Laboratoire des Sciences des Procédés et des Matériaux – UPR 3407
Institut des Sciences de l'Ingénierie et des Systèmes (INSIS)

PhD position

Synthesis, mechanical properties and biodegradability of thin films metallic glasses

Supervision: Prof. Philippe Djemia (LSPM, Université Sorbonne Paris Nord),

Co-supervision: Dr. Fatiha Challali, Dr. Florent Tétard

Financial support: MESR Grant (starting on September 1th 2020; 3 years duration).

Keywords: magnetron sputtering, metallic glasses, mechanical properties, biodegradability.

Start date: September 1st 2020

Short description

The study of amorphous metal films (thin film metallic glasses, TFMGs) is receiving more and more attention due to the excellent mechanical properties: a tensile strength close to theoretical limit, high hardness and elastic deformation [1]. Their disordered atomic structure is the source of unique physical properties that are different from their crystalline counterparts [2]. However, studies on the synthesis and characterization of TFMGs are relatively recent, as efforts have focused on the bulk metallic glasses (BMGs). In this context, the main goal of the study is the TFMGs synthesis by magnetron sputtering on flexible polymer substrates with a structure totally or partially disordered at the nanometric scale. Structural-mechanical relationship will be identify trough the combination of x-ray diffraction, scanning electron microscope, nanoindentation, optoacoustic techniques [3, 4] and micro-tensile tests of films on flexible polymeric substrates [5]. We aim to establish correlation between the elastic and plastic properties of TFMGs, and contribute to a better understanding of the microstructures and local atomic ordering influence on their mechanical properties. In addition, one application of these coatings in the biomedical field is considered, in partnership with the Laboratory for Translational Vascular Research (LVTS, INSERM U1148, Pr. F. Chaubet) who will perform specific biocompatibility tests (cells growth,…).

One application of the films

Vascular stents help restore blood flow when a vessel is blocked, by mechanical crushing of obstructive tissue. From the outset, two conflicting problems arose: making a prosthesis combining sufficient mechanical properties to maintain the permeability of the vessel for several months while promoting complete healing of the vascular wall. The most effective way to achieve this healing is to ensure that the prosthesis gradually dissolves (with controlled speed) until it disappears when its function is fulfilled. Today a stent is generally made of a metal resistant to corrosion in a blood environment, such as stainless steels, cobalt-chromium and titanium alloys, materials which alone have the appropriate mechanical properties essential to the function of prostheses [6-8]. On the other hand, these objects are not bioresorbable and occupy the surrounding vascular tissue for life without possible complete integration. On the one hand, studies have been undertaken on stents made of zinc-based alloys (Zn) obtained by molding or extrusion with good mechanical properties and promising in terms of biodegradability and biocompatibility [9, 10]. On the other hand, polymeric stents have also been widely studied due to remarkable bioresorption capacities; but their main weakness still lies in insufficient mechanical properties [7]. Finally, metal stents covered with polymer have been developed with the ability to locally release active ingredients promoting both better integration of the prosthesis and more efficient tissue healing [11].

However, to date, no study has considered the development of a hybrid polymer / metal stent, both: (i) bioresorbable, (ii) mechanically satisfactory, and (iii) biocompatible. Stents have been studied for a long time at LVTS and collaboration with the LSPM aims to explore the possibilities offered by the 3D structuring of polymers and their coating by magnetron film spraying of amorphous bioresorbable metal alloys with sufficient mechanical properties [6-8]. We will use methodologies [12] already developed by the LSPM and the LVTS for the study of mechanical properties, biochemical and biological evaluation of hybrid structures.

PhD tasks

(i) coatings with thin films of metallic glasses on flat polymeric supports (Kapton or elastomer sheets) and curved structures of polymers obtained by 3D printing;
(ii) study of the structural and mechanical properties of hybrid materials, in particular at the polymer-metal interface,
(iii) control of their degradation kinetics in simulated biological medium,
(iv) in the context of a biomedical application, the evaluation of their mechanical properties in relation to the absorption of the materials constituting the hybrid,
(v) evaluation of compatibility with human vascular cells (collaboration with the LVTS , Pr. F. Chaubet).

Profile
Master degree in physics or materials science.

Further information and application

For further information and application – resume including addresses of referees - and your exam scores (bachelor and master) – please contact:

Prof. Djemia Philippe (djemia@univ-paris13.fr, +33(0)149403482)

Laboratoire des Sciences des Procédés et des Matériaux, UPR 3407-CNRS, Université Sorbonne Paris Nord, 99 Avenue Jean Baptiste Clément, 93430 Villetaneuse, France

The PhD will apply to Ecole Doctorale Galilée ED 146, Université Sorbonne Paris Nord (ecole-doctorale.galilee@univ-paris13.fr)

References:

[1] *Approaching the ideal elastic limit of metallic glasses*, Lin Tian, Yong-Qiang Cheng, Zhi-Wei Shan, Ju Li, Cheng-Cai Wang, Xiao-Dong Han, Jun Sun & Evan Ma (2012) Nat. Comm. **3**:609,1-6

[2] *Local atomic order, electronic structure and electron transport properties of Cu-Zr metallic glasses*, J. Antonowicz, A. Pietnoczka, K. Pękała, J. Latuch, and G. A. Evangelakis (2014) J. App. Phys. **115**,203714

[3] *Mechanical properties of elementary layers involved in a multilayer optical stack by photon-acoustic phonon interaction approaches* (2018) F. Faëse, D. Poinot Cherroret, S. Chatel, L. Becerra, F. Challali, P. Djemia, L. Belliard, Journal of Applied Physics **124** (12), 125307

[4] *Structural-elastic relationships of Zr-TL (TL= Cu, Co, Ni) thin films metallic glasses*, M. Apreutesei, P. Djemia, L. Belliard, G. Abadias, C. Esnouf, A. Billard, P. Steyer (2017), Journal of Alloys and Compounds **707** 126-131

[5] *Fragmentation and adhesion properties of CoFeB thin films on polyimide substrate*, D. Faurie, F. Zighem, A. Garcia-Sanchez, P. Lupo, AO. Adeyeye (2017) Applied Physics Letters **110** (9), 091904

[6] *State of the art: coronary artery stents – past, present and future*, G.G. Stefanini, R. A. Byrne, S. Windecker, A. Kastrati (2017), Eurointervention, **13**(6), 706-716.

[7] *Bioresorbable stents: Current and upcoming bioresorbable technologies*, H.Ying Ang, H. Bulluck, P. Wong, Subbu S. Venkatraman, Y. Huang, N. Foin (2017) International J. of Cardiology, **228**, 931-939.

[8] *Bio-Functional Design, Application and Trends in Metallic Biomaterials*, K. Yang, C. Zhou, H. Fan, Y. Fan, Q. Jiang, P. Song, H. Fan, Y. Chen and X. Zhang (2018) International J. of Molecular Sciences, **19**(1), 4561-4573.

[9] *Biodegradable Metals for Cardiovascular Stents: from Clinical Concerns to Recent Zn-Alloys*, P. K. Bowen, E.R. Shearier, S. Zhao, R.J. Guillory II, F. Zhao, J. Goldman, J. W. Drelich (2016) Advanced Healthcare Materials, **5**, 1121-1140.

[10] *Zinc-based alloys for degradable vascular stent applications*, Ehsan Mostaed, Malgorzata Sikora-Jasinska, Jaroslaw W. Drelich, Maurizio Vedani (2018), Acta Biomaterialia **71**, 1-23.

[11] *Du stent coronaire en métal au stent biodégradable*, Plamen Bokov, Patrice Flaud, (2011) John Libbey Eurotext **23**(9), 465-476

[12] *Thin films of binary amorphous Zn-Zr alloys developed by magnetron co-sputtering for the production of degradable coronary stents: A preliminary study*, N. Annonay, F. Challali, M-N. Labour, V. Bockelée, A. Garcia-Sanchez, F. Tétard, M-P. Besland, P. Djemia, F. Chaubet, (2018) Bioactive materials **3**(4), 385-388.