Vitrified Metals Technologies and Applications in Devices and Chemistry

Final Report Summary - VITRIMETTECH (Vitrified Metals Technologies and Applications in Devices and Chemistry)

VitrMetTech - Marie Curie International Training Network n. 607080 - 01/10/2013-31/01/2018 (http://www.vitrimettech.unito.it/)

Summary of Project Objectives
VitrMetTech (Vitrified Metals Technologies and Applications in Devices and Chemistry) was a MarieCurie ITN project devoted to a new class of metallic materials: metallic glasses and their amorphous/crystalline composites. It contributed to advancing the understanding of glass formability in metals, of mechanical, chemical and magnetic properties by educating a group of young researchers. The PhD students and postdocs were introduced to the field of physical and chemical metallurgy, a highly strategic one for European industry and society. Metallic products and components contribute substantially to the European manufacturing value resulting strategic to compete for sustainable product development and resource efficiency. The objectives of the project were related to the design of technologies for deposition, casting and moulding metallic glasses, to the improvement of the knowledge on mechanical properties to reduce brittleness, to ameliorate the magnetic performance for devices (e. g. actuators) and to new applications in chemistry (e. g. catalysis and spectroscopy on metallic glass derivatives).

Training activities
A comprehensive training program was set up for ITN fellows in an interdisciplinary environment covering all aspect of research and technology on metallic glasses provided by 12 partners and 6 associated partners. Four training workshops were organized in addition to the local PhD programmes of their hosting institutions and to the dedicated secondments.

The training by research within the VitrMetTech project has implied delivering 356,86 person/months out of 360 to Early Stage Researchers and 88.66 person/months out of 90 to Experienced Researchers. Overall 9 ESR have acquired, or will acquire at the completion of studies, a Doctoral title.

11 ESRs were recruited during the project with gender balance of 7 males and 4 females. 7 ERs were recruited during the project with gender balance of 5 males and 2 females.
The Fellows received individual training at each partner institution and through secondments. Each partner acted as a training centre for some topics: casting, thin film deposition, modelling, mechanical testing, magnetic testing, chemical studies. Four Network-Industry Meetings were organized for all Fellows and were open to external attendees: in Cambridge on 15-19 September 2014, Dresden on 14-17 September 2015, Iasi on 20-24 March 2016, Grenoble on 12-15 September 2016. They included lectures and practicals on transferable skills, group work, CV construction, career perspectives, entrepreneurship.

Work performed during the project

A large set of activities was undertaken to cover the synthesis of metallic glasses in sizes from thin films to centimetre large objects. The casting of bulk metallic glasses was simulated evaluating critical parameters for complex alloys and industrial processes for die casting and stamping of metallic glass components were developed. Thin film "nano-glasses" were produced tailoring the local density of the material to enhance stability against shear band movement and make nanoporous thin film catalysts. New formulations of bulk metallic glasses and melt-spun ribbons were developed both as soft ferromagnets for sensors, actuators and energy saving devices and biocompatible alloys, free of toxic elements. The thermodynamic and kinetic stability of glasses was established. The mechanism of plastic flow in metallic glasses was extensively investigated and simulated achieving understanding of the effect of "mechanical annealing" (e.g. shot peening) in the elastic regime, of the origin of shear bands from avalanches of shear transformation zones induced in creep experiments including the effect of the magnetoelastic coupling on the mechanical properties. With a computational approach the structure and mechanical properties of metallic glasses was described with atomistic and molecular dynamics calculations. Metallic glasses both based on noble and transition metals were used as precursors materials to be de-alloyed to obtain porous metals of peculiar nanostructure for electro-catalysis and spectroscopy. Atomic structure analysis of metallic glasses and in-situ de-alloyed materials was performed to follow the evolution of local atomic order and the topography of porous products.

Main Achievements of the Project

All deliverables and milestone were successfully achieved spanning the synthesis of glasses and composites from nanometer to centimetre size, the characterization of structural, mechanical, magnetic, and chemical properties, and the making of devices.

The results on synthesis of alloys and pre-industrial production are:

- Method developed for high pressure die casting of Fe-based bulk metallic glass.
- Determination of the effect of alloying elements on glass forming ability, structure, magnetic, magnetocaloric, and mechanical properties of Fe-based metallic glasses.
- Synthesis of low Young's modulus Ti-based porous bulk glassy alloy without cytotoxic elements.
- Synthesis of "nano-glass" having density fluctuations via magnetron sputtering.
- Micro-forming conditions for various bulk metallic glasses optimized via Newtonian flow in the supercooled liquid region.

Modelling of the structure, atomic diffusion, glass transition have shed light on plastic flow via shear bands:

- Molecular dynamics has shown the inhomogeneous distribution of coordination polyhedra in Cu-Zr metallic glasses causing the rattling of atoms at the origin of the shear transformation zones that ultimately trigger plastic flow.
- An analytical framework was proposed to describe the elasticity, viscosity and fragility of metallic glasses in relation to their atomic-level structure and the effective interatomic interaction.
- A model of the glass transition has shown that the fragility and viscosity of glass-forming materials scales with the interatomic repulsion steepness.

Experiments went along with the modelling to study the dynamics of shear banding:

- The origin of shear bands and their avalanche dynamics in metallic glasses as a function of stress and temperature was determined by creep deformation.
- Time-resolved measurement of shear-band temperature during serrated flow were performed,
- It was demonstrated that rejuvenation of the glass decreases shear band sliding velocity.

Studies on magnetic materials yielded:
- improved alloy formulation for soft magnets having lower coercivity and higher magnetic saturation with respect to base materials.
- nanocrystalline soft magnets produced by controlled glass crystallization.
- composite powders containing nano-crystals and amorphous matrix obtained by ball milling ribbons with good properties.

Using metallic glasses for chemical properties resulted in:

- Tailoring nanoporous gold obtained from metallic glass precursors for use in methanol electro-oxidation
- nanoporous gold substrates in ribbon and thin film form for Surface-Enhanced Raman Scattering.
- Synthesis of nanoporous silver for alkaline fuel cells and of nanoporous titanium usable as biocompatible coating.

Taking advantage of the elastic behaviour of metallic glasses has resulted in

- designing a novel switch made of metallic glass foils.

In summary, VitrMetTech proved to significantly advance the fundamental understanding of glass formation of alloys, mechanical stability and properties of metallic glasses and their derivatives. The results gained appreciation in the metallurgical and physical scientific community posing the European partners in the forefront for research in the field. The industrial advancement is significant and ready to be exploited commercially.


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