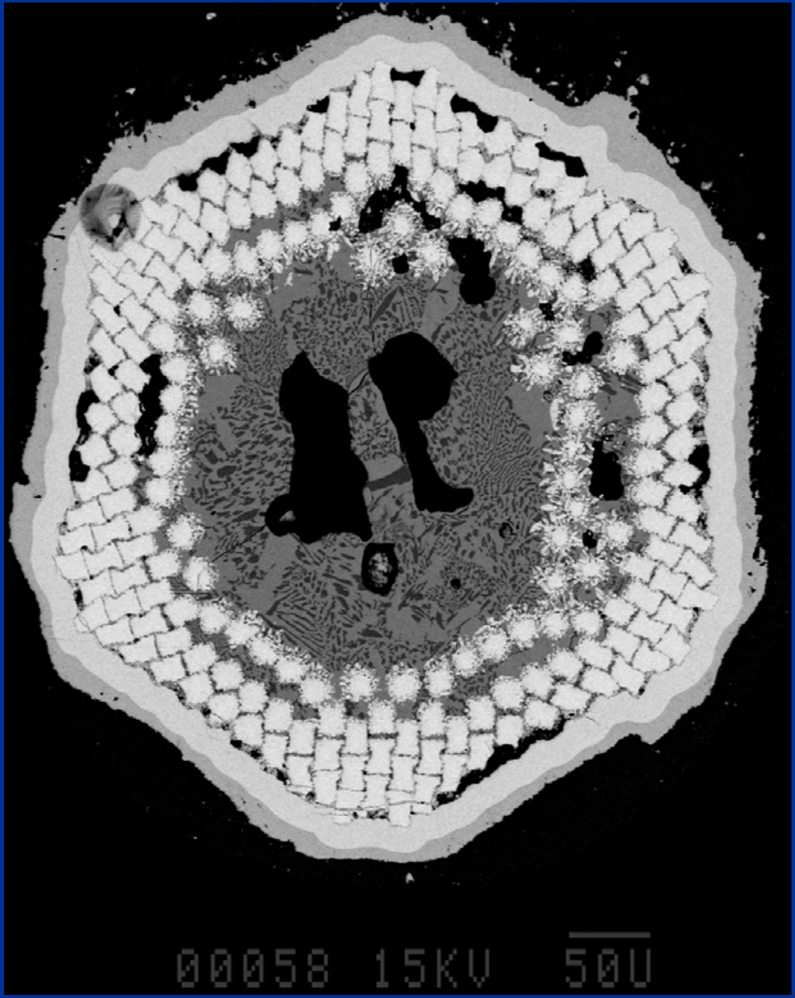
Magnetization loop for high Jc wire shows evidence for partial flux jumps



OST wire with distributed barrier; Jc=3000 A/mm2, D_{eff}=80 microns

Limits to increasing Jc by increasing Nb and Sn volume fractions

- Large magnetization
- Flux jump instabilities
- Lower matrix RRR
- Fabrication issues
- Filament dissolution during reaction step

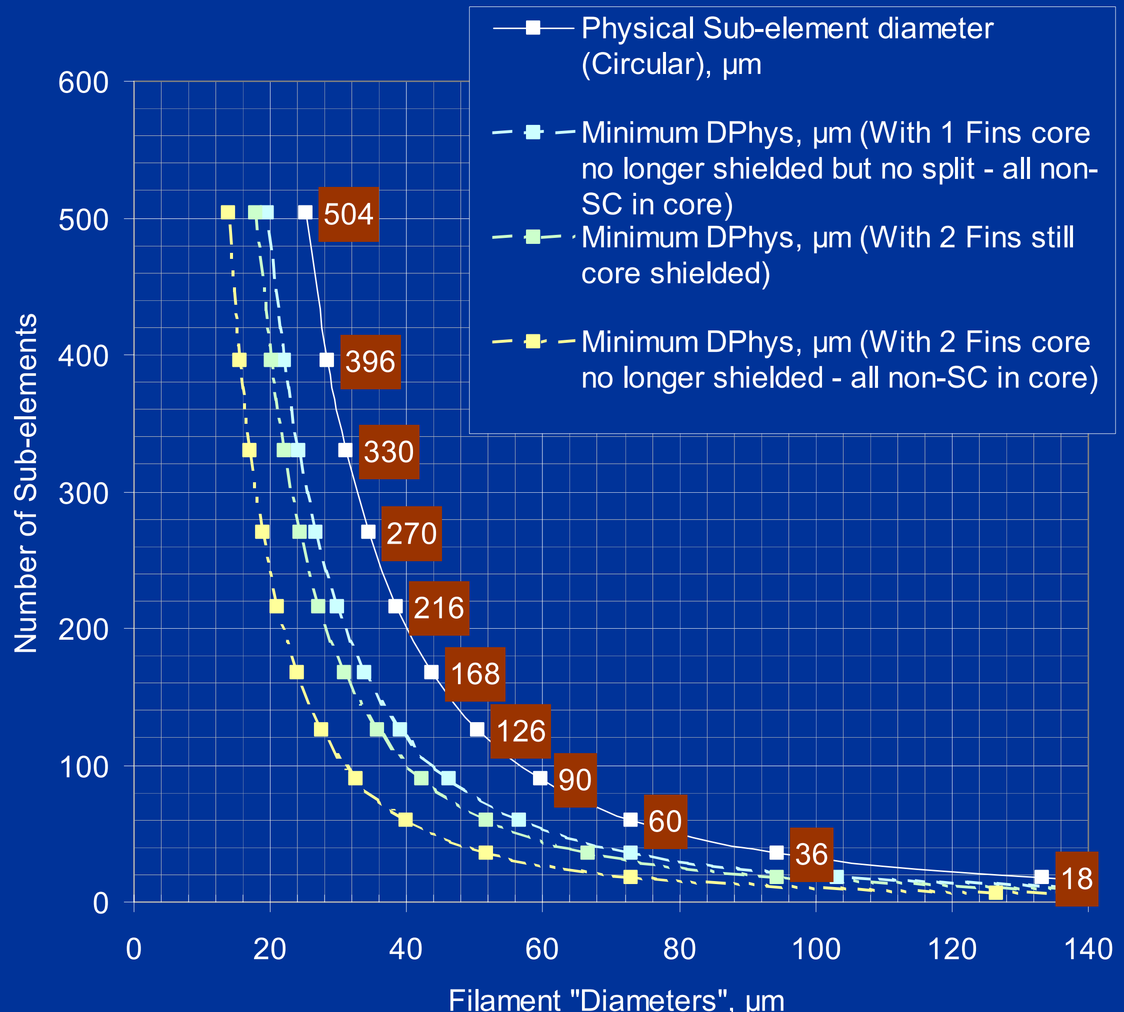


Main emphasis in FY04--reduce D_{eff}

- Increase number of subelements (OST, Supergenics SBIRs)
- Use fins to subdivide subelements (OKAS, Supergenics, OST)
- PIT conductor fabrication (Shape Metal Industries, Supercon)

More Sub-Elements Required . . or

- Large number of sub-elements needed – with associated stacking problems – unless the subelements are sub-divided
- Even so, > 36 subelements required



From P. Lee, PAC'03

Key task for reduced D_{eff} is to determine methods (and limits) for restacks

Subelement restack issues include:

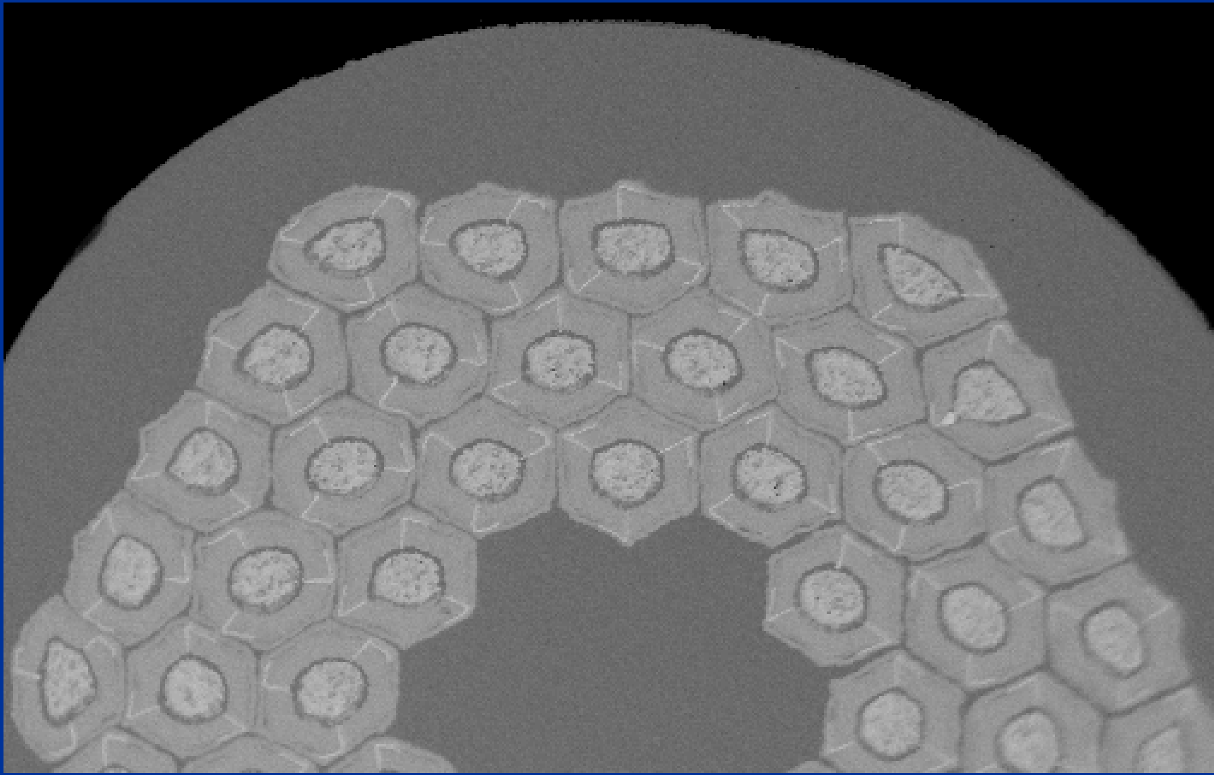
--Single or double restack

--Bonding

--Subelement/barrier distortion

--Matching hardness of components

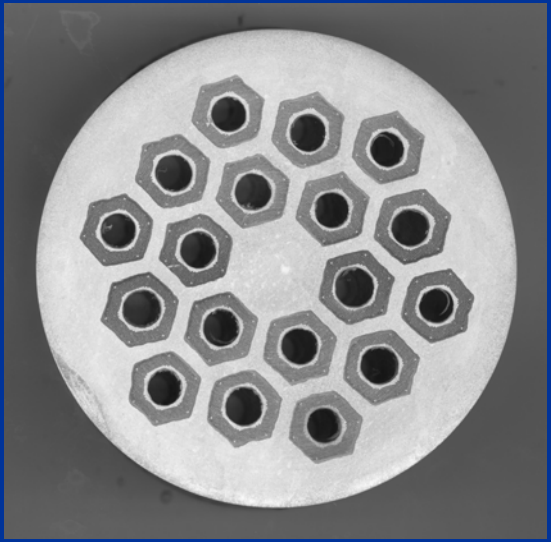
--Sn rod size for HER



OKAS restack with 54 subelements, 3 fins

OST R&D program (FY04)

- Demonstrate HER process for making high $J_{c,}$, low D_{eff} wire
- Distributed barrier design (highest J_c,good D_{eff})
  --127 subelements
  --D_{eff} = 40 μm, 0.6 mm diam.
- Cost reduction/improved piece lengths
- Improved RRR



Hot extruded rod with 18 holes, ready for loading Sn rods

OKAS R&D Program

- Fabricate reduced D_{eff} wire using fins

- Improve drawability of the OKAS internal tin wire

(scaleup work for ITER--will benefit HEP as well)

A New Approach for reducing Deff without increasing number of subelements: fins

- SBIR work by Supergenics/OKAS

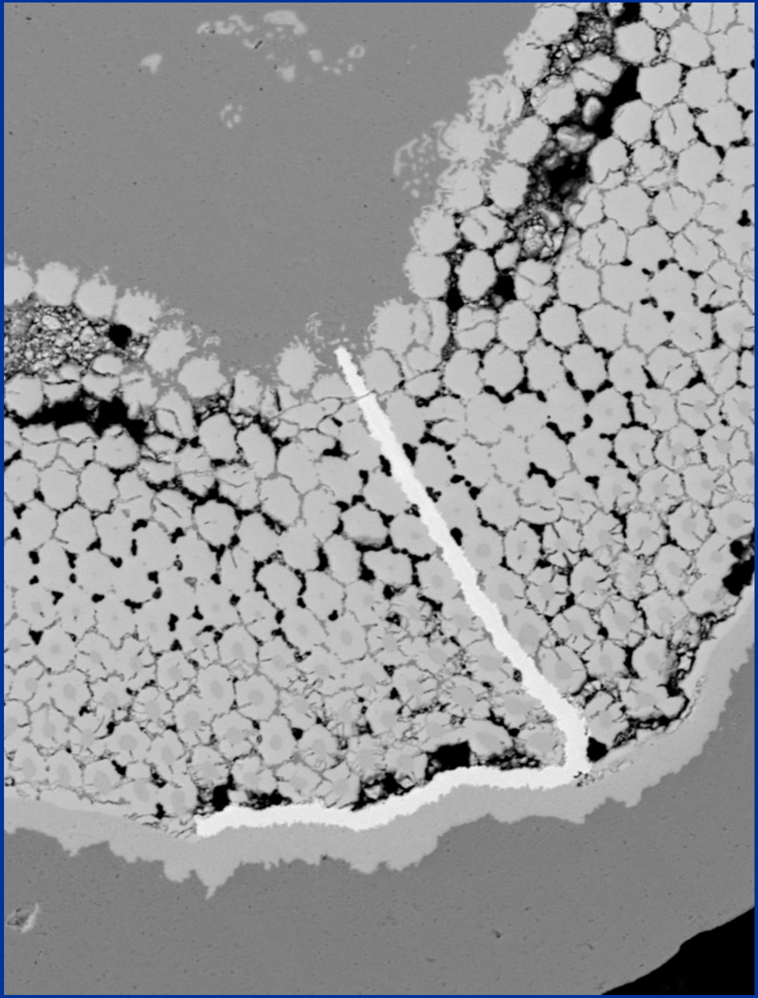
  --radial fins to prevent filaments from coalescing

  --short barrier section to prevent reaction on Nb barrier

  --add more fins to further subdivide Nb_3Sn

  --penalty is only 0.4-0.8 % area fraction per fin

  --Ta 40 wt% Nb alloy



Fin approach is continuing at both Supergenics and OKAS

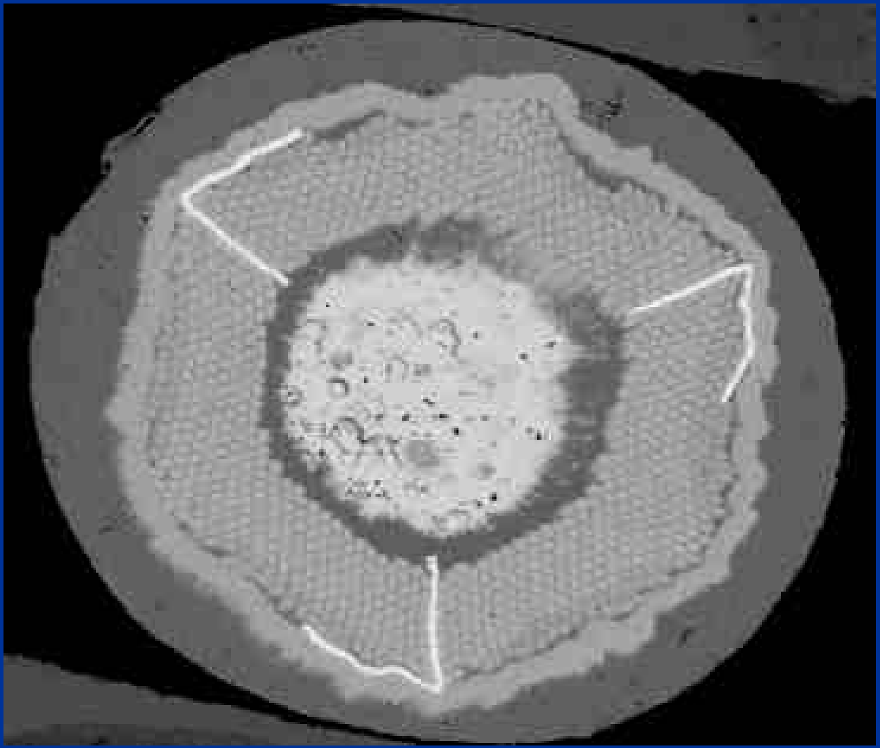
- OKAS
  --three radial fins

  --Ta 40 wt % Nb alloy

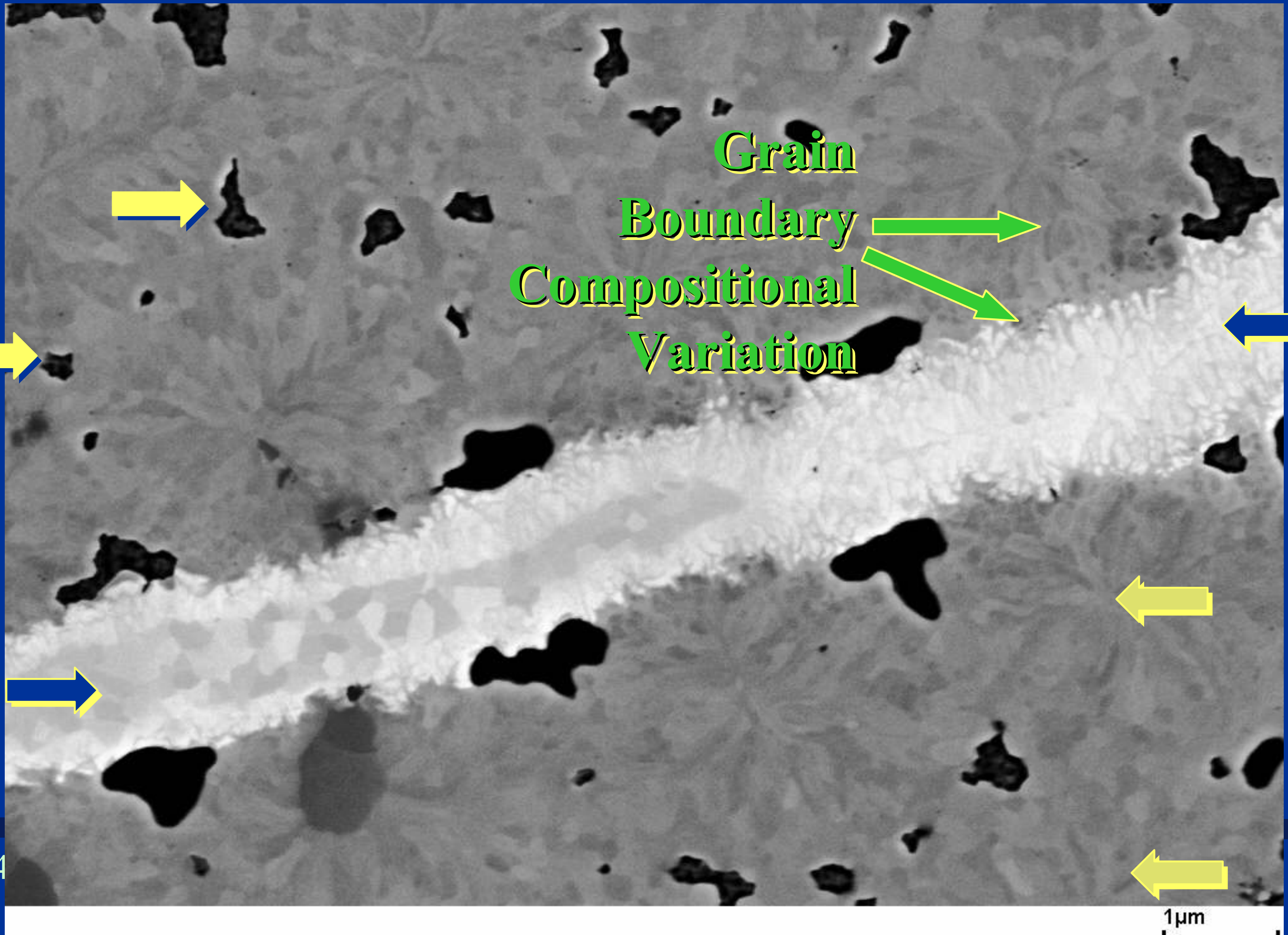
  --add more fins to further subdivide Nb_3Sn

  --use as subelement for restack

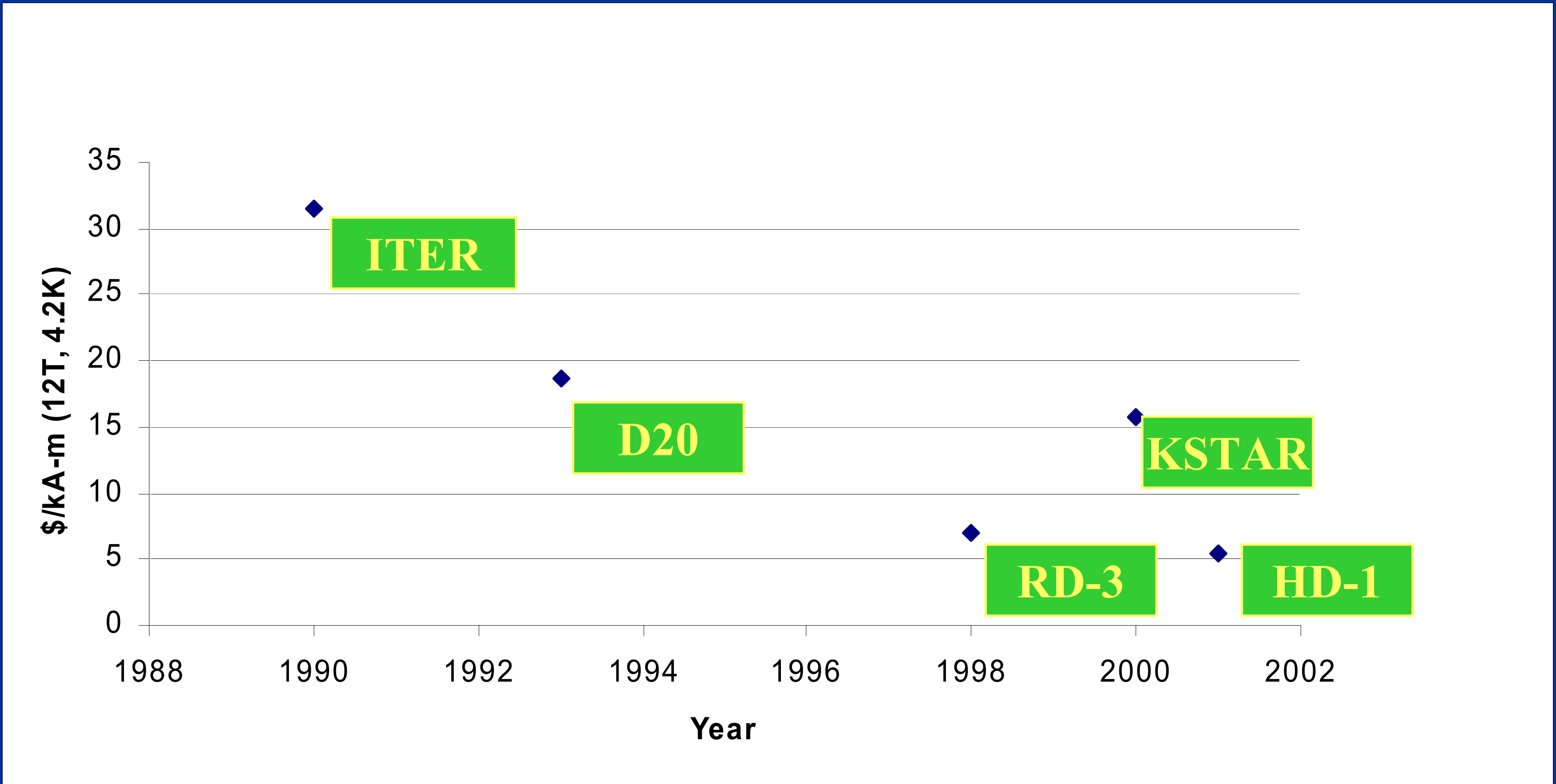
- Should be applicable to many fabrication processes



Features of Fin Reaction – Electron Backscatter--data from P.Lee



Cost/performance improvements for HEP and Fusion-type Nb_3Sn wires



Further improvements must come from process scale-up. New ITER?

Conductor Costs for High Field Accelerator Magnets (12T, 4.2K)

- Nb_3Sn (OST RRP)--$5.75/kA-m
- Nb_3Sn (MJR)--$7.74/kA-m
- Nb_3Sn (PIT)--$28.94/kA-m
- Bi-2212 (PIT)--$57.00/kA-m

These prices are for small, custom-processed orders

U.S. DOE funding for conductor R&D

- $500 K/year for HEP base program (starting in 2000 and continuing in FY05)
  - Nb_3Sn R&D at OST and OKAS
- $2000K--2500K/year for HEP and OFE SBIR program
  - Nb_3Sn R&D at Supercon, Supergenics, Hypertech, Accelerator Technology Corp, Innovare, Superconducting Systems, Alabama Cryogenic
  - Nb3Al R&D at Hypertech, Global R&D, Innovare
  - Insulation R&D at CTD and MCT

Cost reduction tasks for HEP R&D program include

- Billet scale-up

  -- OST HER

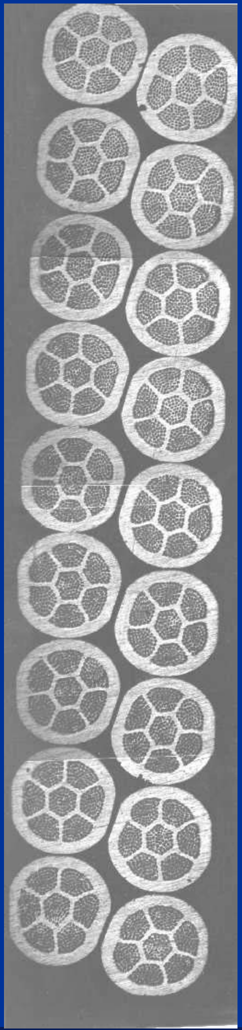
  -- OKAS restack rod

- Improved raw materials
  - Replacement for Sn-Ti alloy
  - Ductile diffusion barriers

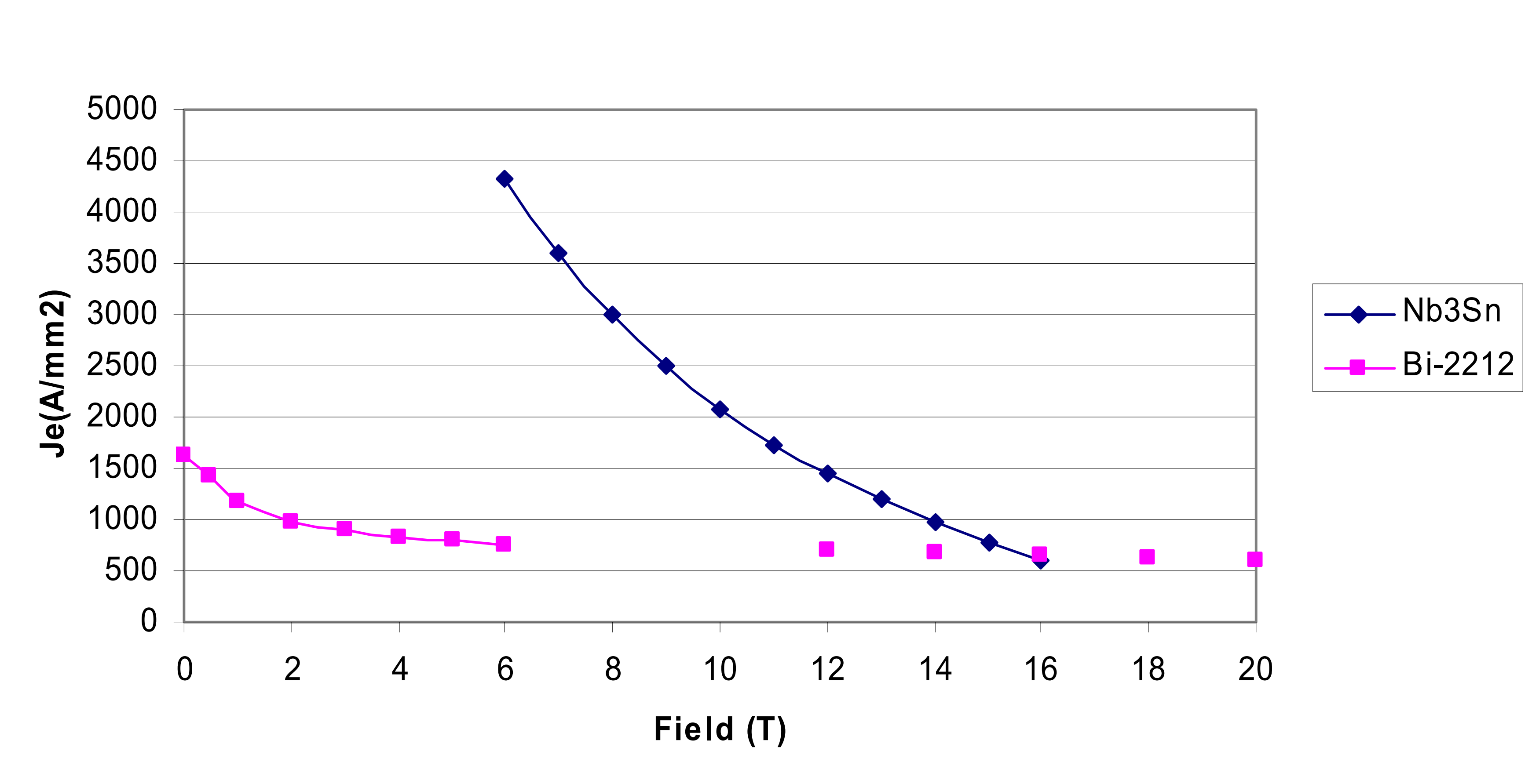
  - Note: We rely on the ITER program to provide the large volume production capability for Nb_3Sn

Bi-2212 round wire shows promise for accelerator magnets

- Jc(12T, 4.2K, non-silver) > 2000 A/mm^2 in new material (Showa, OST)
- Long lengths(> 1500 m) are being produced
- New result: 30 strand cable; Ic = 6.8 kA at 6 T
- React/wind (BNL) and Wind/react (LBNL) coils will be evaluated



Comparison of Je for Nb_3Sn and Bi-2212



Steady progress continues toward program coals

- Long Range Goals
- $J_c = 3000\ A/mm^2$
- $D_{eff} = 40$ microns or less
- Piece length > 10,000 m
- Heat treatment < 400 hr
- Cost: < $1.50/kA-m(12 T)

- Progress
- $J_c = 3000\ A/mm^2$ (FY03)
- Proof of principle shown; practical demos in progress
- 250-1500m for both MJR and RRP internal Sn processes
- 150 hr
- $ 5.50/kA-m (RRP)