Covetics: High-Performance Electrical and Thermal Conductors

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Overview

Timeline

- Project Start date: Aug. 2014
- Projected End date: Sept. 2018*
- Project 80% complete

*Partnering with NETL, a proposal for next phase has been submitted

Barriers

- Process reproducibility
- Nanocarbon analysis
- Nature of bonding between nanocarbon and matrix metal

Budget

	FY 16 Costs	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 14-Project End Date)
DOE Funded	$1.6M	$1.9M	$1.9M	$6.06M
Project Cost Share	0	0	0	Pre-competitive project

Partners

- NETL has considerable expertise & facilities for metal-melting and metal-working/fabrication. Furnaces with multiple size scales & functionalities allow for increased efficiency and rapid scale-up.
- University of Maryland provides key support in the characterization of covetic samples.

The project builds on capabilities at the National Laboratories to advance the development of covetic materials.

Project Objectives

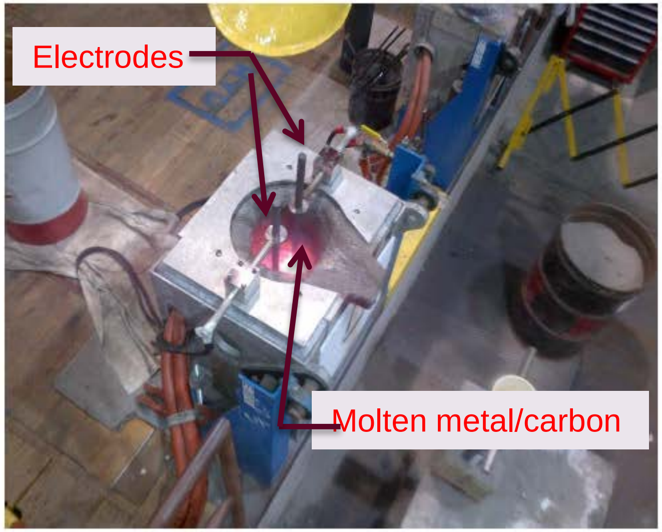
- **Improve** the processing of covetics to consistently produce materials with improved properties. The ultimate goal is to advance the technology for early adoption by U.S. industry.
- **Leverage** state-of-the-art National Lab resources to understand the physics behind novel nanocarbon structure and synthesis of covetic materials.
- **Work** with industry: identify and explore strategic applications.
- **Leverage** covetic technology to advance energy productivity across multiple U.S. manufacturing sectors.
- ***De-risk*** covetics for private investment: Lack of fundamental knowledge makes the technology look speculative and high risk.
- **Develop** new IP to protect U.S. interests.
- **Align** with AMO mission: strategically support high-impact materials processes that can provide quad-level energy benefits.
- **Expand** new capabilities at National Labs to support future development.

Transition AMO-supported innovative technology into U.S. manufacturing capabilities.

Technical Innovation – how is it done today?

Fabrication of Covetic Materials – Nano-carbon Infusion

- Melt the metal, stir in carbon powder, apply electrical current
- Works with a range of metals (Cu, Fe, Al, Au, Ag, etc.)
- Conventional furnaces, electrodes, electromagnetic or gas stirring
- Infrastructure readily available for high-throughput processing



- *Lack of process knowledge*
- *Considerable variation in the properties among samples processed at various laboratories*

Covetics is a new science – much is unknown

Technical Innovation

- **Team and Facilities: ANL, NETL, and University of Maryland (UMD)**
  - Tapping into a wealth of diverse expertise not available to the small business inventors: world-class metallurgists, microscopists, analytical chemists, spectroscopists
  - Atomic resolution and advanced microscopes and beamlines to characterize structure
  - Advanced analytical instruments to measure carbon
  - Melting and rolling facilities at gram- and kg-scale.
- **Controlled conditions, rigorous scientific approach**
  - Industrial process couldn't control all variables; lab system allowed new levels of control
  - Ability to analyze industrial data, combined with lab data and control sample information
  - Consistent sample preparation (which turned out to be critical)
- **Industrial partners** and an end user are already on-board, waiting for knowledge creation to produce and deploy large batches of covetics.

The unique characterization facilities at the DOE Labs provide an ideal opportunity to create fundamental knowledge and understanding of the covetic conversion needed for industry to scale-up the process for commercialization.

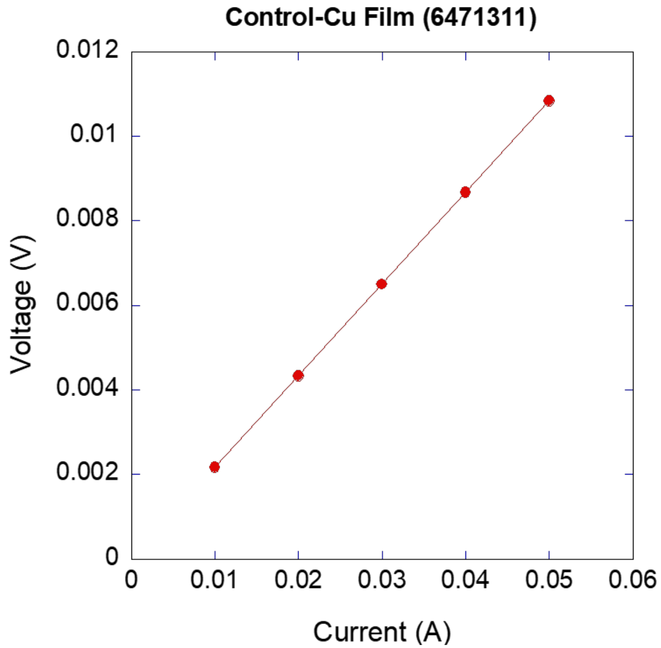
Technical Approach

- Develop in-house conversion systems: gram-scale at ANL.
- Produce covetic materials under controlled conditions (Temp., pO_2, current density, reaction time, etc.) to understand and optimize the conversion process.
- Characterize the microstructure and analyze nanocarbon (samples made by ANL, UMD, NETL, GDC Industries, others) to study the effectiveness of the conversion process; ANL is the "Clearing House."
- Measure thermal/electrical conductivity, melting point, etc. to validate conversions compared to the parent metal/alloys.
- Work with analytical chemists, spectroscopists on carbon analysis.
- Tight feedback loop between ANL and NETL on both processing techniques and results of experiments
- Work with industrial partners to validate measurements at their labs, and understand the requirements for new applications.

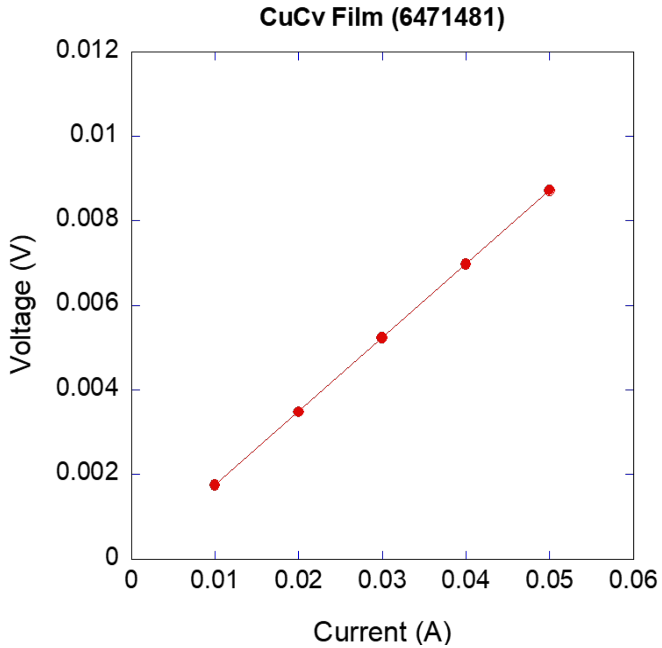
Risks have been lowered: ANL/NETL have now made covetics with improved properties

Results and Accomplishments

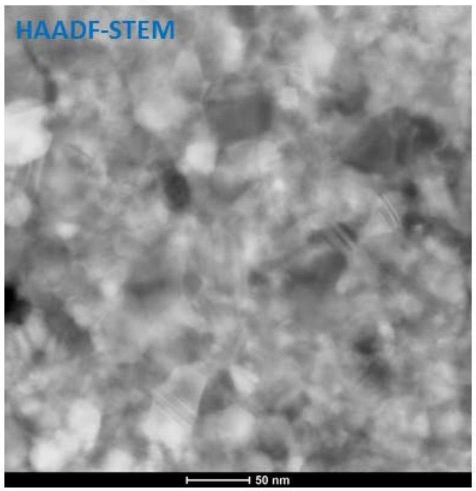
I – V Curves & Electrical Conductivity of the Control-Cu & CuCv films



Sheet resistance = 982.2 mΩ/□
Conductivity = 108.8% IACS



Sheet resistance = 782.7 mΩ/□
Conductivity = 136.6% IACS



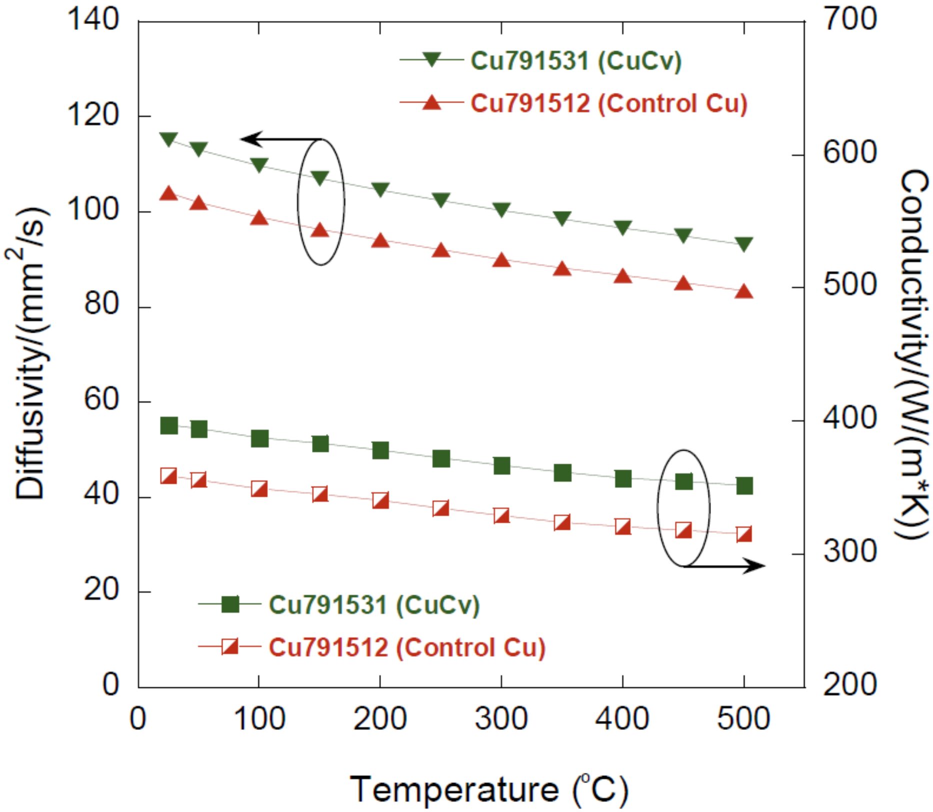
HAADF-STEM image of a CuCv film (carbon nano-particles are 10-50 nm in size)

Bulk conductivity of the Cu-Cv films calculated from the measured sheet resistance ~128-137% IACS*

IACS: International Annealed Copper Standard; 58 MS/m is 100% IACS

Results and Accomplishments (~70 kg batch samples)

Thermal Conductivity of bulk CuCv & Control-Cu (ASTM E 1461; Flash Technique)



Electrical Conductivity of bulk CuCv & Control-Cu samples

- **Control-Cu (15-A127) = 92% IACS**
- **Cu-Cv (16-A106) = 99.2% IACS**

Measured ≈13% higher thermal conductivity & ≈8% higher electrical conductivity in bulk CuCv compared to Control-Cu

Work to be completed:

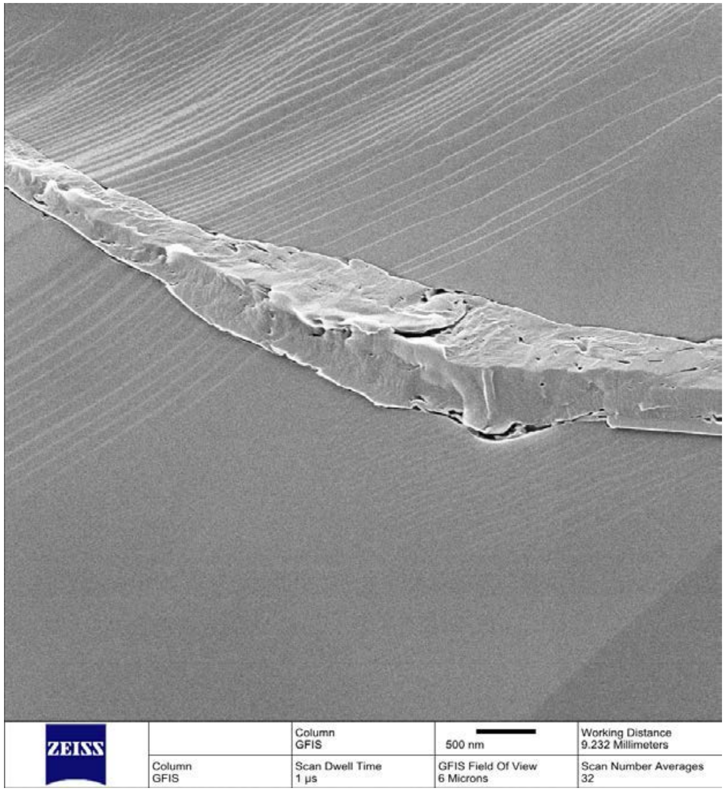
- Eliminate/minimize porosity by hot working as-cast ingots
- Improve melt-processing to consistently produce covetics

Transition (beyond DOE assistance)

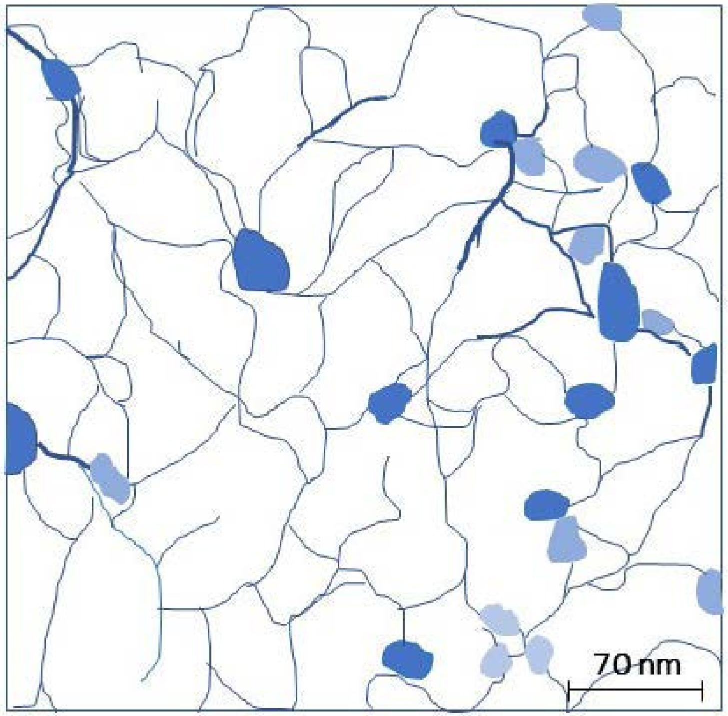
- Developing fundamental knowledge and understanding of the covetic conversion process needed by industry to commercialize the technology.
- This is pre-competitive research. Results are patented, published and presented.
- Two national laboratories and a university are collaborating to create knowledge from early-stage research.
- Covetics hold commercial interest because the process is scalable to tonnage quantities with widespread implications for energy savings in thousands of potential applications from electrical wires to solar cells and batteries.
- The infrastructure is readily available for high-throughput processing, which reduces the risk of developing a cost-effective process for manufacturing covetic materials by U.S. industries.
- Industrial partners to produce covetics and an end user are already on-board and waiting for knowledge creation.
- To protect IP for U.S manufacturers, two patent applications on processing of covetics have been filed.

The project is well-aligned with early-stage research needs.

Questions?



Conversion of carbon into graphene



Network of nanocarbon ribbons