Enhanced Second Generation (2G) High Temperature Superconducting (HTS) Wire for Electric Motor Applications

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American Superconductor Corporation
Brookhaven Technology Grup
Brookhaven National Laboratory
University of Buffalo
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Overview

Project Title: Enhanced Second Generation (2G) High Temperature Superconducting (HTS) Wire for Electric Motor Applications

Timeline:

Project Start Date: 06/01/2017

Budget Period 1 End Date[1]: 05/31/2019

Project End Date: 05/31/2022

Barriers and Challenges:

- The Cost/Performance ($/kA-m) of today's 2G HTS wire does not allow the development of economical high-efficiency HTS-based machines.
- Innovative concepts and manufacturing technologies are needed to improve the wire Cost/Performance metric.

AMO MYPP Connection:

- Project is part of the Next Generation Electric Machines 2 portfolio which supports AMO's MYPP target 3.4: Increase the efficiency of targeted electric machines by 2-3% (a reduction in losses of 28 - 75%)

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$3,751,183	$1,125,740	$4,876,923	23%
Approved Budget (BP-1)	$1,474,976	$422,309	$1,897,285	22%
Costs as of 3/31/19	$1,200,709	$360,275	$1,560,985	23%

Project Team and Roles:

- American Superconductor Corporation (AMSC)
  - Exfoliation, irradiation and thick film development; R2R processing; coil fabrication
- Brookhaven Technology Group (BTG)
  - Co-development of key exfoliation technologies and processing
- Brookhaven National Laboratory (BNL)
  - Ion irradiation development and characterization
- University of Buffalo (UB)
  - Micro-structural analysis and characterization
- All partners are contributing a 20% cost share

(1) – BP1 was extended a year to accommodate the re-location of AMSC's manufacturing and R&D facility

Project Objective(s)

The Challenge:

- Performance of today's "state-of-the-art" HTS wire is suppressed in the presence of magnetic fields, limiting its usefulness in *high-efficiency machine applications* targeted for around 65K operation
  - Current solutions (lower operation temperature, thick HTS layers, complex pinning structures, increased quantities of wire) add to system cost and decrease manufacturing yield
  - The development of cost competitive HTS machines that achieve a 2-3% increase in efficiency (a reduction in loses of 28-75%) requires improvement of the HTS wire in order to reduce the system cost and enable operation near LN_2 temperature

Project Objective:

- A 7-fold increase in critical current (I_c) and a 50% reduction in cost ($/kA-m) of 2G HTS wire designed for commercial electric machine applications operating at ~65K in magnetic fields of ~1.5T

Project Innovations:

- A novel, double-sided HTS wire architecture with a uniformly distributed array of pinning centers
- Innovative manufacturing and cost reduction technologies

Program Challenges:

- Development of a high-yield Reel-to-Reel exfoliation process
- Development of a low-cost Reel-to-Reel ion irradiation process
- Integration into current manufacturing line

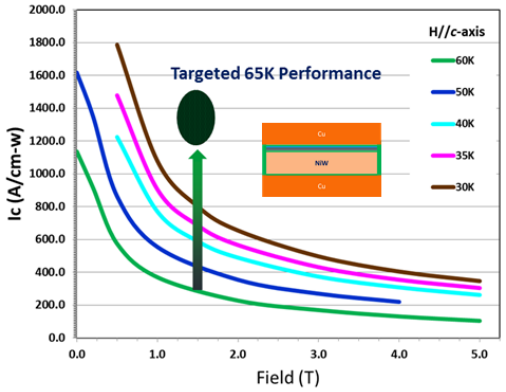
Relevance to US Energy Use and Efficiency:

- This technology also supports the development of high-efficiency motors and generators operating at 30 – 50K, military applications (30 – 50K), power transmission/distribution (77K) and fusion (20K)
- Aids the transition of DOE supported technologies into US manufacturing capabilities
- Strengthens and advances a US-based technology and workforce

Technical Innovation

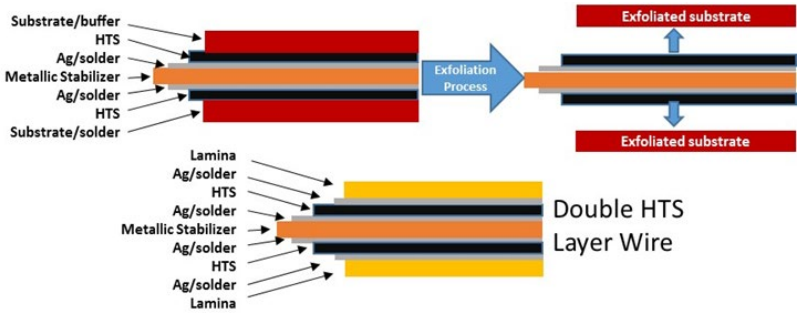
Today's Technology

- The critical current (I_c) in today's commercial 2G HTS wire is severely suppressed in magnetic fields at targeted operating temperatures

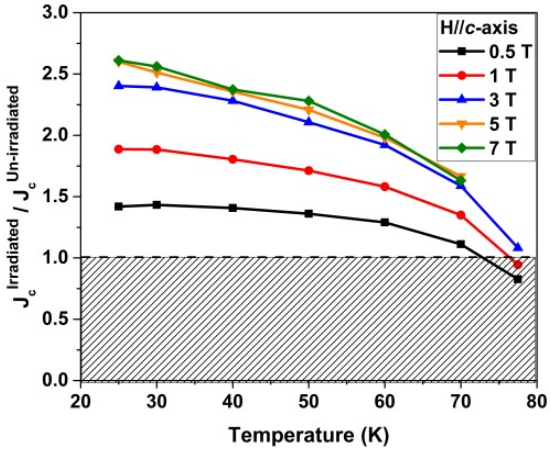


Proposed Technical Innovation:

- I_c can be doubled by an innovative 2-sided wire architecture



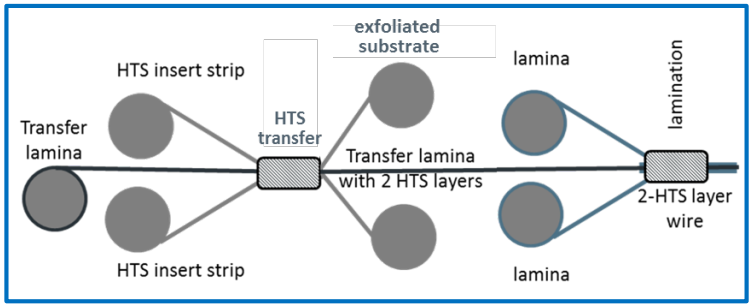
- Suppression of I_c can be reduced by introduction of uniformly distributed pinning defects produced by ion irradiation

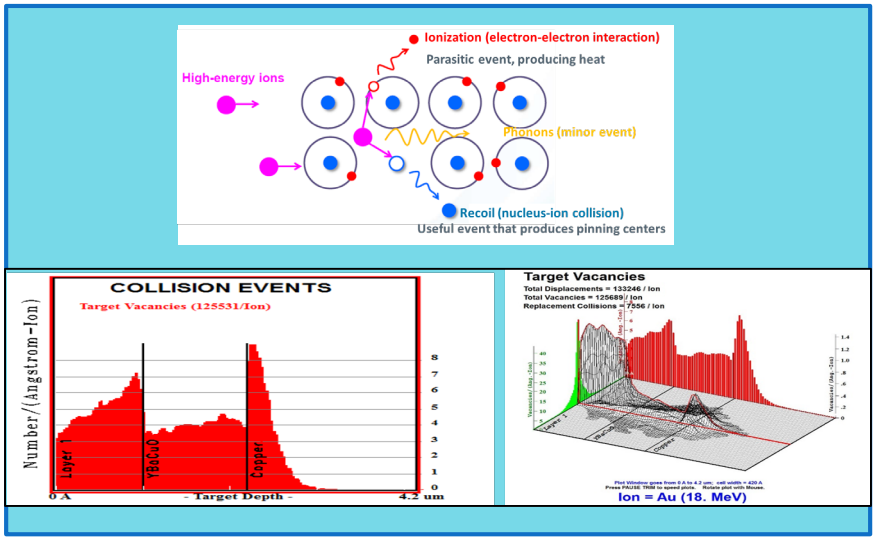


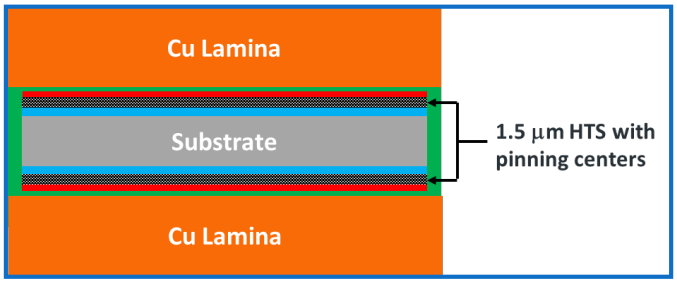
- ***Technologies easily integrated into existing manufacturing line***
- ***Substantial increase in wire I_c and J_e***
- ***Reduced wire cost ($/kA-m)***

Technical Approach – The Innovation

- 2-sided HTS wire architecture
  - Innovative exfoliation process for transferring HTS films to both sides of a non-magnetic substrate (high J_e/reduced materials/re-useable template)
- Uniform pinning sites optimized for enhanced performance in magnetic fields
  - Reel-to-reel ion irradiation (intrinsic uniformity)
  - Ion, dosage and post anneal optimized for temperature and fields of specific application
- Higher I_c
  - Increased HTS layer thickness
- Technology Integration
  - Integration of 3 key innovations into a high performance, reduced-cost HTS wire







Technical Approach – The Team

AMSC:

Leader in development of 2G HTS wire and commercial /military applications

- State-of-the-art 2G wire technology developed with focus on cost, reproducibility and yield.
- HTS wire used in both commercial and military cable and coil applications.
- Leader in development of near-term commercial markets.
- Integration of technologies and development of high-yield, reproducible manufacturing processes

The team, lead by AMSC, has years of experience solving challenging scientific and engineering issues

Brookhaven National Laboratory - Qiang Li (Partner)

- Development of ion irradiation process and optimization for target conditions
- Characterization of pinning enhancement
- Facility for reel-to-reel pilot manufacturing

Brookhaven Technology Group – Vyacheslav Solovyov (Partner)

- Development of exfoliation technology and supporting processes (slitting, rapid, low-temperature annealing, etc.)
- Characterization of double-sided conductor

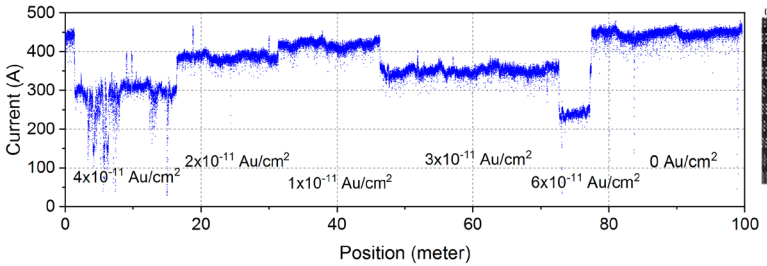
University of Buffalo - Amit Goyal (Partner)

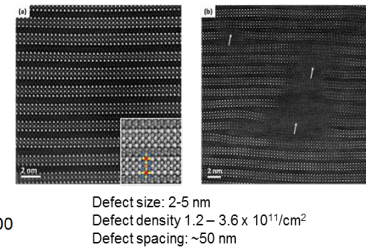
- Microstructural characterization of ion induced pinning centers and HTS layers.

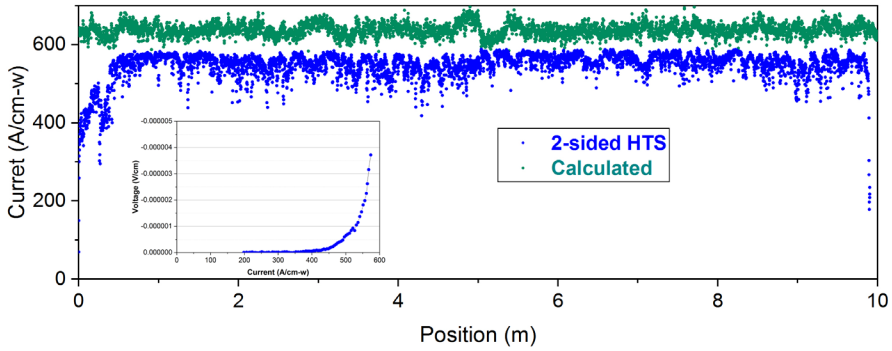
Results and Accomplishments

Project Status / Accomplishments (BP-1)

- Critical Milestones
  - ✓ Demonstrated I_c enhancement by ion irradiation for targeted temperature/field conditions
  - ✓ Fabricated double-sided HTS tape in R2R process with > 90% I_c retention
  - ✓ Demonstrated increased HTS layer thickness
  - ✓ Integrated *Ion Irradiation* and *Exfoliation* technologies

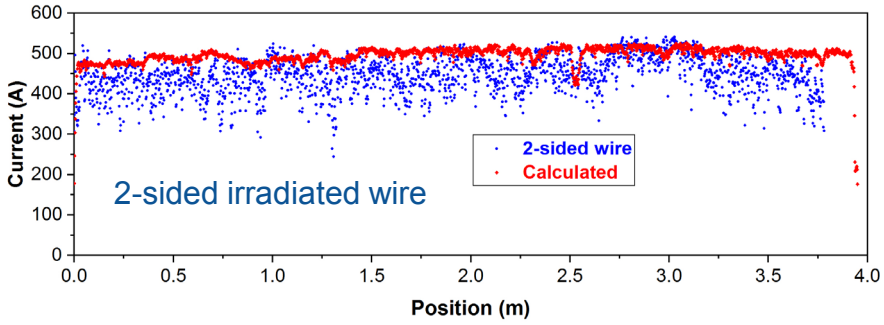






Future Work BP-2/BP-3

- Validate mechanical properties of 2-layer architecture
- Optimize Irradiation for 65K.1,5T applications
- Integration of individual technologies (thicker HTS/2-sided HTS/irradiation)
- Manufacture long length wire
- Validate capability and yield of manufacturing process
- Validate wire performance in test coil



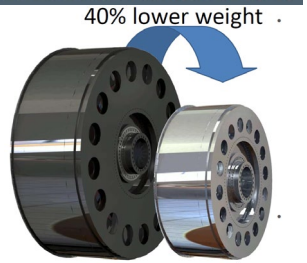
Transition

- **Commercialization Approach**
  - Provide system based solutions to end users
  - Collaboration with OEM's to offer system based solutions
- **Technology Sustainment**
  - Identify applications and establish price sensitivity (wire and system)
  - Target applications based on market size and price sensitivity
  - Increased manufacturing capacity will reduce wire cost and open new markets
  - Target additional markets

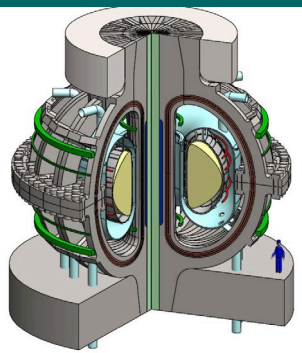
Degaussing/Ship Protection

Cables

Wind Turbines/Generators



Fusion Reactors



Motors