Improved Current Density in 2G HTS Conductors Using Thin Hastelloy® C276 Substrates

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ABSTRACT

SuperPower manufactures high performance 2G HTS wire with exceptional in field performance and high engineering critical current densities. Current production material uses 50 or 100 \( \mu \text{m} \) thick Hastelloy® C276 as the substrate on which the buffer stack, HTS film and stabilizer layers are deposited. The C276 substrate forms the “backbone” of the conductor and provides the mechanical strength to the system. In applications [high current cables, high field magnets] where high engineering current density is critical, a reduction in cross-section of the conductor is warranted. In this presentation, we report on efforts in developing thinner substrate conductors and the resulting performance characteristics. Both electrical and mechanical data on 2G HTS conductors with thinner substrates ranging from 30 – 38 \( \mu \text{m} \) is presented.

The use of the thinner substrate can result in up to a 35% increase in conductor current density with standard 40 \( \mu \text{m} \) thick copper stabilizer. The resulting thinner conductor can also enable more compact, higher current density cabled configurations that can be used in high current applications such as windings for accelerator magnets. Coupled with ongoing advances in pinning at target operating conditions, these thinner conductors offer the magnet designer significantly higher (up to 2.5X) current densities and bring 2G HTS into the operating regime required for broad adoption in future magnet systems. We will also discuss some of the issues addressed in modifying the production line to adapt to these newer architectures.
SuperPower’s (RE)BCO superconductor with artificial pinning structure provides a solution for demanding applications

- Hastelloy® C276 substrate
  - high strength
  - high resistance
  - non-magnetic
- Buffer layers with IBAD-MgO
  - Diffusion barrier to metal substrate
  - Ideal lattice matching from substrate through REBCO
- MOCVD grown RRBCO layer with BZO nanorods
  - Flux pinning sites for high in-field $I_c$
- Silver and copper stabilization
Thinner substrates offer improved current density while still providing strong mechanical support

- Current 2G HTS production material based on either 50 or 100μm Hastelloy® C276 substrate
  - For standard Cu thickness of 40μm total, the conductor thickness of current production 2G HTS conductor is ~ 0.095mm.

- Thinner Hastelloy® C276 of 25, 30 and 38μm thicknesses are being evaluated
  - For standard Cu thickness of 40μm total on a 30μm Hastelloy® C276 substrate, conductor thickness is reduced to ~75μm
  - This implies a 27% increase in current density

Baseline is 40 micron thick copper stabilizer
Thinner substrates enable improved current density cable development

Status:
• 38 μm thick substrate material has been processed through slitting with good Ic performance (~300A/12mm)
• 25 μm and 30 μm material is in process development ~100m of each available for trials
• 30 μm material selected for next product offering
  – Large quantity ordered from supplier

Markets:
• Immediate impact on high field magnets due to increased Je (~30%)
• Large demand for high Je CORC cables
  • Higher Je due to thinner cross section
  • More flexibility enables tighter, smaller diameter cables with higher Je
• Enhanced pinning Je increase (2x) coupled with improved Je from thinner substrate (1.3x) can result in more than 2.5x improvement over current production material in key magnet markets (high field, HEP, motors/generators)
Microstructure of production MOCVD HTS wires with standard 7.5% Zr doping

5 nm sized, few hundred nanometer long BZO nanocolumns with ~ 35 nm spacing created during in situ MOCVD process with 7.5% Zr
Enhanced pinning through added Zr or other pinning structures

- >68% improvement demonstrated in wire performance at wind generator operating condition of 30 K, 2.5 T
- Increase in Ic to over 1500A demonstrated (summer 2014)
- Structured, well-timed process for transfer of these advancements into production coupled with thin substrate development
Cell 1 – Electropolishing

- Electropolishing is used to remove defects on the Hastelloy® C276 tape surface prior to buffer deposition
- Standard run conditions modified to adjust tension control
- Examples of EP run data on thinner substrate materials at given run speed and polishing current
Cell 1 – Buffer deposition

- Buffer deposition serves multiple purposes
  - Diffusion barrier
  - Critical texture layer
  - Lattice matching
- Standard buffer deposition used with adjustment of tape tensioning

Texture of long 38 µm tape (M3-1113-16)

PB1478-2/SMG692/PB1472-2/EPR793.2

Avg. Texture = 6.8deg.
Cell 1 - Buffer deposition

- Other texture development data on samples of thinner substrate material
Cell 2 – 2G HTS (RE)BCO film deposition by MOCVD

- Deposition of the 2G HTS (RE)BCO film by MOCVD on thinner substrates involved studies on the effects of
  - Line tension
  - Line speed and tape heating
  - Good $I_c$ developed over significant piece lengths

\[
\begin{align*}
\text{Avg. } I_c &= 375A \\
\text{Stdev } I_c &= 7.5A
\end{align*}
\]
Cell 3 – Ag cap layer deposition, slitting

- Post MOCVD Ag cap layer deposition by cylindrical magnetron sputtering
- Tension and line speed adjusted as needed for thinner substrates to mitigate overheating during Ag deposition
- Standard ~2μm thick Ag depositions
- Slitting the thinner (38 μm) substrate tapes required tooling adjustments
  - Initial (standard) tooling setup resulted in low yield and tearing
  - Adjusted tooling (tighter tolerances) resulted in good yield and clean slits
M3-1113-16 (38 μm) slit in 4-4-4 mm

MOCVD

Avg. 375A, Stdev 7.5A

Slit

Avg. 151A, Stdev 3.7A

FS

Avg. 162A, Stdev 3.0A

MS

Avg. 141A, Stdev 6.1A

BS

107m

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Mechanical properties of various thickness substrates comparable

- Tensile tests of tapes as received from vendors prior to electropolishing.
Tensile testing of 38 µm substrate tapes compared with 50 µm during processing

- Compared with that of 50 µm substrate
  - Similar small elongation before LMO
  - Yield strength not lower at After MOCVD and After Ag
  - Yield strength expected to be lower After Cu (given same Cu thickness)
Summary

- SuperPower has targeted 30 μm thick Hastelloy C276® substrates for production
- Thinner substrate 2G HTS (RE)BCO conductors offer improved current density for magnet applications
- The flexibility of the thinner 2G HTS (RE)BCO conductors will enable higher current density cables for multiple applications
- The ability to process thinner substrate 2G HTS (RE)BCO conductors has been demonstrated and is being scaled up to production levels
- The enhanced Jc of the thinner tapes coupled with improvements in flux pinning will lead to conductor with >2x improvements in performance being available in the near future