I/UCRC Executive Summary - Project Synopsis	**Date**: April 2022
Center/Site: CANFSA/Colorado School of Mines	
Tracking No.:59L In-situ Visualization of Microstructure Evolution in Metallic Alloys Under Additive Manufacturing Conditions	**E-mail :** hesmondhalgh@mines.edu **Phone :** (330) 208–7001
Center/Site Director: CANFSA/M. Kaufman/P. Collins/A. Clarke	**Type: (Continuing)**
Project Leader: Oliver Hesmondhalgh	**Proposed Budget**: $320K, leveraged

Project Description: This project will develop a fundamental understanding of microstructure development and grain refinement under additive manufacturing (AM) conditions, including under the repeated cycles of heating and cooling. Experimental in-situ and ex-situ visualization, as well as modeling of phase transformations and microstructure evolution will be conducted. Phase field modeling of rapid solidification dynamics will be informed by and compared to experimental results.

Experimental plan: Dynamic Transmission Electron Microscopy (DTEM) at Lawrence Livermore National Lab (LLNL) and in-situ synchrotron x-ray radiography at the Advanced Photon Source (APS) will be used to capture local solidification conditions in the melt pool of Al-Ge and Al-Si samples of varying compositions. This allows for in-situ observations of rapid solidification dynamics at unprecedented length and time scales. Ex-situ observations of these samples through Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) at Mines will allow for additional analyses of regions of interest. Complex thermal cycling of novel Ti alloys will also be performed to study the origins of grain refinement.

Related work elsewhere: Progress in understanding microstructure selection during directional solidification has been made by x-ray imaging and models of solidification dynamics, where the solid-liquid interface is assumed to be in local thermodynamic equilibrium. Classical models have been successfully used to understand grain refinement in undercooled melts. This work will seek to understand microstructure development during rapid solidification.

How this project is different: New in-situ capabilities, such as DTEM and simulated AM at the APS, will allow for validation of microstructure predictions and a new phase field (PF) model under development suitable for the high solidification velocities encountered during AM, where the solid-liquid interface is not in local thermodynamic equilibrium. The role of anisotropic interface properties during AM will also be better understood.

Milestones for the current proposed year: Determine unknown parent/product orientation relationships in novel Ti alloys, understand metastable phase formation in Al-Ge alloys, and grain competition in Al-Si alloys. TEM analysis will be completed for an Al-Ge publication, potentially using the new ASTAR crystal orientation and phase mapping package at Mines.

Deliverables for the current proposed year: Summarize Al-Ge DTEM results of microstructure development and support Al-Si microstructure characterization to better understand grain competition during rapid solidification. Results will be presented at the AMPM conference in June 2022.

How the project may be transformative and/or benefit society: Gaining insight into microstructural evolution and grain refinement will allow for the prediction and control of AM processes, as well as alloy design for AM. This will allow the expansion of AM to a broader range of higher-risk structural applications.

Research areas of expertise needed for project success: Dual-beam SEM with EBSD and FIB lift-outs, TEM of FIB lift-outs and of DTEM foils, image analysis techniques, phase transformations, solidification, crystallographic texture, and thermodynamics.

Potential Member Company Benefits: Enhanced understanding of alloy design and ways to control microstructure evolution during AM is of interest to extend the potential applications of AM components, which can reduce cost, lead time, and environmental impacts compared to traditional production methods.

Progress to Date: A manual image analysis process has been developed to estimate solidification velocities from DTEM data, which has been compared to an automated process developed by Gus Becker (Mines). These results are being used to inform PF modeling of grain competition in Al-Si alloys. Al-Ge DTEM and ex-situ microscopy is being analyzed to understand metastable phase formation.

Estimated Start Date: Fall 2021	**Estimated Knowledge Transfer Date**: Spring 2025

The Executive Summary is used by corporate stakeholders in evaluating the value of their leveraged investment in the center and its projects. It also enables stakeholders to discuss and decide on the projects that provide value to their respective organizations. **Ideally, the tool is completed and shared in advance of IAB meetings to help enable rational decision making.**