# MM 13 Symposium Modern Metallic Materials Design III

Time: Tuesday 10:15–13:15 Room: IFW B

MM 13.1 Tue 10:15 IFW B

**Formation and properties of Ce-based Metallic Plastics** — •Bo Zhang and Wei Hua Wang — Institute of Physics, Chinese Academy of Sciences, Beijing 100080, P. R. China

We report the formation and unique properties of the polymerlike Ce-based bulk metallic glasses. Ternary Ce-Al-Cu(Co,Ni) glassy rods of 1-3 mm in diameter can be easily formed in a wide composition range by a conventional copper-mold cast method. Substituting Ce with low cost Ce-rich misch metal (MM), MM-Al-Cu bulk glasses have the similar glass forming ability (GFA) as that of Ce-Al-Cu. With minor addition of extra elements like Fe, Co, Ni, Nb, Zn and Si, the critical diameter of full glassy rods of the matrix Ce-Al-Cu can be remarkably enhanced from 2 mm to at least 3-10 mm. It is found that the often-cited empirical criteria for bulk metallic glass formation cannot interpret the formation and addition effect on GFA in the metallic glasses. The striking effect and mechanism of the microalloying on the GFA of the metallic glasses are studied. These materials with extremely low glass transition temperature Tg (341 K - 439 K, even below the boiling temperature of water) and excellent deformability at low temperatures, which can be regarded as metallic plastics, should have potential applications.

MM 13.2 Tue 10:30 IFW B

**Ductile Cu-Zr- base bulk metallic glasses** — •J. Das[1,2], M.B. Tang[3], K.B. Kim[1], B.C. Wei[4], W.H. Wang[3], and J. Eckert[1] — [1]FG Physikalische Metallkunde, FB 11 Material- und Geowissenschaften, Technische Universität Darmstadt, Petersenstraße 23, D-64287 Darmstadt, Germany — [2]IFW Dresden, Institut für Metallische Werkstoffe, Postfach 270016, D-01171 Dresden, Germany — [3]Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China — [4]Institute of Mechanics, Chinese Academy of Sciences, Beijing 100080, China

Usually bulk metallic glasses exhibit strength values superior to conventional crystalline alloys, often combined with a large elastic limit and rather low Young's modulus. However, the major drawback for engineering applications is their limited room temperature ductility and toughness due to the localized deformation processes linked to shear banding. In this work we report on a new class of metallic glass in a simple Cu-base alloy. Addition of 5 at.% Al increases the glass-forming ability of binary Cu50Zr50. The resulting Cu47.5Zr47.5Al5 glass exhibits high strength (2265 MPa) together with large room temperature ductility up to 18%. After yielding a strong increase in the flow stress is observed during deformation. The interaction and intersection of shear bands increases the flow stress of the material with further deformation, leading to a "work hardening"-like behaviour and yields a continuous rotation of the shear angle up to fracture resulting in a high compressive ductility. This work was funded by the Chinesisch-Deutsches Zentrum für Wissenschaftsförderung (Grant No. GZ032/7) and the Deutsche Forschungsgemeinschaft (Grant Ec111/12)

MM 13.3 Tue 10:45 IFW B

**Local amorphization/nanocrystallization in a bulk Ni45Cu5Ti33Zr16Si1 alloy during solidification** — •K. B. Kim[1], S. Yi[2], H. Choi-Yim[3], J. Das[1,4], W. Xu[1], W. L. Johnson[5], and J. Eckert[1,4] — [1]FG Physikalische Metallkunde, FB 11 Material- und Geowissenschaften, Technische Universität Darmstadt, Petersenstraße 23, D-64287 Darmstadt, Germany — [2]Department of Materials Sciences and Metallurgy, Kyungpook National University, 1370 Sankyuk-dong, Buk-gu, Daegu 702-701, Korea — [3]Department of Physics, Sookmyung Women*s University, Seoul 140-742, Korea — [4]IFW Dresden, Institute für Metallische Werkstoffe, Postfach 270016, D-01171 Dresden, Germany — [5]Keck Laboratory of Engineering Materials, California Institute of Technology, Pasadena, California 91125, USA

A local amorphization/nanocrystallization at the interfaces between B2 ordered Ni(Ti,Zr) phase and NiTiZr phase with P63/mmc has been investigated in a multicomponent Ni45Cu5Ti33Zr16Si1 alloy during solidification. So far there are several well-known mechanisms for interfacial amorphization in the solid state but no interfacial instability-driven amorphization/nanocrystallization during transition from liquid to solid state has ever been reported. The curvature of the interfacial area of the ordered Ni(Ti,Zr) phase is locally negative accompanying reverse atomic diffusion. This results in the frustration of the strong ordering tendency of the Ni(Ti,Zr) phase, and induces local amorphization/nanocrystallization.

MM 13.4 Tue 11:00 IFW B

**Solidification and magnetic properties of Fe-Cr-Mo-Ga-P-C-B bulk metallic glasses** — •Jürgen Eckert[1], Mihai Stoica[2,3], Nicolle Radtke[2], Stefan Roth[2], Ludwig Schultz[2], Jürgen Eckert[1], and Wei Hua Wang[4] — [1]Darmstadt University of Technology, Petersenstr. 23, D-64287 Darmstadt, Germany — [2]IFW Dresden, PF 270016, D-01171 Dresden, Germany — [3]Present address : LTPCM-CNRS UA29, INP Grenoble 38402, France — [4]Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China

Our work focused on $(Fe_{77.5-x-y-z}Cr_xMo_yGa_zP_{12}C_5B_{5.5}$ with (x,y,z) = (4,4,4), (4,4,2), (4,4,0) and (2,2,2)) alloys, which were cast into different geometries. The structure of the samples was checked by X-ray diffraction. Thermal stability studies and isothermal annealing were done in a differential scanning calorimeter (DSC). The fracture strength for the as-cast samples is around 3 GPa and the fracture strain reaches 2%. The Vickers hardness HV for the as-cast samples is about 885, and increases to 902 upon annealing. The fracture of this Fe-based BMG is not propagating along a well-defined direction and the fractured surface looks irregular. Instead of veins, the glassy alloy develops a high number of microcracks. The coercivity of as-cast samples is lower than 10 A/m, decreasing to 0.7 A/m after annealing. The saturation polarization at room temperature is around 0.8 T, increasing up to 1 T at 77 K. This work was funded by the National Science Foundation of China (Grants No. 50371098 and 50321101), the Chinesisch-Deutsches Zentrum für Wissenschaftsförderung (Grant No. GZ032/7) and the Deutsche Forschungsgemeinschaft (Grant Ec 111/12)

MM 13.5 Tue 11:45 IFW B

**Effect of the S/L interface on the solidification of immiscible alloy** — •Jie He[1], Jiuzhou Zhao[1], and Lorenz Ratke[2] — [1]Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, P R China — [2]Institute for Space Simulation, DLR, Cologne 51147, Germany

Directional solidification experiments have been carried out for Al-Bi based immiscible alloys at different solidification rates. The morphology of the solid/liquid (S/L) interface and the possible interaction modes between the droplets and the interface were discussed. A numerical model has been developed based on the population dynamic approach to calculate the formation of the microstructure under the common actions of the minority phase nucleation, growth, droplet motion ahead of the interface and the interaction between the interface and the droplets. Calculations have been carried out according to the practical solidification conditions. The effect of the interaction between the interface and the droplets has been discussed. The calculated results agree well with the experimental ones. This work will favor further understanding the solidification process of immiscible alloys.

MM 13.6 Tue 12:00 IFW B

**Microstructure evolution in rapidly solidified immiscible alloys** — •Frank Schmidt-Hohagen [1], Lorenz Ratke[1], and Jiuzhou Zhao[2] — [1]German Aerospace Center, Inst. of Space Simulation, Köln — [2]Inst. of Metal Research, Chinese Academy of Sci., Shenyang, China

When a hypermonotectic alloy is cooled from the single-phase liquid state into the miscibility gap, the components are no longer miscible and two liquid phases develop. Generally the liquid-liquid decomposition of an initially homogenous liquid begins with the nucleation of the liquid minority phase in the form of droplets, which grow by diffusion. Reaching the non-variant monotectic reaction temperature the matrix liquid decomposes into a solid and a second phase, being not distinguishable from the liquid minority phase that emerged in the miscibility gap. The size spectra of the drops of both processes merge the larger the cooling rate. Within a suitable interval of cooling rates they become, however, distinguishable and then the spectra stemming from the liquid-liquid decomposition gives unique access to the nucleation process inside the miscibility gap. Immiscible alloys like Al-Pb offer a great potential as for instance self-lubricating bearings in automotive applications, if a finely dispersed microstructure is achieved. This can be obtained under conditions of rapid cooling. In order to explore the potential of rapid solidification of immiscible alloys, investigations of the microstructure of different Al-Pb alloys were carried out, varying over a wide range of alloy-concentrations and cooling rates. The experimental results, obtained with the help of different methods, are compared with numerical simulations of the decomposition and the microstructure evolution process.

MM 13.7 Tue 12:15 IFW B

**Rapid solidification of Cu-Co alloy** — •Jiuzhou Zhao[1], Matthias Kolbe[2], Jianrong Gao[3], L. L. Gao[1], Lorenz Ratke[2], and Dieter M. Herlach[2] — [1]Institute of Metal Research, CAS, Shenyang 110016, China — [2]Institute of Space Simulation, German Aerospace Center DLR, D-51170 Cologne, Germany — [3]Key Lab of Electromagnetic Processing of Materials, Northeastern University, Shenyang 110004, China

A model is developed to describe the microstructure evolution in Cu-Co drops during cooling in the metastable miscibility gap in the liquid state. Calculations have been carried out according to the solidification experiments with $Cu_{84}Co_{16}$ alloy under drop tube conditions to the investigation of the kinetics of the liquid-liquid phase transformation in Cu-Co drops. It is demonstrated that the microstructure development is dominated by the common action of the nucleation and the diffusional growth of the minority phase droplets under the rapid solidification conditions. The calculated distribution of Co-precipitates and their average radius as a function of cooling rate are compared with the experimental results. The agreement is satisfactory.

MM 13.8 Tue 12:30 IFW B

**Metal-like growth of silicon during rapid solidification** — •Riping Liu[1], Q. Wang[1], Q. Jing[1], M. Z. Ma[1], Christian Panofen[2], and Dieter M. Herlach[2] — [1]Key Laboratory of Metastable Materials Science and Technology, Yanshan University, Qinhuangdao 066004, Hebei, P. R. China — [2]Institute of Space Simulation, German Aerospace Center DLR, D-51170 Koeln, Germany

In the theory of crystal growth, two idealized mechanisms, lateral growth and continuous growth, have been proposed. Systems with atomically rough or diffuse interfaces are thought to grow by the continuous growth mechanism. In this case, the solid-liquid interface is assumed to be rough on atomic scale so that the atoms can attach themselves uniformly on the interface. The grown crystals present non-faceted surface morphologies, as for metals. On the other hand, the solid-liquid interface may be atomically smooth except for the presence of atomic steps. Crystal growth in this case is lateral or edgewise. Atoms transferring from liquid to solid are first attached to the steps. The finally grown crystals often present faceted morphologies, as for silicon, germanium, and most of compounds.

Silicon is normally considered to grow in a faceted way. From our experiments on solidification of undercooled melt, however, growth of silicon at the beginning is continuous, just like that of metals. But with increasing of the crystal size or decreasing of the undercooling level, it will be transited to the faceted way.

MM 13.9 Tue 12:45 IFW B

**Solidification of undercooled Si, Si-Co and Si-Ge melts** — •Christian Panofen[1], Riping Liu[2], and Dieter M. Herlach[1] — [1]Institue of Space Simulation, German Aerospace Center (DLR), 51147 Köln, Germany — [2]Key Laboratory of Metastable Materials Science & Technology, Yanshan University, Qinhuangdao 066004, P. R. China

Pure Si, dilute Si-Co and Si-Ge melts were undercooled and solidified containerlessly by electromagnetic and electrostatic levitation techniques in a high purity environment. Large melt undercoolings of up to 330 $K$ were achieved by this experiment procedure.

Crystallization of the undercooled melt was externally triggered by a nucleation stimulus needle at preselected undercooling and well defined position at the surface of the sample. In this way the velocity of the solidification front was measured as a function of undercooling by using a high speed CCD camera to record the propagation of the solid-liquid interface through the undercooled melt. High growth velocities of pure Si up to 16 $m/s$ were determined.

The growth behavior was analyzed within current theories of crystal growth in undercooled melts. Special emphasis was placed to the transition from faceted planar to dendritic growth. The results of the growth measurements were correlated to microstructure formation upon undercooling prior to solidification.

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MM 13.10 Tue 13:00 IFW B

**Undercooling and unidirectional solidification of Ni-Cu melts by electromagnetic levitation facility** — •Qiang Wang[1], Riping Liu[1], Q. Jing[1], M. Z. Ma[1], Christian Panofen[2], and Dieter M. Herlach[2] — [1]Key Laboratory of Metastable Materials Science and Technology, Yanshan University, Qinhuangdao 066004, Hebei, P. R. China — [2]Institute of Space Simulation, German Aerospace Center DLR, D-51170 Koeln, Germany

Deep undercooling of metallic melt is a widely used method for investigation of nucleation and crystal growth during solidification. To obtain deep undercooling, electromagnetic levitation has been proved to be one of the most important techniques. A great deal of research has been given to nucleation, crystal growth, metastable phase formation (including metallic glass formation), thermal and physical properties of the undercooled melts, etc. Usually, the melt samples treated by this technique are spherical influenced by the gravity and the surface tension.

In this experiment, we report a new way to produce cylindrical undercooled melt samples with temperature gradients at different levels, and to investigate rapid unidirectional solidification of the undercooled melts. The cylindrical sample of Ni-Cu alloy, 5mm in diameter and 50 mm in height, was wrapped in dehydrated $B_2O_3$ flux in a quartz tube, and then heated by a gradient RF coil in an electromagnetic levitation facility. Treated by several cycles of heating and cooling, undercooling and directional solidification of the sample were obtained.