PhD Position at IJL

High Entropy Alloys Thin Films Grown by Molecular Beam Epitaxy

General information

Workplace: Institut Jean Lamour, Nancy, France
Type of contract: PhD contract with University of Lorraine
Contract period: 36 months
Expected date of employment: October 2025
Remuneration: 2200 €-2300 € / month (gross salary)
Desired level of education: Master's degree in materials science, physics or chemistry.

Context

The term high entropy alloy (HEA) [1] refers to a random metallic solid solution composed of at least five elements each in equi- or quasi-equiatomic concentration (between 5 and 35 at.%). Without a principal element, these materials adopt simple crystallographic structures such as solid solution phases like body-centered cubic, face-centered cubic and more recently hexagonal close-packed structures. The concept of HEA offers new perspectives in the design of materials and metallic alloys with multiple possible combinations and compositions. The exploration of such a field of research will lead to new bulk and surface properties, as evidenced by the latest development of HEA nanoparticles in the field of heterogeneous catalysis [2] or even by the ever-increasing use of HEAs in the form of functional coatings. Indeed, recent studies have reported remarkable surface properties of these materials including, for example, good resistance to oxidation, corrosion and even wear. Although this field of research is well documented, only one study has reported the characterization of the atomic structure of a single crystal surface of an HEA under ultra-high vacuum [3], reflecting the scarcity of such samples.

To the best of our knowledge, the growth of HEA as epitaxial thin films is very limited and essentially restricted to the CrMnFeCoNi alloy prepared by laser-assisted MBE (Molecular Beam Epitaxy) on MgO substrates using a Cu buffer layer [4]. The growth of epitaxial layers of CoCrFeNi(001) were also successfully achieved by magnetron sputtering using single-crystal MgO substrates [5]. Finally, oxide-based HEAs (named HEO) with 5 cations $MgCoNiCuZnO_5$ and 6 cations $MgCoNiCuZnXO_6$ (X=Sc, Sb, Sn, Cr or Ge) could also be epitaxially grown on MgO by pulse laser deposition [6]. Consequently, the very limited number of studies of single-crystal HEA model systems does not allow for an atomistic description of the surfaces and interfaces necessary for understanding the resulting physical phenomena. Answers are awaited on the phase stability, chemical distribution at the nanoscale, and on the surface and interface structures of thin HEA films. The study of these crucial aspects requires model systems.

The goals of this thesis will therefore be to synthesize HEA by MBE and to provide HEA single crystals in the form of thin epitaxial layers for three distinct chemical families (transition metal, refractory, rare earth), making it possible to study their physical and chemical surface and interface properties. This approach represents an alternative to compensate for the lack of single crystals from conventional techniques (Czochralski, Bridgman, etc.). The structures (volume/surface/interface) will be characterized by surface and materials science techniques. Subsequently, the adsorption of a metal on these thin films will provide information on the mechanisms of adsorbate nucleation and identify any phase decomposition at the nanoscale and/or transformation at the HEA-metal monolayer interface.

This approach will lead to an atomistic description[1] of surfaces and metal/HEA interfaces, knowledge necessary to adapt this material for applications. This project is based on the expertise of 2 research teams, 3 technical centers and on facilities unique in IJL.

Constraints and risks

The position you are applying for is located in a sector relating to the protection of scientific and technical potential. It therefore requires, in accordance with the regulations, that your arrival be authorized by the competent authority of the Ministry of Higher Education, Research and Innovation.

About the Institut Jean Lamour

The Institute Jean Lamour (IJL, https://ijl.univ-lorraine.fr/) is a joint research unit of CNRS and Université de Lorraine. **Focused on materials and processes science and engineering, it covers: materials, metallurgy, plasmas, surfaces, nanomaterials and electronics.**
It gathers 183 researchers/lecturers, 91 engineers/technicians/administrative staff, 150 doctoral students and 25 post-doctoral fellows. Partnerships exist with 150 companies and our research groups collaborate with more than 30 countries throughout the world.
Its exceptional instrumental platforms are spread over 4 sites; the main one is located on Artem campus in Nancy.

Application

Applicants are invited to send CV, cover letter, names of references and M1/M2 marks together to the advisor and co-advisor:

Prof. Stéphane Andrieu (Prof. UL), Email : stephane.andrieu@univ-lorraine.fr
Dr. Julian Ledieu (DR2-CNRS), Email : julian.ledieu@univ-lorraine.fr

The PhD student will be affiliated to the C2MP doctoral school (Chemistry - Mechanics - Materials – Physics, https://doctorat.univ-lorraine.fr/en/doctoral-schools/c2mp/presentation).

The PhD student will be hosted by two Research groups: « SPIN » (101) and « Surface and Metallurgy » (203) of the Institut Jean Lamour, CNRS-Université de Lorraine, Campus Artem, Nancy.

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[2] Y. Yao, Z. Huang, P. Xie, S.D. Lacey, R.J. Jacob, H. Xie, F. Chen, A. Nie, T. Pu, M. Rehwoldt, D. Yu, M.R. Zachariah, C. Wang, R. Shahbazian-Yassar, J. Li, L. Hu, Science, 359 (2018) 1489.
[3] J. Ledieu, M. Feuerbacher, C. Thomas, M.-C. de Weerd, S. Sturm, M. Podlogar, J. Ghanbaja, S. Migot, M. Sicot, and V. Fournée, Acta Mater. 209, (2021) 116790.
[4] Y. Ling, J. Chen, A. He, G. Wang, W. Yu, M. Xu, Z. Han, J. Du and Q. Xu, J. Appl. Phys. 131, 233904 (2022).
[5] H. Schwarz, J. Apell, H.K. Wong, P. Henning, R. Wonneberger, N. Rösch, T. Uhlig, F. Ospald, G. Wagner, A. Undisz and T. Seyller, Adv. Mater. 35, 2301526 (2023).
[6] J.L. Braun, C.M. Rost, M. Lim, A. Giri, D.H. Olson, G.N. Kotsonis, G. Stan, D.W. Brenner, J.-P. Maria and P.E. Hopkins, Adv. Mater. 30, 1805004 (2018).