Innovative Design and Future Development of Chemically Complex Intermetallic Alloy

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Abstract: Intermetallic materials are bestowed by diverse ordered superlattice structures together with many unusual properties. In particular, the advent of chemically complex intermetallic alloys (CCIMAs), which are also called as the high-entropy intermetallic alloys (HEIMAs), has been received considerable attention in recent years and offers a new paradigm to develop novel metallic materials for advanced structural applications [1-5]. These newly emerged CCIMAs exhibit synergistic modulations of structural and chemical features, such as self-assembled long-range close-packed ordering, complex sublattice occupancy, and interfacial disordered nanoscale layer, potentially allowing for superb physical and mechanical properties that are unmatched in conventional metallic materials[1,2]. In this paper, we critically review the historical developments and recent advances in ordered intermetallic materials from the simple binary to chemically complex alloy systems. We are focused on the unique multicomponent superlattice microstructures, nanoscale grain-boundary segregation, and disordering, as well as the various extraordinary mechanical and functional properties of these newly developed CCIMAs. Finally, perspectives on the future research orientation, challenges, and opportunities of this new frontier are provided. This conceptual design of CCIMAs may lead to families of high-temperature structural materials that might avoid some of the drawbacks of high-temperature alloys currently in use, which will be of great interest for a broad range of aerospace, automotive, nuclear power, chemical engineering, and other applications.

Keywords: Ordered superlattice, high-entropy effect, Chemically complex intermetallic, Sublattice occupancy, Grain-boundary engineering

1 Representative results and discussions

Fig. 1. Unusual nanoscale interfacially disordered structure of the superlattice materials.

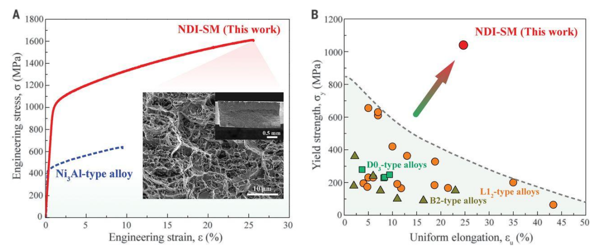

Fig. 2. Exceptional mechanical properties and thermal stability of the newly designed CCIMA.

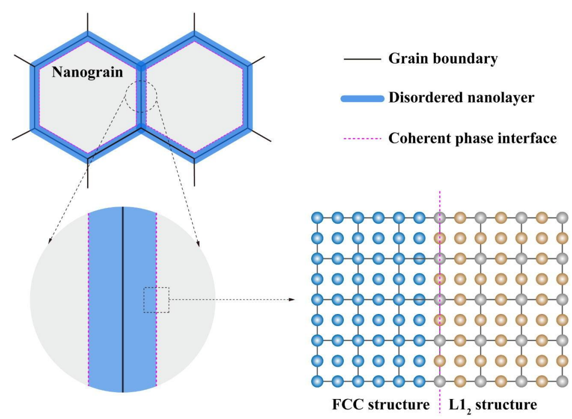

Figure 3. Schematic illustration of the conceptual design of stable nanograined CCIMAs in the future.

We discovered that nanoscale disordered interfaces can effectively overcome the embrittlement problem[1,4,6]. Interfacial disordering is driven by multielement co-segregation that creates a distinctive nanolayer between adjacent micrometer-scale superlattice grains. This nanolayer acts as a sustainable ductilizing source, which prevents brittle intergranular fractures by enhancing dislocation mobilities. Our superlattice materials have ultrahigh strengths of 1.6 gigapascals with tensile ductilities of 25% at ambient temperature. Simultaneously, we achieved negligible grain coarsening with exceptional softening resistance at elevated temperatures. Designing similar nanolayers may open a pathway for further optimization of alloy properties. 3D printing may also greatly promote the large-scale applications of CCIMAs[7].

2 Conclusion

The concept of CCIMAs represents a new and promising frontier for the innovative design of novel materials and devices. As a newly emerged metallic material, several CCIMAs with long-range ordered superlattice structures composed of various multiple alloying elements have been demonstrated with many novel and unprecedented properties and thus they are being actively explored for numerous promising applications, in particular for advanced structural applications. The combinatorial approaches including the state-of-the-art microanalysis techniques (such as the 3D-APT) and theoretical simulations (such as the DFT first-principles calculation) play crucial roles in revealing their intrinsic metallurgical behaviors. Inspired by these attractive findings, we believe that more and more novel high-performance metallic materials with superb structural/functional properties can possibly be discovered based on chemically complex intermetallic systems. In the near future, to further speed up the well-targeted quantitative design and controllable fabrication of CCIMAs with optimized properties, significant effort should be devoted to fundamentally elucidating the alloying behaviors and associated microstructural evolutions of CCIMAs, as well as the atomistic mechanisms behind them. Moreover, to promote their large-scale industrialization, more attention should be paid to the new high-throughput experimental work to systematically evaluate their microstructure-sensitive properties under various service conditions, especially under harsh environments like high temperatures, cryogenic temperatures, high-energy irradiation, etc.

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