Directorate/Division: Civil, Mechanical and Manufacturing Innovation (CMMI) Dynamics/Advanced Manufacturing (CMMI/AM) **Opportunity:** NSF 25-586

Title: In-Situ Gas Alloying for Controlled Nanodispersion in High-Entropy Alloy Matrices (IGNITE-HEAs)

PI: Monsuru Ramoni, University of Texas Rio Grande Valley, monsuru.ramoni@utrgv.edu

Summary: The IGNITE-HEAs project aims to revolutionize physical metallurgy by pioneering in-situ gas alloying during Directed Energy Deposition (DED) to achieve controlled nanodispersion in high-entropy alloys (HEAs). By injecting reactive gases (e.g., 5–15% N_2, O_2) into the DED melt pool, this approach synthesizes nanoscale ceramics (Cr_2N, Al_2O_3, SiC) in real time within HEA matrices (CoCrFeNiMn, AlCoCrFeNi, HfNbTaTiZr), leveraging DED's rapid solidification (10^4–10^6 K/s) and melt pool dynamics to ensure uniform dispersion. This scalable, real-time method overcomes limitations of conventional dispersion strengthening, such as agglomeration and poor scalability, to produce alloys with enhanced microstructure and mechanical properties for extreme environments. The project integrates multiscale modeling (MD, CFD, CALPHAD) with experimental validation to establish a predictive framework for gas-metal interactions and nanoparticle nucleation in metal alloys, advancing materials discovery for extreme environments.

Intellectual Merit: The project addresses critical gaps in dispersion strengthening, non-equilibrium processing, and HEA compositional complexity by developing a predictive framework for in-situ gas alloying during DED. Unlike traditional methods (e.g., mechanical alloying, LPBF), IGNITE-HEAs enables precise control of nanoparticle size (20–200 nm), spacing (0.5–2 µm), and volume fraction (3–8%) in HEAs, targeting ≥20% hardness improvements with minimal loss of ductility. Multiscale modeling will elucidate solute trapping, phase stability, and dispersion strengthening mechanisms across FCC, FCC+B2, and BCC HEA architectures, providing fundamental insights into gas-metal reactions and melt pool dynamics. The project's originality lies in its real-time, scalable approach for dispersion strengthening, informed by the PI's prior DED bimetallic research, and its alignment with NSF's AI and nuclear energy priorities through applications in radiation-resistant alloys for modular nuclear reactors.

Broader Impacts: IGNITE-HEAs integrates transformative research with STEM empowerment in the Rio Grande Valley, a region with a significant low-income population. The HEA-INSPIRE initiative will engage 100–125 high school students and 25–50 teachers through summer camps at UTRGV's $3.5M Advanced Manufacturing Research Facility, fostering hands-on learning in additive manufacturing and alloy design. Over 200 undergraduate and graduate students will benefit from new course modules and vertically integrated research teams, gaining skills in TEM analysis and COMSOL simulations. The project supports UTRGV's R1 aspirations, strengthens the STEM workforce pipeline, and aligns with the U.S. Materials Genome Initiative by advancing scalable materials discovery for critical infrastructure.

Project Description: In Year 1, a multiscale modeling framework (MD, CFD, CALPHAD) will be developed to predict gas-metal interactions and nanoparticle nucleation in HEAs, validated by DED experiments with controlled gas delivery (5–15% N_2/O_2), and launch HEA-INSPIRE, integrating educational modules and summer camps. Year 2 will optimize DED parameters (laser power: 500–2000 W, scan speed: 5–15 mm/s) to synthesize nanoparticles (Cr_2N, Al_2O_3, TiN) with a volume fraction of 3–8%. Year 3 will characterize nanoparticle dispersion (interparticle spacing: 0.5–2 µm) using transmission electron microscopy (TEM), scanning transmission electron microscopy with energy-dispersive spectroscopy (STEM-EDS), and electron backscatter diffraction (EBSD), correlating microstructures with mechanical properties (target: >20% hardness increase). Year 4 will develop a structure-property-process model to predict hardness, elastic modulus, and high-temperature strength, validated by nanoindentation, and high-temperature mechanical testing. Year 5 will scale findings to broader alloy systems. Results will be disseminated via publications, conferences, UTRGV platforms, and collaborations with the Alabama Materials Institute and the University of North Texas.

Budget Justification Summary: NSF CAREER Proposal

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Project Period: Jan 1, 2026 – Dec 30, 2030 (5 years)

I. Personnel Salaries/Wages & Fringe Benefits ($204,234)

Principal Investigator (PI): Dr. Monsuru Ramoni (1 month/year academic effort) – Total salary: $60,760; Fringe benefits: $10,937.

Graduate Research Assistant (PhD): Full-time for 4 years – Total direct wages: $120,489; Fringe benefits: $12,048.

II. Participant Support & Tuition Remission (IDC Exempt) ($52,411.47)

PhD Student Tuition Remission (9 credit hours/year): $52,411.47 (5 years).

III. Operating Expenses ($123,900)

Gases, Sensors, Equipment: $22,000 (years 1-2) – essential for controlled alloying experiments.

Metal Powders: $41,800 – key materials for high entropy alloy fabrication.

Equipment User Fees: $27,000 – access to specialized UTRGV lab facilities.

Publication Fees: $12,000 – open-access publication.

Conference Registrations (TMS, MRS): $11,100 – dissemination and networking.

K-12 STEM Outreach: $10,000 – broader impacts initiative.

IV. Travel ($29,500)

MRS Conference Attendance: $29,500 – domestic conference travel for PI/GRA presentations and professional development.

V. Indirect Costs (IDC) ($171,664.32)

Calculated at 48% of Modified Total Direct Costs (MTDC): $171,664.32

Total Direct Costs: $410,045.47

Total Project Costs (Direct + Indirect): $581,709.79