METGLASS Workshop
Metallic glasses: past, present & future
Sarajevo
Bosnia and Herzegovina
25 - 28 September 2014
www.pmf.unsa.ba/fizika/metglas

Programme
and
Book of Abstracts
Title:

Programme and the Book of Abstracts

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Preface

METGLASS workshop focusses on metallic glasses (amorphous alloys prepared by quenching the molten alloys) which are just one, but distinguished area of research in the disordered condensed matter systems. Because of their conceptual (e.g. the „problem of the nature of glass transition“ etc.) and technological relevance (e.g. transformer cores, medical and sporting goods, etc.) metallic glasses are currently among the most actively studied metallic materials and are likely to remain so in the years to come.

Long tradition (since 1970´s) of the research of metallic glasses in our region, expected to help to reestablish and foster the cooperation (initiated by Professors B. Leontić and E. Babić from Zagreb and Professor E. Girt from Sarajevo) involving laboratories from different institutions and countries. In this highly competitive research such cooperation is neccessary since it enables a more efficient use of manpower and material resources and direct exchange, or confrontation of ideas in this region. In a view of that and of strong aplicative potential of metallic glasses we ensured the participation of the researchers from the institutions with direct links to industry (The Metallurgical Institute "Kemal Kapetanović" Zenica, University of Zenica and Faculty of Metallurgy, University of Zagreb), which is a novel feature of METGLASS.

As a venue of METGLASS we have chosen Sarajevo (Bosnia and Herzegovina) both because of a very active research of metallic glasses at the Faculty of Sciences of the University of Sarajevo and because of central position of Sarajevo in our region. Accordingly, most of the work on organization of METGLASS was skillfully performed by the researches from the group of Dr. Suada Sulejmanović (and their students) in Sarajevo. In spite of very short notice (the announcement in a late July) the workshop attracted considerable attention as seen from 40 participants (including about dozen students) from four countries. All the participants were most impressed by the excellent local arrangements, which had been organized by the members of the Local Committee.
A three day programme featured a series of „horizontal“ themes (preparation, structure, relaxation, crystallization and properties) culminating in two round table discussions, numerous informal discussions and local media coverage. The enclosed abstracts of the plenary/invited talks show a broad range of aspects of metallic glasses covered at METGLASS. We hope that the post-workshop results will be equally good, in particular that fruitful collaborations will develop in the years to come and look forward for the next workshop.

Organizing committees
Faculty of Science Sarajevo
5 November, 2014
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K. Biljaković (Institute of Physics, Zagreb, Croatia)
M. Đekić (Faculty of Science, University of Sarajevo, Bosnia and Herzegovina)
D. Starešinić (Institute of Physics, Zagreb, Croatia)
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A. Salčinović Fetić (Faculty of Science, University of Sarajevo, Bosnia and Herzegovina)
Programme

Thursday, September 25, 2014

14:30-15:00 Registration
15:00-17:00 Lectures (chairman E. Babić)
   15:00-15:45 S. Sulejmanović, NON-ISOTHERMAL CRYSTALLIZATION IN PARTIALLY CRYSTALLINE METALLIC GLASS Fe\textsubscript{38}Ni\textsubscript{36}B\textsubscript{18}Si\textsubscript{8}
   15:45-16:10 O. Milat, X-RAY AND ELECTRON DIFFRACTION STUDIES OF AMORPHOUS AND PARTIALLY DISORDERED STRUCTURES
   16:10-16:35 D. Pajić, EVOLUTION OF MAGNETIC AND CHEMICAL ORDER ON NANO-SCALE IN Hf-Fe METALLIC GLASSES
   16:35-17:00 R. Ristić, MAGNETIC SUSCEPTIBILITY AND SUPERCONDUCTIVITY OF TE-TL METALLIC GLASSES: INFLUENCE OF ELECTRONIC STRUCTURE

Friday, September 26, 2014

8:45-9:00 Opening ceremony
9:00-11:00 Lectures (chairman S. Sulejmanović)
   9:00-9:45 E. Babić, METALLIC GLASSES: PAST AND PRESENT
   9:45-10:10 A. Salčinović Fetić & K. Hrvat, CuZr (BULK) METALLIC GLASSES: PRODUCTION, PROPERTIES AND APPLICATIONS
   10:10-10:35 M. Đekić, K\textsubscript{0.3}MoO\textsubscript{3} THIN FILMS WITH CHARGE DENSITY WAVES (CDW)
   10:35-11:00 D. Dominko, MECHANISMS OF VARIABLE RANGE HOPPING (VRH)

11:00-11:30 Coffee break
11:30 – 13:00 Lectures (chairman K. Biljaković)
   11:30-12:15 O. Beganović, B. Fakić & M. Rimac, THE AVAILABLE RESEARCH CAPACITY IN THE FIELD OF NEW MATERIALS DEVELOPMENT IN THE INSTITUTE OF METALLURGY “KEMAL KAPETANOVIĆ” ZENICA
   12:15-12:40 Lj. Slokar, RESEARCH INFRASTRUCTURE AT FACULTY OF METALLURGY IN SISAK
   12:40-13:05 K. Zadro, THERMAL AND GEOMETRICAL MAGNETIC PHASE TRANSITION IN CERTAIN AMORPHOUS FERROMAGNETS
13:05-15:00 Lunch
15:00 – 17:00 Lectures (chairman A. Kuršumović)
   15:00-15:45 N. Mitrović, IRON BASED BULK METALLIC GLASSES
   15:45-16:10 D. Stanić, MAGNETIZATION PROCESSES IN METALLIC GLASSES
   16:10-16:35 M. Prester, MAGNETIC DYNAMICS STUDIES OF THE METALLIC GLASS Fe_xNi_{80-x}B_{18}Si_2 SYSTEM
   16:35-17:00 M. Očko, PHYSICAL PRINCIPLES OF THERMOELECTRIC DEVICES: COULD AMORPHOUS RIBBONS FULFIL THE REQUIREMENTS OF THERMOELECTRIC DEVICES

17:00-17:30 Coffee break
17:30-18:30 Round table
19:30- Workshop dinner

Saturday, September 27, 2014

9:00-11:00 Lectures (chairman N. Mitrović)
   9:00-9:45 A. Kuršumović, STRUCTURAL RELAXATION IN METALLIC GLASSES BELOW T_g
   9:45-10:10 K. Biljaković, FINGERPRINT OF GLASSES IN LOW TEMPERATURE THERMODYNAMICS
   10:10-10:35 D. Starešinić, ANALYSIS OF HEAT CAPACITIES OF METALLIC GLASS ALLOYS Cu_{55}Hf_{45-x}Ti_x
   10:35-11:00 D. Ristić, RAMAN SCATTERING ON AMORPHOUS AND NANO-COMPOSITE MATERIALS

11:00-11:30 Coffee break
11:30-12:30 Round table
13:00-Excursion
PLENARY LECTURES
NON-ISOTHERMAL CRYSTALLIZATION IN PARTIALLY CRystALLINE METALLIC GLASS Fe$_{38}$Ni$_{36}$B$_{18}$Si$_8$

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Partially crystalline metallic glass Fe$_{38}$Ni$_{36}$B$_{18}$Si$_8$ in the form of ribbons was obtained by melt-spinning in the Laboratory of Metal Physics, Faculty of Science in Sarajevo, in 1990. The diffractogram shows a set of crystalline peaks superimposed on an amorphous matrix and we characterized those as partially crystalline. Scanning electron microscopy with energy-dispersive X-ray spectroscopy was performed to examine the homogeneity and chemical composition of the material. Differential scanning calorimetry shows a two-step crystallization process. Applicability of Johnson-Mehl-Avrami model adapted for non-isothermal process was confirmed. The average values of overall activation energies for the first peak is 337 kJ/mol and for the second peak is somewhat larger, 346 kJ/mol. The values of overall activation energies of crystallization obtained for both peaks by means of different methods are in good agreement. The value of the Avrami coefficient indicates abnormal grain growth already observed in multicomponent metallic glasses of similar composition.

Acknowledgement: This work is dedicated to the memory of Redžep Baltić, Master of Science and assistant at the Department of Physics, who perished while returning home from work in April, war year of 1993. The examined sample is one of the ferromagnetic samples made by him.
We start with a brief review of progress in research and applications of metallic glasses (MG) over last 60 years. The milestones, such as their discovery, fabrication of bulk MGs (BMG) and the progress in commercialization of MGs will be emphasized. Next, we briefly review early research of rapidly quenched alloys in Zagreb and fruitful collaboration in this research between Zagreb and Sarajevo (initiated by Professors B. Leontić and E. Girt in 1969.) We show that till 1990, the research and fabrication of MGs in Zagreb and Sarajevo was at the forefront of research in this field. This showed very clearly at the EC-Yu Colloquium on Advanced Materials, held in September 1988, in Sarajevo. We compare some predictions from this Colloquium with the present achievements in the field of MGs. Further, we outline the impact of the discovery of BMGs in 90-ties (at first in multicomponent and then in binary transition metal alloys) on the further development of this field of research. We will use binary BMGs (which are the base of more important multicomponent BMGs) in tackling still unsolved problem of the origin of high glass forming ability (GFA), which enables the formation of BMGs. Some largely ignored features of binary Cu-Ti,Zr,Hf MGs, such as ideal solution behaviour are emphasized and their relation with GFA and formation of BMGs in Cu-Zr,Hf alloys is proposed. On the basis of previous results for Cu-Zr MGs we propose a novel criterion for selection of potential BMG forming alloys, which may apply to multicomponent systems based on transition metals, too.
IRON BASED BULK METALLIC GLASSES

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Multicomponent Fe-based alloys of complex chemical compositions: A1/A2: Fe_{72-x}Nb_xAl_5Ga_2P_{11}C_6B_4 (x=0, 2), A3: Fe_{77}Al_{2.14}Ga_{0.86}P_{8.4}C_{5}B_{4}Si_{2.6}, B1/B2/B3: Fe_{62-x}Cu_xCo_8Ni_6Zr_8Nb_2B_{14} (x=0, 0.5 and 1) and C1: Fe_{65.5}Cr_4Mo_4Ga_4P_{12}Cr_5B_{5.5} were prepared by different processing.

(1) ribbons which are about d=30 mm thick and w=2 mm wide were produced by rapidly quenching using a single-roller technique in a vacuum chamber,

(2) rod form samples were prepared by injection (or suction) cooper mold casting in a vacuum chamber,

(3) hot compaction of amorphous powders prepared by ball milling of as-spun ribbons.

Thermal and microstructure characterization (performed by DSC, XRD and Mössbauer spectroscopy) was used to correlate glass forming ability, microstructure and thermo/thermo-magnetic treatments with optimum soft magnetic properties or improved mechanical properties.
THE AVAILABLE RESEARCH CAPACITY IN THE FIELD OF NEW MATERIALS DEVELOPMENT IN THE INSTITUTE OF METALLURGY “KEMAL KAPETANOVIĆ” ZENICA

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Among other activities Metallurgical Institute "Kemal Kapetanović" is engaged in experimental research in the field of metallurgy and metallic materials, from the experimental production and processing to the production of prototypes and small series. Also, the Institute is engaged in testing of the materials in order to determine their characteristics.

Some of Institute's equipment for liquid metal production, plastic deformation and material characterization are presented in this presentation. Equipment for liquid metal production enables to eliminate one or more of metallurgical influencing factors that determine the quality of the liquid metal: refractory materials of the crucible, slags and atmosphere. Equipment for metal forming by plastic deformation includes equipment for hot, warm and cold deformation, while test equipment includes equipment for chemical analysis, and mechanical and metallographic testing.
STRUCTURAL RELAXATION IN METALLIC GLASSES BELOW $T_g$

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Metallic glasses, as well as other glasses, form by continuous “hardening” during undercooling of a melt at a sufficiently high rate, “freezing” at glass transition temperature ($T_g$) before crystallization has time to nucleate and develop. The formed state is seldom fully relaxed, but incorporates quenched-in defects associated with a so-called free volume, $v_f$. During a subsequent heating $v_f$ is irreversibly annealed out below $T_g$ ($\alpha$ relaxation), resulting in a meastable amorphous structure with the properties that can be cycled reversibly between the values characteristic of different annealing temperatures ($\beta$ relaxation).

The $\beta$ relaxation has a strong impact on density, Young’s modulus, creep and creep recovery, free energy and stress-relief. At least two distinct mechanisms were observed, easily illustrated by so called cross-over effect showing that the glass state is not uniquely defined by a physical property value, rather thermal history must be taken into account. A spectrum of relaxation times has been used to describe rather complex relaxation kinetics. Some early (1980s) results as well as more recent results are presented in a variety of super-quenched glassy (tapes) systems like: Cu-Zr, Cu-Ti, Cu-Hf, Cu-Hf-Ti, Cu-Zr(Ti, Hf), Fe-Ni-B, Al-Y-Ni. The appearance of $\beta$ relaxation is similar to that observed in short range ordering of crystalline alloys and it is proposed that similar changes in short range order occur in metallic glasses. Differences in the kinetics of initial relaxation and subsequent ordering and disordering are accounted for in terms of $v_f$ loss.
INVITED LECTURES
X-RAY AND ELECTRON DIFFRACTION STUDIES OF AMORPHOUS AND PARTIALLY DISORDERED STRUCTURES

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Atomic structure of metallic glasses is not completely disordered as one would think. It has some degree of order intermediate between a crystal and a liquid, eventually. A number of traditional and new x-ray and electron diffraction methods are outlined here in order to reveal how they provide information on type, level, and range of crystal structure disorder. A few case studies of short-range and long-range (dis)order in metallic alloys and ceramics will be presented: crystallization of Zr$_{75}$Fe$_{25}$ amorphous phase; cation subsystem “melting” in superionic phase of the Cu$_{2-x}$Se crystal; absence of 3D lattice periodicity in Al$_{65}$Cu$_{23}$Co$_{12}$ decagonal quasicrystal; precipitation of nanocrystals within amorphous WC$_{1-x}$ thin films and multilayers; planar (2D) and linear (1D) disorder of subsystems in composite structures of two compounds related to high-T$_c$ superconducting cuprates.

Information on crystal structure is usually obtained either in reciprocal space by a kind of diffraction/scattering experiment, or in direct space by some kind of atomic resolution microscopy. This correspondence and relations between the direct and reciprocal space will be illustrated by switching between imaging and diffraction mode in a transmission electron microscope. Contemporary diffraction techniques are based on synchrotron, neutron and/or electron beams which spatially scan across/through the specimen, on short pulses, and on extended continuous range of wavelengths. In addition, various kind of temporary resolved measurements, and energy resolved spectroscopy (such as Extended X-ray/Neutron Absorption Fine Structure, or Electron Energy Loss Spectra analysis) provide element and site specific information on electronic charge and spin state. Advanced computer control experiments with acquisition and processing of “multichannel data sets” improve our insight into atomic structure and dynamical properties of complex materials ranging from highly ordered proteins to highly disordered amorphous alloys.
EVOLUTION OF MAGNETIC AND CHEMICAL ORDER ON NANO-SCALE IN Hf-Fe METALLIC GLASSES

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Static and dynamic magnetic behaviour of Hf100-xFe x (20 ≤ x ≤ 90) metallic glasses in the temperature range 1.5–300 K and magnetic fields up to 5.5 T reveal some important conclusions about the chemical order. For 25 ≤ x ≤ 43 the magnetic susceptibility increases rapidly with x due to the onset of magnetic correlations in the vicinity of the transition into the ferromagnetic state, xc~50. However, for 35 ≤ x ≤ 43 the alloys consist of self-assembled magnetic nanoclusters embedded within a paramagnetic matrix. This was concluded after study of the slow dynamics of magnetization and characteristic behaviour of ac-susceptibility, which were explained with the thermal activation of magnetic moments of the nano-clusters over the anisotropy barriers. These clusters grow rapidly with increasing x. In this way, magnetic method showed as very convenient in indicating the evolution of chemical order on nanometer scale. Altogether, Hf-Fe glassy alloys evolve from the superconducting and paramagnetic through the superparamagnetic to the ferromagnetic state with increasing iron content. This might be of relevance for other systems with the non-trivial magnetic behaviour.
MAGNETIC SUSCEPTIBILITY AND SUPERCONDUCTIVITY OF TE-TL METALLIC GLASSES: INFLUENCE OF ELECTRONIC STRUCTURE

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TE-TL (TE=Ti,Zr,Hf and TL=Ni,Cu) alloys show wide glass-forming ranges which enables detailed study of the change in the electronic structure and properties on alloying and, thus a thorough comparison between the model and experimental data. Amorphous TE-TL alloys have been extensively studied in recent decades and interest in these alloys further increased after the discovery of TE-TL based bulk metallic glasses (BMGs). In amorphous TE-TL alloys the properties that are directly related to the electronic density of states (DOS) often show linear variations with TL content. The effect of alloying with TL can be approximated by the dilution of amorphous TE. Thus, one can extrapolate the data for glassy TE-TL alloys to zero TL content in order to deduce the properties of amorphous TE (also in Cu-TE alloys we extrapolate data to zero TE to deduce the properties of amorphous Cu). The magnetic susceptibility was measured with a SQUID magnetometer MPMS in a magnetic field B<5.5T or with Faraday method. Superconductivity transition temperature was obtained from resistivity measurements. We explained magnetic susceptibility by adding Pauli susceptibility $\chi_p$, the temperature-independent ionic core diamagnetism $\chi_{ion}$ and the orbital paramagnetism $\chi_{orb}$. The Pauli paramagnetism of the d-band $\chi_p$ is enhanced over the free-electron value, $\chi_0^0$, due to exchange interaction, $\chi_p=S\chi_0^0$, where S is the Stoner enhancement factor. $\chi_p$ is only weakly dependent on temperature. We use the specific heat and superconducting transition temperature data (ours and from literature) to determine the electron density of states (bare and “dressed”), corresponding free-electron value for the Pauli paramagnetism $\chi_p^0$, and the Stoner enhancement factor S. All observed and derived parameters depend sensitively on selected TE.
CuZr (BULK) METALLIC GLASSES: PRODUCTION, PROPERTIES AND APPLICATIONS

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Metallic glasses belong to a variety of new materials produced in the last fifty years. Bulk metallic glasses (BMG) represent the materials of the future, since they have great potential for practical use.

This paper consists of a short historical introduction to metallic glasses and systematic review of properties and applications of produced conventional and bulk CuZr metallic glasses. The CuZr system is particularly interesting because it is one of the few binary systems that can form BMGs.

The results and experience in production of ribbon-form partially crystalline CuZr metallic glasses in the Metal Physics Laboratory at Faculty of Science in Sarajevo is also presented. In order to examine and explain the extraordinary properties of these materials, several characterizations have been made.
K$_{0.3}$MoO$_3$ THIN FILMS WITH CHARGE DENSITY WAVES (CDW)

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Quasi-one-dimensional metal (q-1D) K$_{0.3}$MoO$_3$, exhibits so-called Peierls transition to a charge density wave (CDW) state with periodic charge density modulation and concomitant lattice distortion at a transition temperature T$_p$=180 K. Despite the fact that the physical properties of q-1d bulk materials have been widely investigated, they can drastically change due to reduced dimensionality if the material is in the form of thin film.

We present results of the production of K$_{0.3}$MoO$_3$ thin films by pulsed laser deposition (PLD). Standard characterization techniques showed that our films are composed of nano-sized metallic grains and presence of CDW in grains was unambiguously proved by femto-second time resolved spectroscopy (fs-Trs). This technique also showed that the amplitude mode appears in films at a temperature that is some 30 K lower than in the crystal.

Transport measurements in a wide temperature range indicated smeared Peierls transition in some films, at a temperature that is some 30 K lower than in bulk, which is in accordance with fs-Trs. We have established a connection between film morphology and resistance, namely films with better ordering show lower resistance and more pronounced anomaly at 150 K. Furthermore, our films appear to be well fit by variable range hopping conductivity (VRH) in the almost entire temperature range, which is a characteristic of disordered materials.
MECHANISMS OF VARIABLE RANGE HOPPING (VRH)

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The aim of this presentation is to introduce various types of VRH (variable range hopping) process: Mott and Efros-Shklovskii regime and VRH in metallic grains. Transport and dielectric properties often point to the VRH or VRH-like behavior. I will discuss how to use data analysis and fitting parameters to evaluate whether or not VRH process is taking place in studied samples.
RESEARCH INFRASTRUCTURE
AT FACULTY OF METALLURGY IN SISAK

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In June 1991 Faculty of Metallurgy became an independent scientific and educational unit of the University of Zagreb. The activities of the Faculty of Metallurgy are conducted in three Departments consisting of the total of seven Laboratories and one Chair, as well as the Secretariat. Research activities in Department of Process Metallurgy include the production of raw iron and steel, measurements of metals resistance to various forms of corrosion, structure and properties of carbon materials, usage of waste and secondary products of metallurgical processes etc. Investigations in Department of Physical Metallurgy are based on research of constitution and structure of alloys, production of alloys in the laboratory conditions, testing of materials by standard methods, thermal processing, welding etc. In Department of Mechanical Metallurgy research activities include testing of deformability of metals materials, numerical analyses, research of heat transfer etc. Research in general is primarily focused on microstructure and properties of various metal and non-metal materials and it is related to the energy industry and environment protection. Faculty experts are actively involved in scientific research solving the real technical and technology problems in industry using the equipment existing at Faculty such as: light microscope with digital camera and corresponding software, scanning electron microscope with energy-dispersive spectrometer, differential scanning calorimeter, potentiostat/galvanostat, atomic absorption spectrometer, machine for mechanical testing, Vickers hardness tester, different pyrometers as well as devices for metallographic specimen preparation etc.
THERMAL AND GEOMETRICAL MAGNETIC PHASE TRANSITION IN SOME AMORPHOUS FERROMAGNETS

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We have analysed the process of thermal demagnetization and magnetic phase transition in several amorphous FeₓNi₈₀₋ₓB₁₈Si₂ alloys with the concentrations of magnetic atoms, x, in the vicinity of the critical concentration for the onset of the long-range ferromagnetic order, x_c ≈ 2.3 at% Fe. We have assumed that the (dis)appearance of long-range magnetic order is a percolation phenomenon i.e. that the percolation correlation length describes the magnetic structure of the alloys with the concentration close to the magnetic percolation threshold.

High sensitivity ac susceptibility measurements show that disorder does not affect the critical behaviour in the immediate vicinity of the transition temperature, T_c, but manifests itself in a broader range above T_c. The non-monotonic variation of the effective critical exponent, γ*, of the initial magnetic susceptibility is found to be less pronounced with increasing x-x_c and disappears around x=20. It has been suggested that such variation of γ* is a consequence of the magnetic inhomogeneity and reflects an interplay between the temperature dependence of the magnetic correlation length and the size of the magnetic inhomogeneities given by the percolation correlation length. Also, we have described the thermal demagnetization in terms of magnetic excitations including the contributions of both the long-wavelength magnons and short-wavelength (localised) fractons, depending on the ratio of the excitation’s wavelength and the percolation correlation length. Our results indicate that the magnetic inhomogeneity, inherent to the dilute ferromagnets, is well described in terms of the percolation theory.
The measurements on amorphous ferromagnetic ribbons have shown that direct (\(J_D\)) and alternating (\(J_A\)) core-current can affect the \(M-H\) loop and cause effects like decrease the coercive field \(H_c\) (hence decrease hysteresis loss \(E\)), shift the center of the \(M-H\) loop (C) along the \(H\)-axis, and change the permeability, maximum (\(M_m\)) and remanent (\(M_r\)) magnetization of the sample. These effects are associated with transverse field \(H_p\) generated by \(J_D\) (static \(H_p\)). The magnitude of \(H_p\) increases linearly with the distance from the center of the ribbon and reaches the maximum at its surface, hence the term “surface field”. In order to explain the observed effects and to better understand the magnetization processes in these samples, a simple phenomenological model for the influence of surface fields \(H_p\) on the magnetization of the sample has been developed.

For the coercive field, the model predicts linearly decreasing \(H_c\) with \(H_p\) (at not too small \(H_p\)). The measurements of \(H_c\) vs. \(H_p\) for a number of amorphous ferromagnetic ribbons (both magnetostrictive and nonmagnetostrictive) agree well with the model prediction for moderate values of static \(H_p\), whereas, at elevated \(H_p\)s, \(H_c\) tends to saturation. Furthermore, in very soft amorphous ferromagnetic ribbons surface pinning of domain walls leads to deviation in behavior of \(H_c\) from that predicted by simple model on all values of \(H_c\) and for all \(H_p\) (static and dynamic). The observed deviations from the model predictions motivated us to revise the model taking into account the complex domain structure of a real sample and the influence of the high surface field on this structure. In addition to the description of the ‘unusual’ influence of \(H_p\) (both static and dynamic) on the \(M-H\) loops and their parameters for nanocrystalline FeCuNbSiB ribbon we also present here an improved model, which fully accounts for the observed phenomena.

1. S. Sabolek, E. Babić, I. Kušević, M. Šušak, D. Posedel and D. Stanić, *The origin of the surface field enhanced coercive field in nanophase Fe\(_{73.5}\)Cu\(_{1}\)Nb\(_{3}\)Si\(_{15.5}\)B\(_{7}\) ribbon*, Fizika A, 15 (2006) 1-16
MAGNETIC DYNAMICS STUDIES OF THE METALLIC GLASS
Fe$_x$Ni$_{80-x}$B$_{18}$Si$_2$ SYSTEM

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Paradigm of Reentrant Phase Transition phenomena (RSG) permeates understanding of amorphous dilute ferromagnets’ magnetism for decades. The main idea is that a combined effect of frustrated exchange interactions and disorder renders the spin glass (SG) order more favourable at low temperatures than the ferromagnetic long range order dominating at higher temperatures (up to the Curie temperature). There is therefore a phase transition (or cross-over) to the ground SG state at the reentrant phase transition/cross-over temperature $T_c$, indicated by peak in imaginary part of AC susceptibility and decrease in the real one, the RSG’s hallmarks.

Within our general programme of magnetic dynamics studies of various ferromagnetic systems, by the use of high resolution AC susceptibility and, more importantly, dynamic hysteresis in the minor loops range, we have recently measured the ribbon-shaped samples from the Fe$_x$Ni$_{80-x}$B$_{18}$Si$_2$ series. The main experimental parameter in the latter studies was the area swept by minor hysteresis loop. On basis of our previous experience with ferromagnetic domain wall dynamics in other ferromagnetic systems we were looking for experimental fingerprints of this dynamics in the subject amorphous ferromagnet system. Besides characteristic behaviour of minor loop area, a simple but realistic model for domain wall dynamics reveals the elliptic shape of minor loops, with the ellipsis’s long axis levelling-off by cooling, as a second feature characterizing the latter dynamics. Surprisingly, both features were found to characterize our observations deep in the ferromagnetic phase of the subject samples investigated so far, at temperatures usually referred to as the reentrant phase transition temperature $T_c$. We therefore conclude that the latter observations indicate the relevance of domain wall dynamics for interpretation of low-temperature physics of amorphous diluted ferromagnets.
PHYSICAL PRINCIPLES OF THERMOELECTRIC DEVICES: COULD AMORPHOUS RIBBONS FULFIL THE REQUIREMENTS OF THERMOELECTRIC DEVICES

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Thermoelectric (TE) devices work without pollution, without CO₂ and other greenhouse gases emission and can convert waste heat from various sources into electrical energy. These characteristics are quite in accordance to Kyoto's demands. However, in spite of this and many good technical properties, the usage of TE devices is very poor because of their low power output and of low cost effectiveness. Power output of TE devices is mainly determined by the TE figure of merit (ZT) of TE working materials: $ZT = (\alpha^2 \sigma / \kappa) T$, where $\alpha$ is the Seebeck coefficient, $\sigma$ is electrical conductivity and $\kappa$ is specific heat conductivity and $T$ is temperature. One takes if the ZT value of the working materials was 3, TE devices could replace many of the corresponding conventional ones. Kyoto conference renewed the work on the improvements of the characteristics of TE devices. Thus searching for or creating good TE materials became an attractive area of solid state, both experimentalist and, moreover, theoreticians because the problem is still on physically fundamental level. Although, some research recently announced materials which have ZT close to 3, in commercial usage is only Bi₂Te₃ which has ZT ≈ 1.

Here we shall discuss possibility of using amorphous ribbons as TE material. The amorphous character of this material goes in favour, as well as relatively low resistivity but the Seebeck coefficient of amorphous materials is very low and thus usually one does not discuss such a possibility. However, we shall show two points, a physical one, and an ecological one, which indicate possible use of amorphous materials, not going into good properties of ribbons which are also demanded for TE working materials. We argue that ZT higher than 3 is not a decisive criterion when a TE device uses waste heat, hence, a free energy. But, a TE working material should fulfil:

$$P_{C_{max}} = \frac{\alpha_{np}^2 T_c^2}{2R} - K \Delta T > 0$$

In the lecture we shall explain this expression, but here we can say that this criterion is less restrictive than ZT > 3.

Ecological reasons and global warming will force us to find every possibility for TE devices application, especially these ones which use waste heat. In addition, we think that the future cost effectiveness will be rather different than today's one because of expected imposed "ecological laws" which mankind certainly should bring.

The lecture will be given in form:
1. Introduction
2. Thermoelectric effects
3. Thermoelectric devices
4. On some characteristic/possible TE materials
   Could amorphous ribbons fulfil the requirements of TE devices?
5. Perspectives of applications of TE devices
FINGERPRINT OF GLASSES IN LOW TEMPERATURE THERMODYNAMICS

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The Debye model predicts a $T^3$ dependence of the specific heat $C_p$ at sufficiently low temperatures ($T$) in insulators and it reproduces a wealth of data in isotropic crystals. Amorphous compounds also show universal low-$T$ thermal properties which are, however, anomalous with respect to those of the corresponding crystalline phases. The best known fingerprints of glasses appear in specific heat and thermal conductivity. There are two anomalies that show up as an excess to the constant $C_p(T)/T^3$ in glasses and amorphous systems: the upturn below 1 K and a broad bump at $T\sim10$ K. As little was known about the second feature other than its bosonic character, so it became known as the “boson peak” (BP). Since then, the origin of the BP has remained a puzzle and the main topics in a very wide field of glasses from both experimental and theoretical point of view. There are even some expectations that the clarification of the BP origin may also help to solve an even older problem, namely to explain the peculiarities of the glass transition itself.

In this short overview two limiting cases will be presented for long (L) and short (S) range (R) order (O): „superstructural glass” (LRO) and metallic glass (SRO). On general grounds we show that the $C_p$ of incommensurate (IC) modulated systems bears many similarities with that of amorphous systems and that IC systems could provide a model approach to low-$T$ behavior of glasses. On the other side, the possible correlation between glass forming ability (GFA) and BP in metallic glasses might shed new light to this puzzle.
ANALYSIS OF HEAT CAPACITIES OF METALLIC GLASS ALLOYS
\( \text{Cu}_{55}\text{Hf}_{45-x}\text{Ti}_x \)

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We have investigated the low temperature heat capacity of \( \text{Cu}_{55}\text{Hf}_{45-x}\text{Ti}_x \) metallic glasses in the entire range of Ti concentrations, \( x=0-45 \). We have established the most appropriate procedure for the analysis of data and for the estimate of low temperature electronic and phonon contributions. Both contributions exhibit monotonous Ti concentration dependence, demonstrating that there is no relation of either the electron density of states at the Fermi level or the Debye temperature to the increased glass forming ability (GFA) in the Ti concentration range \( x=15-30 \). Our results indicate that the thermodynamic parameters (e.g. reduced glass temperature) remain the most assertive indicators of GFA for bulk metallic glasses. However, we discuss the possibility to correlate more subtle glass-like contributions to the heat capacity, such as the Boson peak, with GFA.
RAMAN SCATTERING ON AMORPHOUS AND NANO-COMPOSTIE MATERIALS

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Amorphous and nanocomposite materials have very different Raman spectra in respect to bulk crystalline materials. In particular the modes in these materials tend to be localized because of disorder induced localization (amorphous materials) or quantum confinement (nanocomposite materials). This affects greatly the Raman spectra of both the acoustical and optical phonons. Particularly interesting is the Raman spectrum of acoustical phonons which exhibits low frequency peaks not observed in Raman spectra of crystalline materials. We will discuss these effects both from a theoretical and an experimental point of view for both amorphous and nanocrystalline materials.
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**Postscript**

This workshop on Metallic Glasses arose out of an idea of dr. Katica Biljaković from Institute of Physics in Zagreb to organize an international meeting devoted to all aspects of disorder in condensed matter systems. Such a meeting would identify areas of special interest in this broad research field, as well as the mutual interests of the participants and therefore help to develop (or „thicken-up”) the cooperation among the participants from different institutions. Simultaneously, the anticipated significant participation of the students and post-docs at the meeting was hoped to arise the awareness of students and young researchers of this, probably most challenging, field of research in the contemporary condensed matter physics and the material science.

Since this ambitious (demanding) idea came out somewhat too late (June) to be realized in the same academic year, it was soon replaced by the idea of the present METGLASS workshop.

The pleasure and enthusiasm following the workshop, shared by all participants, guarantees a basis and start of a traditional gathering with the same subject which could in the future develop into a larger scientific conference and METGLASS organisation every two years.

Following an arrangement made at METGLASS, students of the Faculty of Science visited the Metallurgical Institute „Kemal Kapetanović“ at the University of Zenica. In addition to a tour of the laboratories, the work on several theses was arranged.

*Visit to the Metallurgical Institute „Kemal Kapetanović“ in Zenica*

At the METGLASS round table possibilities of collaboration were presented which would reflect primarily in the use of the Institute’s research infrastructure for the needs of scientific research and writing of students’ theses.
25 - 28 September 2014, Faculty of Science, Sarajevo, BiH
www.pmf.unsa.ba/fizika/metglas

METGLASS Workshop

Metallic glasses: past, present & future

Contemporary research and production of metallic glasses (MG)

Due to exceptional fundamental and technological importance of these novel materials, especially of bulk metallic glasses (BMG), our intention is to foster the collaboration between research groups in Zagreb and Sarajevo, to include researchers from wider region and to establish the cooperation with relevant industries. Workshop will provide deep insights into this very active field to younger researchers and will also help to find out the needs for the upgrades in research and production capacities for BMG in this region.

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Faculty of Science, University of Sarajevo, BiH
Faculty of Science, University of Zagreb, Croatia
Institute of Physics, Zagreb, Croatia

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