Project Title: Metal(Cu,Al)/CNT Composite Wires for Energy Efficient Motors

Contract Number: DE-EE0007864

University of central Florida
Project Period: 05/01/2017-04/30/2020

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DE-EE0007864

Overview

Timeline

- Project Started May 2017
- Projected End date June 2020
- Project 33% complete

Budget

	FY 17 Costs	FY 18 Costs	FY 19 Costs	Total Planned Funding (FY 20-Project End Date)
DOE Funded	_	$361,914	$310,222	$1.0M
Project Cost Share	_	$177,739	$152,400	$367,440

Barriers

- The Key barriers were to develop the metallic (Cu,Al)/CNT composites with stable increased thermal and electrical properties compared to the pure metals.
- For the budget period I the key barriers were to densify the metallic composites with powder metallurgy processes.

Partners

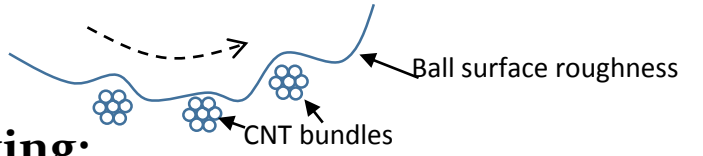
- The university of Central Florida is developing the technology under a team consists of multiple groups
- The technology will transfer to industrial partners once it is mature.

Project Objectives

- The resistance of conductors not only wastes significant amount of electricity but also limits the power density of electric machines. The goal of this project aims to significantly increase the thermal and electrical conductivities of metal wires used in motors through integration of carbon nanotubes with metals (Cu, Al).
- Motors in manufacturing sector consumes significant amount of energy. If the energy efficiency can be increased by 1% for these motors the energy saving would be $1B/year.
- The objectives of the project are to increase the thermal and/or electrical conductivity of Cu and Al by 50% that the new wires can reduce the energy consumption by 33%. This project aligns well with DOE's goal to reduce the energy consumption by 50% in 10 years.
- The challenge is high with difficulties ln dealing with CNTs

Technical Innovation-CNT Dispersion

- **Ball milling:** bundled CNT particles are added into ball milling machine together with metal powders that extensive ball milling is executed to disperse CNTs. However, due to the large differences in contact, ball milling can not disperse CNTs well, and also may damages CNTs. The resultant conductivity results are lower than the pure metals.

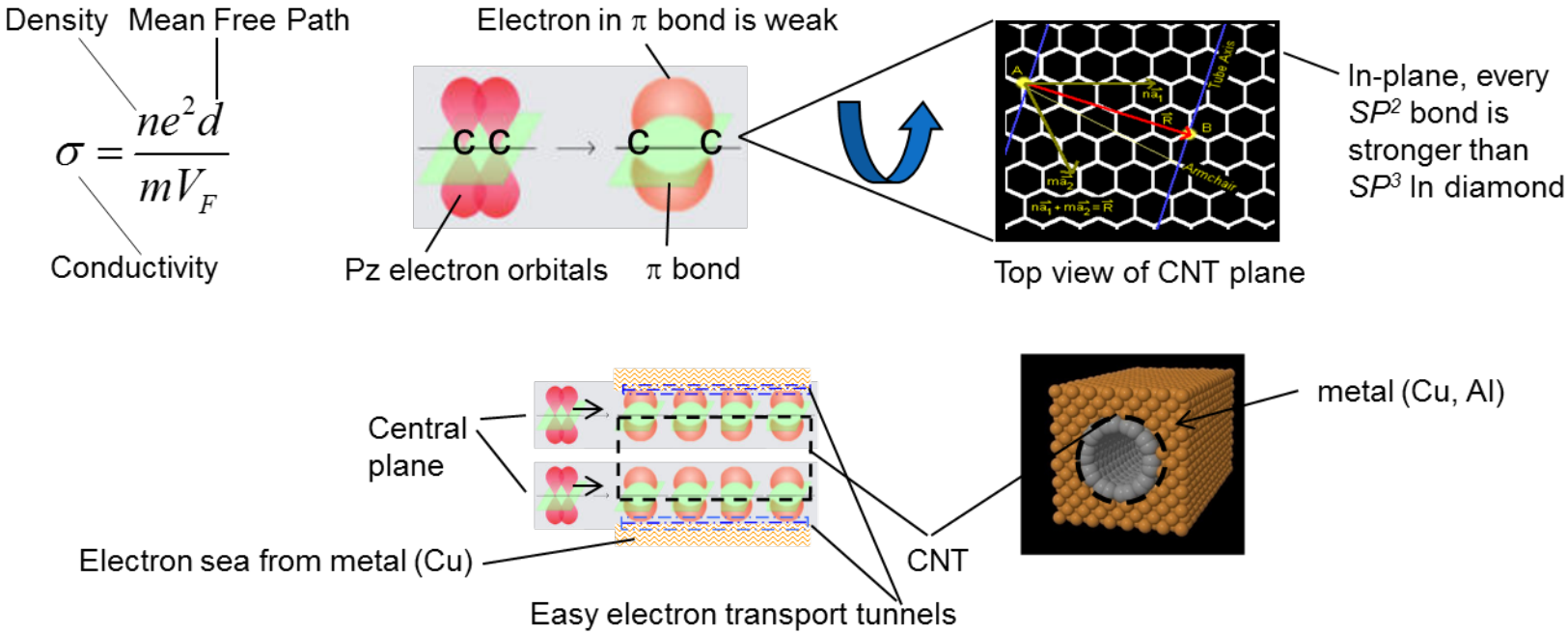


Sketch of ball milling process

- **Molecular mixing:**
  - Molecular mixing relies on first reducing coper oxide onto CNTs from the electrolyte solution and then reducing the copper oxide to copper.
  - The purity of copper after reduction is not guaranteed, therefore although the mechanical strength can be increased but no report can be found on the conductivity.
- **Hot extrusion:**
  - Molten metal mixed with CNTs and high pressure is used to extrude the mixture to align CNTs within the metal. 2X increased in conductivity was reported but no details available about the dispersion of CNTs in the metal after extrusion.
- **Direct casting:**
  - CNT bundles in the form of powders were directly added into a molten metal and mixed with various methods, including the ultrasonic as well as the mechanical mixing. No increased conductivity results can be identified.

Technical Innovation

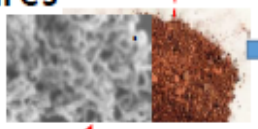
Core Science in Ultraconductive Nanocarbon Metal Composite

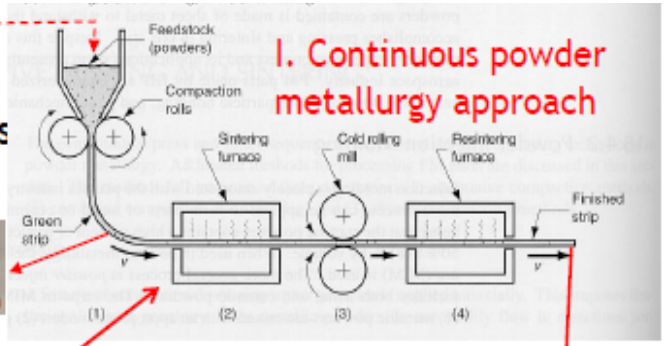


- Tight binding of SP^2 bond produces mean free path up to 30μm for carbon nanotube, or about 700 times greater than copper (40nm), but with lower electron density.
- The CNT surface can be used as easy tunnels for electrons and large free electron density can be provided by metal (copper/Al) via electron redistribution.
- Good CNT dispersion in metal is the key, since inter CNTs produces large resistance.

Technical Approach

- 1.optimization in material design
- 2. Treatment of CNTs and fabrication of metal/CNT powders
- 3. Fabrication of metal/CNT rods
- 4. Fabrication of metal/CNT wires
- 5. Characterization





I. Continuous powder metallurgy approach

Quantum Wise for Material design

1a. Determine CNTs and suppliers

2. Treatment of CNTs

1b. Fabrication of CNTs if necessary

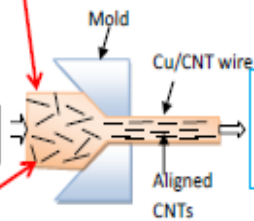
3. Fabrication of metal/CNT powders

4. Post treatment of metal/CNT powders

5. Continuous powder metallurgy

7. metal/CNT rods for wires

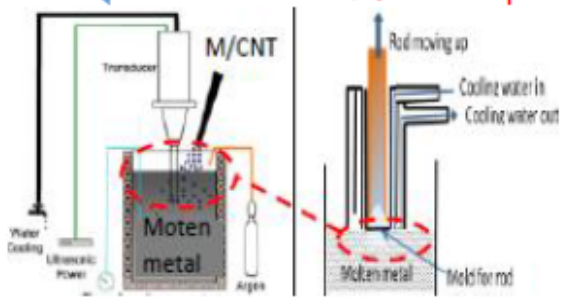
5. Upward Continuous casting



g. 11 Sketch of Cu/CNT wire by cold rming and CNT alignment

Final wires for characterization

II. Upward continuous casting



Advantages

- Guided by material design
- Complete dispersion of CNTs
- Good interfacial bonding
- Concept proven by results
- Can be scaled up for applications
- Cost effective

Technical Approach

- Design microstructure of metal/CNT interaction by quantum mechanics calculations
- Dispersion of CNTs in electrolyte assisted with sonication
- Encapsulation of CNTs with metals to retain the dispersion and obtain the desired interfacial bonding
- Fabrication of metal/CNT composites with powder metallurgy process (Year one)
- Metal/CNT composites with casting process (Year two)
- Fabrication of metal/CNT wires (Year three)
- Validation by extensive characterization studies
- CNT addition is less than 1%, the added cost is <4%
- Dr. Quanfang Chen's group is focusing on material design and fabrication as well as characterization.
- Dr. Yuanli Bai's group is focusing on the compaction and deformation associated with material processing as well as the wire fabrication processes.

Results and Accomplishments

The main focus of Year 1 has been on powder metallurgy process as planned. Results so far are listed in the following:

Summary of Period I results against milestones (10% > pure metals)

	Targeted Thermal Conductivity	Actual Results on Thermal Conductivity	Targeted Electrical Conductivity	Actual Results on electrical conductivity
Metal (Al,Cu) CNT Composites	10% better than pure Al	85% better than pure metal (Al, Cu)	10% better than pure Al	12.5% to 26% better than pure metal

The main focus of Year 2 (budget period II) will be on casting process as planned, as there are some issues associated with the powder metallurgy process. The targeted milestones for the budget period II will be 30% increase in thermal and electrical conductivities.

The targeted final results by the end of budget period III will be 50% increase in thermal and/or electrical conductivities than pure metal, and the wires' energy consumption will be 33% less than the pure metal wires.

Transition (beyond DOE assistance)

- Motors in manufacturing consume large portion of electricity and the resistive heating of windings is accounted.
- Further development of better wires suitable for motor windings will be carried out by teaming up with industrial partners.
- The partner for motor design with the metal/CNT composite to obtain desired wire shape and size will be the Advanced Motor Technologies Inc., a Florida high tech company.
- The partner for metal/CNT wire fabrication will be the California Fine Wires. Both the Advanced Motor Technologies and the California Fine Wires were involved in the proposal stage.

Questions?

Thank you very much for your attention!