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High Throughput Studies on Irradiated High Entropy Alloys

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Development of next-generation nuclear reactors requires new alloys for structural materials subjected to higher temperature and under extreme environments. One of the main criteria of selection of these materials is excellent mechanical properties and corrosion resistance for prolong neutron irradiation at high temperature. High Entropy Alloys (HEA) are a new class of alloys and could be good candidates to fulfill this role. However, considering the extremely large compositional space of HEAs, manufacturing, characterizing, and studying the evolution of their properties induced by irradiation using conventional methods is not compatible with the deployment timeline of these reactors.

In this study, a combination of high-throughput and automated techniques of alloy manufacturing, characterization, and irradiation have successfully developed to study the evolution of microstructure hardness and swelling under ion irradiation. The combination of these techniques has allowed us to study 50 different HEA compositions in the CrFeMnNi a practical amount of time. Additive manufacturing has demonstrated the ability to quickly produce arrays of samples with compositions very close to those targeted. For this project, series of alloys were printed using Optomec LENS MR-7 in a closed chamber filled with argon and fed by four independently controlled powder hoppers. Phase and microstructure were determined using X-Ray Fluorescence, X-Ray Diffraction, Scanning Electron Microscopy-Energy Dispersive Spectroscopy (Figure 1c). Sample with 25 alloys composition were irradiated at Madison Ion Beam Laboratory capable of irradiating large sample using high-throughput stage (Figure 1 a-b). Samples were examined for hardness evolution and void swelling of a wide composition of the Cr-Fe-Mn-Ni systems using high-throughput profilometry (Figure 1d). Automated 3D slicing was carried out using the Thermo Scientific Helios Hydra DualBeam (G4) instrument to elucidate microstructural evolution of features like voids (Figure 2). These approaches have the potential to dramatically reduce the development time and costs of materials for future nuclear reactors [4].

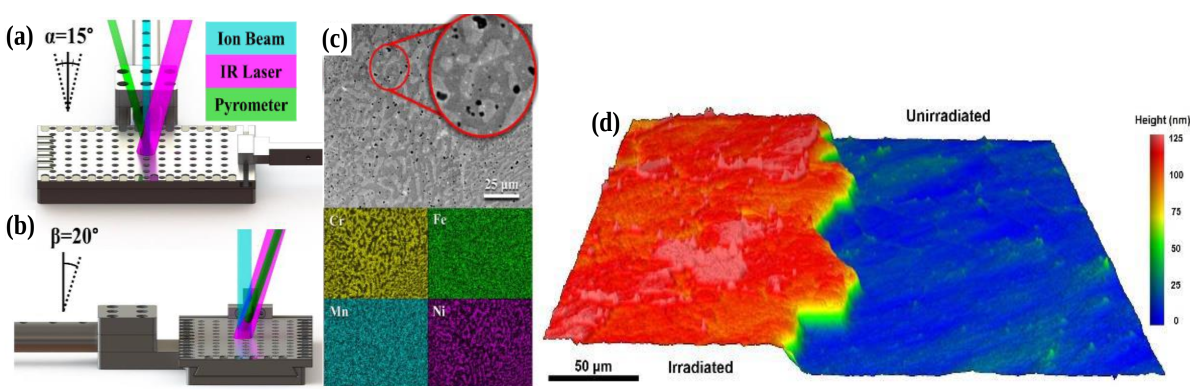

Figure 1

Figure 1. (a-b) Illustration of the ion beam and IR laser impinging on a sample with 25 different alloys while the temperature is measured by the pyrometer. (a) and (b) offer different views of the triple-beam (ion beam, IR laser, pyrometer) condition, to show the orientation relationship between the beams. (c) Representative SEM images and EDS chemical maps from the HEA sample (Cr42Fe17Mn20Ni21) collected using high throughput approach. Insets are provided in red circles at a magnification 3x greater than the base images to highlight the porosity distributions. (d) Representative 3D visualization of sample height map from optical profilometry from one of the samples. Height has been visually exaggerated by a factor of 10 for clarity.

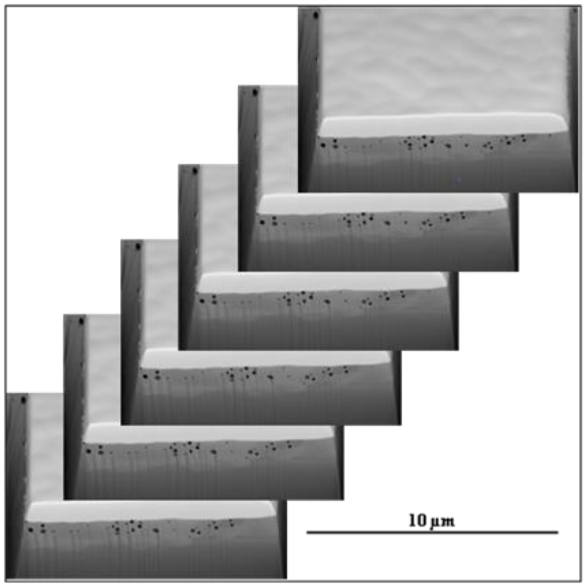

Figure 2. 3D slicing of Cr15Fe35Mn15Ni35 sample irradiated at 500 °C to 200 dpa using 5-MeV Ni ions.

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