High-Performance Electrical and Thermal Conductors (“Covetics”)

CPS Agreement Number: 28418
Argonne National Laboratory
Oct. 2018 – Sept. 2021

U. (Balu) Balachandran
Argonne National Laboratory

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Overview

Project Title: High-Performance Electrical and Thermal Conductors (“Covetics”)

Timeline:

- Project Start date: Oct. 2018
- Project End date: Sept. 2021
- Partnered with NETL and responded to AMO FY19 Lab Call

Project Budget & Costs:

Budget	DOE Share	Cost Share	Total
Total Planned Project Budget	\$6300K	\$0	\$6300K
FY18 Amount Received	\$2100K	\$0	\$2100K
Total Planned FY19 Amount	\$4200K	\$0	\$4200K
Costs as of 3/31/19	\$1152K	\$0	\$1152K

AMO MYPP Connection:

- 3.1 Advanced Manufacturing Technology Areas
- 3.1.5 Advanced Materials Manufacturing

Barriers & Challenges:

- Process reproducibility
- Product uniformity
- Nanocarbon analysis
- Knowledge of processing conditions

Project Team & Roles:

- **Lead and its Role:** ANL: Processing at ~200-gm-scale; Analytical Chemistry, Microstructural examination, and characterization of Conductivity; Project Management.
- **Team Members and their Roles:**
  - NETL: Processing up to multi-kg-scale; metal working/fabrication
  - U. Texas: Computational simulation
  - U. Maryland: Spectroscopic characterization
  - Air Force Lab (AFL): Conductive-AFM
  - GDC Industries: Aluminum covetics

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

Project Objectives

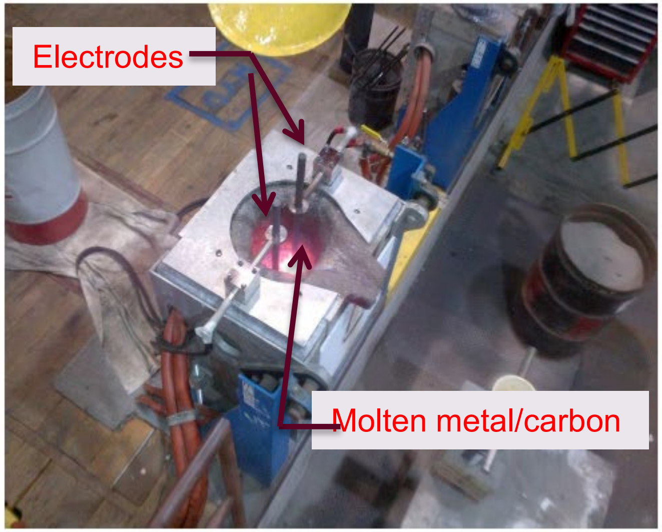
- **Improve** the processing of covetics to consistently produce materials with improved properties. The ultimate goal is to advance the technology for early adoption by U.S. industry.
- **Leverage** state-of-the-art National Lab resources to understand the physics behind novel nanocarbon structure and 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.

Project aligns with AMO's MYPP Target 5.2: Develop scalable manufacturing processes for a range of materials with 50% or greater improvement in thermal or electrical conductivity.

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



Covetics is a new science – much is unknown

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

Technical Innovation
What's new in our approach?

- **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 over all process parameters; ability to analyze data
  - Consistent sample preparation (which turned out to be critical)
- **Scalable processing for transition into U.S. manufacturing capabilities**
- **Industrial partners** and end users 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

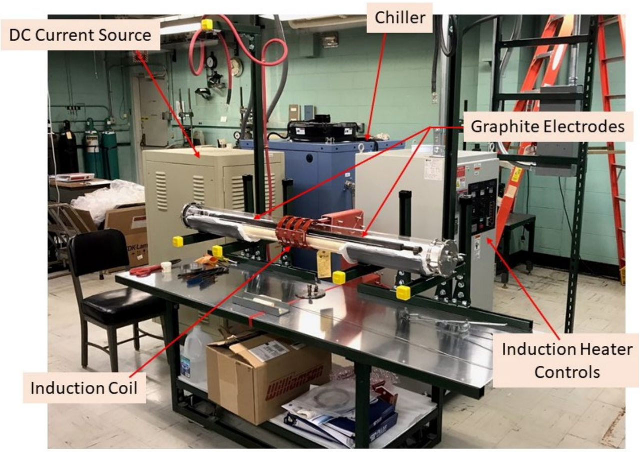
- Develop in-house conversion systems: gram-scale at ANL & multi-kg-scale at NETL. *(ANL, NETL)*
- Produce covetic materials under controlled conditions (Temp., pO_2, current density, reaction time, carbon level, electrode materials, etc.) to understand and optimize the conversion process. *(ANL, NETL)*
- Characterize the microstructure and analyze nanocarbon to study the effectiveness of the conversion process. *(ANL)*
- Measure thermal/electrical conductivity, on micro-scale (AFL) & macro-scale (ANL) to validate conversions. *(ANL, AFL)*
- Work with analytical chemists & spectroscopists. *(ANL, NETL, UMD)*
- Communicate quickly and frequently on both processing techniques and results of experiments. *(ANL, NETL)*
- Protect IP for U.S. manufacturers by filing patents. *(ANL, NETL)*
- Work with industrial partners to validate measurements. *(ANL, NETL)*

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

Results and Accomplishments

Accomplishments:

- Produced covetics with enhanced properties compared to conventional metals:
  - ~25% higher electrical conductivity in copper covetic (CuCv) films
  - ~8% higher electrical & ~13% higher thermal conductivity in bulk CuCvs
  - ~8% higher electrical & ~10% higher thermal conductivity in bulk aluminum covetics (AlCv)



- Evaluated the effect of processing atmosphere on covetic conversion; made CuCvs in ~200-gm-scale at ANL; re-melted/rolled into sheets at NETL
- Evaluated the effect of trace impurities on conductivity
- Commissioned an induction heating system for covetic processing
- A patent application on covetic processing was filed on Dec. 4, 2018

Future work:

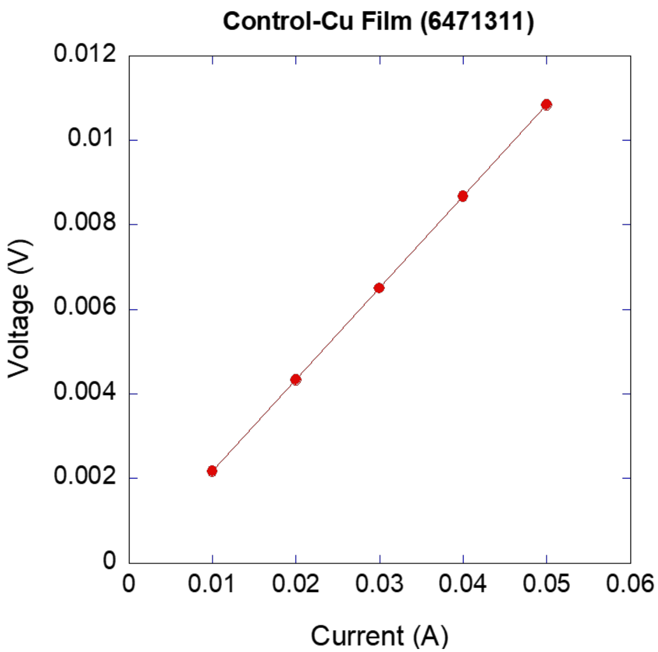
- Evaluate the effect of current density, reaction time/volume, type/level of carbon
- Eliminate/minimize porosity by hot working as-cast ingots
- Optimize processing parameters to reproducibly make multi-kg-scale CuCvs
- Establish qualification criteria for industry to commercialize the technology

Transition (Beyond DOE Assistance)

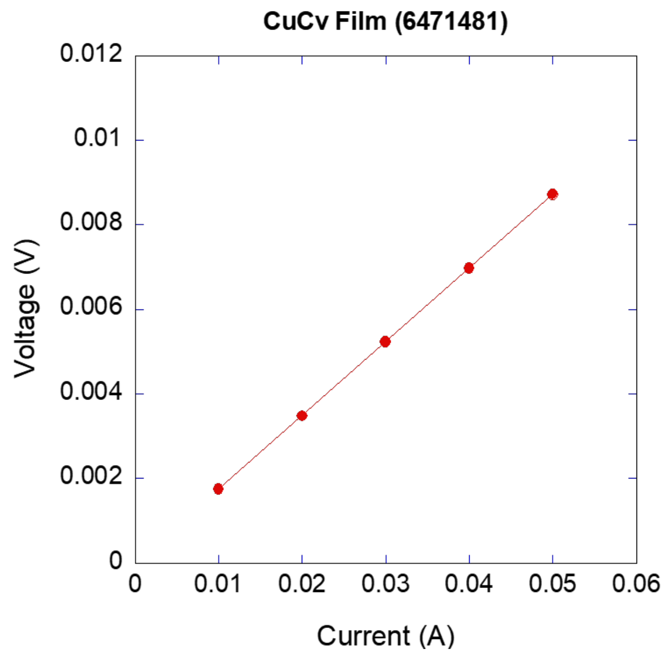
- Developing fundamental knowledge and understanding of the covetic conversion process needed by industry to commercialize the technology.
- This is pre-competitive research. Results are patented, published and presented.
- Two national laboratories and a university are collaborating to create knowledge from early-stage research; project well-aligned with early-stage research needs.
- Covetics hold commercial interest because the process is scalable to tonnage quantities with widespread implications for energy savings in hundreds 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 end users are already on-board and waiting for knowledge creation.
- To protect IP for U.S manufacturers, three patent applications on processing of covetics have been filed.

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

Questions?



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



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

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

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