NATIONAL SCIENCE CENTRE (NCN) GRANT SONATA 19 – Damian Kalita

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The rapidly increasing global demand for energy consumption combined with the shift towards zero-emission clean energy sources forces the development of new advanced nuclear technologies characterized by higher safety, better fuel efficiency, and lower long-term environmental effects. Among them, nuclear fusion seems to be the future of nuclear energy. The upcoming fusion systems could provide more reliable and economical nuclear energy, but their efficiency will greatly rely on the performance of the structural materials. The key components of fusion reactors will be exposed to unprecedented conditions, i.e., high operating temperature, and significant radiation damage caused by high-energy neutrons and α-particles (He nuclei). The materials currently used in operating fission reactors have not been designed to withstand such extreme conditions. This accelerated the development of new radiation-resistant structural materials for new generations of nuclear reactors.

The project aimed to investigate the irradiation-resistance of the novel group of concentrated solid solution alloys (CSAs). Those alloys contain multiple elements (typically 2 – 5) in the equimolar or near-equimolar ratio and form simple solid-solution systems, such as face-centered cubic (FCC) or body-centered cubic (BCC). The random distribution of different-size atoms in the crystal structure of CSAs creates severe lattice distortions, which macroscopically results in unique properties of these materials such as high strength or excellent creep resistance. Recent studies showed that the radiation resistance of CSAs exhibiting the FCC structure is superior in comparison to pure elements or their conventional counterparts. However, the irradiation behavior of the refractory CSAs with the BCC structure, which are promising candidates for the structural materials of fusion reactors, was not investigated so far in details.

Taking this into consideration, the project assumes the investigation of the effect of He-induced defects accumulation on the microstructure and mechanical properties of BCC-CSAs. This phenomenon is critical for the performance of fusion materials since they are subjected to both He-ion irradiation from plasma and the formation of He in their microstructure by the transmutation reactions. In order to establish the irradiation resistance of this group of materials three different equimolar alloys, which vary in lattice distortions, were selected and fabricated using a magnetron sputtering technique – WTaCrV, MoTaTiV, and MoTaTiVZr. In order to simulate the conditions of the fusion reactor, the materials were subjected to the He^{+} ion irradiation, allowing for the introduction of He-induced structural defects as well as He^{+} + Ni^{2+} irradiation to mimic the effect of high energy neutrons on the evolution of these defects. The materials will be studied with respect to the occurrence and the evolution of irradiation-induced defects using scanning and transmission electron microscopy (SEM and TEM). The changes in the mechanical properties of the alloys will be investigated using a nanoindentation test. Finally, based on the conducted studies, the BCC-CSA with the highest irradiation resistance will be selected, fabricated in bulk form using the arc melting method, and thoroughly investigated, taking into account its microstructure, phase stability, high-temperature mechanical properties, and resistance to high-temperature ion irradiation.

It is believed that the applied set of experiments will contribute to a better understanding of the performance of refractory BCC-CSAs in the fusion environment. The fundamental knowledge of the elementary processes that take place in the structure of these materials during the interaction with high-energy ions will allow to understand the root of their irradiation-resistance and how the properties of these materials may be adjusted to the requirements of future nuclear reactors. It is expected that the high chemical complexity of CSAs, affects the He diffusivity, ultimately leading to the formation of smaller, more dispersed defects that are less detrimental to the performance of the proposed materials. The research is an original approach to the development of irradiation-resistant materials, which will undoubtedly meet with great interest in the nuclear materials community.