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Mg-based glasses and their potential for a new generation of biodegradable implants

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Abstract

Bulk metallic glasses (BMGs) are a new class of alloys that can be manufactured as massive amorphous pieces in dimensions of up to several centimeters via conventional casting techniques, i.e. by applying cooling rates of less than 100 K/s [1]. Due to their non-crystalline nature they show great hardness, a yield strength which is about twice as high as that of their crystalline counterparts, and elasticity which is about ten times higher [2]. In addition, because BMGs suffer no equilibrium phase diagram restrictions, their degradation characteristics may be tailored by integrating large amounts of alloying elements into the homogeneous (glass) structure, i.e. BMGs offer much scope for alloy 'chemistry' alteration.

Biodegradable implants have recently attracted great interest, because they offer the advantage of not requiring surgical removal after serving their purpose. They also circumvent negative effects of permanent implants such as long-term physical irritation and chronic inflammation. In this context magnesium is a very interesting candidate because of its great biocompatibility, its Young's modulus (similar to that of bone), and its fast degradation performance. Unfortunately, however, corrosion of magnesium alloys in aqueous solutions is generally accompanied by the formation of hydrogen, and too-rapid degradation of Mg may result in the development of gas bubbles which hinder tissue/bone growth and thus the healing process.

In this talk I will discuss the mechanical and electrochemical properties of Mg-based BMGs [3], and report on the dramatic reduction or complete cessation of hydrogen evolution achieved during the degradation of $Mg_{60+x}Zn_{35-x}Ca_5$ ($0 \leq x \leq 7$) glasses [4]. I will show that above a Zn alloying threshold of 28 at.%, a Zn- and oxygen-rich passivating layer forms on the alloy surface, and explain

this using an electrochemical model which takes the degradation of Zn in simulated body fluid into account. *In-vitro* and *in-vivo* studies confirm the absence of hydrogen evolution and reveal tissue compatibility as good as that observed for crystalline Mg implants. Thus, these MgZnCa glasses present a unique opportunity for bioabsorbable implant applications, e.g. in vascular intervention, general bone surgery, and pediatric fracture fixation.

[1] J. F. Löffler, *Intermetallics* 11 (2003) 529–540.
[2] J. F. Löffler, A. A. Kündig, F. H. Dalla Torre, in *CRC Materials Processing Handbook*, edited by J. R. Groza *et al.* (Taylor & Francis CRC Press, 2007).
[3] B. Zberg, E. R. Arata, P. J. Uggowitzer, J. F. Löffler, *Acta Mater*. 57 (2009) 3223–3231.
[4] B. Zberg, P. J. Uggowitzer, J. F. Löffler, *Nature Mater*. 8 (2009) 887–891; highlighted in *Nature* 461 (2009) 701.

Biosketch

Jörg F. Löffler studied physics and materials science at Saarland University, Germany, and carried out his diploma thesis work at the Institute of New Materials, Saarbrücken. In 1994 he transferred to the Paul Scherrer Institute and the ETH Zurich, where he earned his doctorate in the magnetism of nanostructured materials and neutron scattering (1997). After a short stay as a postdoctoral researcher at the Paul Scherrer Institute, he took up a post at the California Institute of Technology as an Alexander von Humboldt Fellow, where he worked with Prof. William L. Johnson in the area of bulk metallic glasses. In 2001 he was appointed tenure-track Assistant Professor at the University of California, Davis.

Since 2003, Jörg F. Löffler has been on the faculty of the ETH Zurich; first, as a tenure-track Assistant Professor and since 2007 as a Full Professor. He chairs the Laboratory of Metal Physics and Technology at the ETH Zurich and serves as Head of the Department of Materials from 2010 – 2012.

The principal areas of Prof. Löffler's research are the synthesis and characterization of novel nanostructured and amorphous materials; magnetic, optical, and mechanical properties on the mesoscale; the use of metals for medical and photonic applications; and neutron scattering and synchrotron radiation. His work has received distinctions at several international conferences. Other awards include the ETH Zurich's Silver Medal for the excellence of his Ph.D. dissertation and the Masing Memorial Award of the German Society for Materials. Jörg Löffler was a member of the German National Merit Foundation from 1991 to 1997 and holds a Visiting Faculty position at the California Institute of Technology. He is a member of the editorial boards of *Intermetallics* and *Metallurgical and Materials Transactions A*.