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"Studies of Alloy Structures and Properties"

Annual Summary Report

1 December 1976 to 1 December 1977

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Submitted by:

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During the period of twelve months covered in this summary (1 December 1976 to 1 December 1977 the following staff members and graduate students have been directly involved in the research programs:

Dr. Pol Duwez, Professor of Applied Physics and Materials Science

Dr. W. L. Johnson, Assistant Professor of Materials Science since April 1977

Dr. J. Durand, Research Fellow in Applied Physics

Dr. R. D. Shull, Research Fellow in Materials Science since January 1977

Dr. Ellen R. Domb, Visiting Research Associate in Applied Physics since July 1977

S. J. Poon, Graduate Student in Applied Physics

A. Williams, Graduate Student in Applied Physics

In addition, about six undergraduate students have worked part time as student assistants.

During this contract period, the following reports and publications have been prepared:

TECHNICAL REPORTS:

No. 80
CALT-822-91	Ferromagnetic and Antiferromagnetic Coupling
in Amorphous $(\text{Ni}_{100-c}\text{Mn}_c)_{78}\text{P}_{14}\text{B}_8$
A. Amamou
December 1976
No. 81
CALT-822-92	Spin-Glass Ordering and Superconductivity in
Amorphous $\text{La}_{80}\text{Au}_{20}$ Alloys Doped with Gd
S. J. Poon and J. Durand
January 1977
No. 82
CALT-822-93	Magnetic Field Dependence of Resistivity Minima
in Amorphous La-Gd-Au Alloys with High Gd
Content
S. J. Poon, J. Durand, and M. Yung
February 1977
No. 83
CALT-822-94	Remanent Magnetization of Amorphous La-Gd-Au
Alloys with High Gd Content
S. J. Poon and J. Durand
April 1977
No. 84
CALT-822-95	NMR and Mössbauer Studies of the Amorphous
System $\text{Fe}_{79}\text{P}_{21-x}\text{B}_x$
A. Amamou and J. Durand
May 1977
No. 85
CALT-822-96	Magnetic and Transport Properties of Amorphous
Ferro Magnetic Gd-Au, Gd-Ni and Gd-Co Alloys
Obtained by Splat-Cooling
J. Durand and S. J. Poon
June 1977
No. 86
CALT-822-97	Paraconductivity of Three Dimensional Amorphous
Superconductors-Evidence for a Short Wavelength
Cutoff in the Fluctuation Spectrum
W. L. Johnson
October 1977

PUBLICATIONS

1. Pol Duwez, "Glass and Glass Products", McGraw-Hill Yearbook of Science and Technology 1976 Review, 242-244, (1977).
2. S. J. Poon and J. Durand, "Remanent Magnetization of Amorphous La-Gd-Au Alloys with High Gd Content", Commun. on Physics, 2, 87-93 (1977).
3. R. Hasegawa, W. A. Hines, L. E. Kabacoff and Pol Duwez, "Nuclear Magnetic Resonance Study of ^{31}P and ^{195}Pt in the Metallic Glass System $(\text{Ni}_{1-x}\text{Pt}_x)_{75}\text{P}_{25}$ ", Solid State Commun., 20, 1035-1038 (1976).
4. J. Durand, "Concentration Dependence of the Magnetic Properties in Amorphous Fe-P-B Alloys", IEEE Transactions on Magnetics, MAG-12, 6, 945-47 (1976).
5. S. J. Poon and J. Durand, "The Ruderman-Kittel-Kasuya-Yosida Interaction in Amorphous $\text{La}_{80}\text{Au}_{20}$ Alloys with Dilute Gd Impurities", Solid State Commun., 21, 793-795 (1977).
6. A. Amamou, "Magnetism and Local Environment Model in $(\text{Ni}_{1-x}\text{Co}_x)_{0.78}\text{P}_{0.14}\text{B}_{0.08}$ Amorphous Alloys", IEEE Transactions on Magnetics, MAG-12, 6, 948-950 (1976).
7. S. J. Poon and J. Durand, "Superconductivity and Spin-Glass Regime in Amorphous $\text{La}_{80}\text{Au}_{20}$ Alloys Doped with Gd", Solid State Commun., 21, 999-1002 (1977).
8. Neville I. Marzwell, "Magnetic and Electrical Properties of Amorphous Pd-Co-P Alloys", J. of Magnetism and Magnetic Materials, 5, 67-77 (1977).
9. S. J. Poon, J. Durand and M. Yung, "Magnetic Field Dependence of Resistivity Minima in Amorphous La-Gd-Au Alloys with High Gd Content", Solid State Commun., 22, 475-479 (1977).
10. J. Durand and M. Yung, "Electronic and Magnetic Properties of Amorphous Fe-P-B Alloys", Amorphous Magnetism II, 272-288 (1977).
11. S. J. Poon and J. Durand, "Critical Phenomena and Magnetic Properties of an Amorphous Ferromagnet: Gadolinium-Gold", Physical Review B, 16, No. 1, 316-330 (1977).

12. J. Durand, "Magnetic Regimes in Amorphous Ni-Fe-P-B Alloys", Amorphous Magnetism II, 305-318 (1977).
13. S. J. Poon and J. Durand, "From Superconductivity to Ferromagnetism in Amorphous Gd-La-Au Alloys", Amorphous Magnetism II, 245-256 (1977).
14. William A. Hines, Lawrence T. Kabacoff, Ryusuke Hasegawa and Pol Duwez, " ^{31}P Nuclear Magnetic Resonance Study in the Metallic Glass Systems $(\text{Ni}_{1-y}\text{Pt}_y)_{75}\text{P}_{25}$ and $(\text{Ni}_{0.50}\text{Pd}_{0.50})_{100-x}\text{P}_x$ ", Amorphous Magnetism II, 333-337 (1977).
15. K. Raj, A. Amamou, J. Durand, J. I. Budnick and R. Hasegawa, "NMR and Mössbauer Studies of the Amorphous System $\text{Fe}_{79}\text{P}_{21-x}\text{B}_x$ ", Amorphous Magnetism II, 405-415 (1977).
16. J. Durand and S. J. Poon, "Magnetic and Transport Properties of Amorphous Ferromagnetic Gd-Au, Gd-Ni, and Gd-Co Alloys Obtained by Splat-Cooling", IEEE Transactions on Magnetics, MAG 13, 1556-1558 (1977).
17. David G. Onn, T. H. Antoniuk, W. D. Johnson, J. Durand, "Low Temperature Specific Heat and Magnetic Susceptibility of Several Metallic Glasses". To be published in J. Appl. Phys.
18. K. Raj, J. Durand, J. I. Budnick, and S. Skalski, "NMR Studies of Metal and Metalloid Site Hyperfine Field Distributions in Magnetically Ordered Amorphous Alloys". To be published in J. Appl. Phys.
19. J. Durand and S. J. Poon, "Crystal-Field Effects and Magnetic Interactions in Amorphous $\text{Ce}_{80}\text{Au}_{20}$ ". To be published in J. Appl. Phys.
20. W. A. Hines, L. T. Kabacoff, R. Hasegawa, and Pol Duwez, "NMR Knight Shifts in the Ni-Pd-P and Ni-Pt-P Metallic Glasses: Composition and Temperature Dependences". To be published in J. Appl. Phys.
21. S. J. Poon and J. Durand, "Magnetic Cluster Mean-Field Description of Amorphous La-Gd-Au Spin Glasses". Submitted to Phys. Rev.
22. W. L. Johnson, C. C. Tsuei, and P. Chaudhari, "Paraconductivity of Three Dimensional Amorphous Superconductors-Evidence for a Short Wavelength Cutoff in the Fluctuation Spectrum". Submitted to Phys. Rev.

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1. FROM SUPERCONDUCTIVITY TO FERROMAGNETISM IN AMORPHOUS Gd-La-Au ALLOYS

(completed)

S. J. Poon and J. Durand

Splat cooled alloys of composition $(\text{La}_{100-x}\text{Gd}_x)_{80}\text{Au}_{20}$ have been obtained by complete substitution of gadolinium for lanthanum in amorphous $\text{La}_{80}\text{Au}_{20}$ matrix. Results of high field magnetization (up to 70 kOe), ac and dc low field susceptibility, and resistivity measurements over temperature range of 1.7 to 300°K for these alloys are reported. The $\text{La}_{80}\text{Au}_{20}$ alloys are superconducting at 3.5°K. For $x \lesssim 1$, a suppression of T_c described by the relation $dT_c/dx \approx -4.0^\circ\text{K}$ per atomic per cent gadolinium is observed. For alloys within the concentration range $1 \lesssim x \lesssim 70$, maxima in low field susceptibility measurements are observed. The 'ordering' temperatures T_M are proportional to x for $1 \leq x \leq 16$, similar to those observed in crystalline spin-glass alloys. For $16 \lesssim x \lesssim 70$, T_M is increasing at a faster rate than in the low concentration region, and this intermediate type of ordering corresponds to a mictomagnetic regime. As $x \gtrsim 70$, a ferromagnetic regime emerges. The maximum Curie temperature is observed for $\text{Gd}_{80}\text{Au}_{20}$ at $\sim 150^\circ\text{K}$. The moment per gadolinium atom is found to be constant and close to that of the crystalline value throughout the concentration range investigated. Results of resistivity measurements are correlated with the magnetic properties of different regimes in the magnetic phase diagram.

Results of bulk magnetic measurements are reported for splat-cooled amorphous alloys $(\text{La}_{100-x}\text{Gd}_x)_{80}\text{Au}_{20}$ over the concentrated region between the dilute ($x \leq 1$ at. %) and the ferromagnetic range ($x > 70$ at. %). For

$x \leq 40$ at. % alloys, low field susceptibility maxima occur at temperatures proportional to x , and the reduced remanent magnetization $M_{rs}(T)/x$ depends only on the reduced temperature T/x . Our results are analysed in the spirit of a phenomenological model of uncompensated magnetic clouds. The interplay of the RKKY interaction and of the anisotropic dipolar forces is sufficient to account for the order of magnitude of the remanent magnetization for $x \leq 40$ alloys.

2. MAGNETIC REGIMES IN AMORPHOUS Ni-Fe-P-B ALLOYS

(completed)

J. Durand

A complete substitution of iron for nickel has been obtained by splat-cooling in amorphous alloys of composition $(\text{Ni}_{100-y}\text{Fe}_y)_{79}\text{P}_{13}\text{B}_8$. Results of high field magnetization (up to 70 kOe), ac and dc low field susceptibility, Curie temperature and resistivity measurements over a temperature range of 1.7 to 300°K are reported. The $\text{Ni}_{79}\text{P}_{13}\text{B}_8$ alloy is not ferromagnetic, but the magnetization behavior as a function of field and temperature is typically that of alloys in the critical concentration range for ferromagnetism. The $\text{Fe}_{79}\text{P}_{13}\text{B}_8$ alloy is ferromagnetic with a Curie temperature T_c of 616°K. For $y = 1$ at.%, the Fe atoms are magnetic. The variation of the moment per Fe atom as a function of y is discussed. When y is increased, the Ni atoms are likely to be polarized progressively and the moment per Ni atom would be roughly constant for $y \geq 30$ at.%. Various magnetic regimes were defined as a function of the Fe content. The value of T_c reaches a maximum for $y \approx 90$ at.%, and extrapolates to zero for $y \approx 7$ at.%. Alloys within the range $1 \leq y \leq 10$ at.% did not exhibit well-defined Curie transition, but sharp maxima in low field susceptibility measurements were observed at T_M . The value of T_M is proportional to y for $1 \leq y \leq 4$ at.%, like in classical spin-glass regimes. For $4 < y \leq 10$ at.%, the variation of T_M as a function of y implies a more complicated type of magnetic ordering (mictomagnetism or superparamagnetism). Homogeneous ferromagnetic ordering emerges only for $y > 10$ at.%. Results of resistivity measurements are discussed in relation to the magnetic properties of different regimes in the magnetic phase diagram.

3. ELECTRONIC AND MAGNETIC PROPERTIES OF AMORPHOUS Fe-P-B ALLOYS

(completed)

J. Durand and M. Yung

The ternary diagram of the amorphous phase in the splat-cooled Fe-P-B system was investigated by X-ray diffraction measurements. Alloys were found to be amorphous within the Fe concentration range $75 \leq c_{Fe} \leq 83$ at.%. For a fixed Fe concentration, B substitutes for P over a large scale, the maximum substitution occurring for $c_{Fe} = 80$ at.%. Concentration dependence of the electronic and magnetic properties was systematically studied in alloys within the whole amorphous diagram by means of bulk magnetization $\bar{\mu}$ (4.2°K), Curie temperature T_c and electrical resistivity ρ measurements from 4.2°K up to the amorphous-crystalline transformation. The composition dependence of $\bar{\mu}$ and T_c when B substitutes for P at a constant c_{Fe} suggests the existence of two different short range orders in the amorphous alloys, corresponding to ϵ and ϵ_1 crystal structures in the $Fe_3P_{1-x}B_x$ compounds. The concentration dependence of $\bar{\mu}$ and T_c when P (or B) substitutes for Fe at a constant c_B (or c_P) is explained by a comparison between the amorphous Fe and the fcc Fe. A minimum in the variation of ρ as a function of temperature T occurs at T_M . The temperature dependence of ρ is expressed by a phenomenological law:

$$\rho(T) = \rho_0 + A \log T + B T^2 + CT.$$

The concentration dependence of T_m and of the coefficients A and B is discussed in relation with the magnetic and structural properties of the amorphous Fe-P-B alloys.

4. CRITICAL PHENOMENA AND MAGNETIC PROPERTIES OF AMORPHOUS GADOLINIUM BASED FERROMAGNETS

(completed)

J. Durand and S. J. Poon

Since it was shown that the techniques (such as sputtering and coevaporation) used for preparing magnetic bubble materials have some influence on their magnetic properties (e.g. anisotropy), a comparison with splat-cooled amorphous alloys obtained directly from the melt seems to be desirable. In addition, both experimental and theoretical investigations on the transport properties of amorphous ferromagnets are barely seen in the literature. The bulk samples provided by the splat-cooling technique are most suitable for magnetization and transport measurements. Such studies have been made on amorphous $\text{Gd}_{80}\text{Au}_{20}$, $\text{Gd}_{68}\text{Ni}_{32}$, and $\text{Gd}_{67}\text{Co}_{33}$ alloys over a temperature range of 1.8 - 300°K in fields up to 70 kOe. The respective Curie temperatures (T_c) are 150, 125 and 170°K. The saturation moment (extrapolated to 0°K) equals $7.0 \pm 0.1 \mu_B$. The exchange integrals are also estimated. The magnetoresistivity data can be correlated to the magnetization measurements. We also have preliminary transport results with applied field parallel and perpendicular to the foil plane. The anisotropy is in-plane for Gd-Co. For the Gd-Au and Gd-Ni alloys, there is no well-defined easy axis. Detailed study of critical phenomena is also carried out around T_c for the $\text{Gd}_{80}\text{Au}_{20}$ samples. General trends for the magnetization and specific-heat exponents are noted for amorphous ferromagnets undergoing a second order phase transition. The effects of structural disorder on the magnetic properties are compared and discussed with recent theories on amorphous magnetism.

5. KONDO EFFECT, SPIN CORRELATIONS, AND SUPERCONDUCTIVITY
IN AMORPHOUS ALLOYS DOPED WITH MAGNETIC IMPURITIES

(completed)

S. J. Poon and J. Durand

We have studied the effects of spin correlations on the superconductivity of amorphous $\text{La}_{80}\text{Au}_{20}$ alloys doped with Ce and Gd (up to 1 at.%). For the LaCeAu alloys, both magnetization and resistivity measurements in the normal state exhibit features characteristic of a Kondo system ($T_K \sim 0.3$ to 0.4°K), which is also manifested in the $T_c(x)$ behavior. In the crystalline LaCe alloys, this phenomenon is compensated by the interactions among the spins. In the amorphous state, the domination of the single impurity effect is probably due to the attenuation of the pair interactions. For the La-Gd-Au alloys, the domination of the spin-glass behavior over the Kondo effect is demonstrated by the scaling relations between M/x , H/x , and T/x , and by negative paramagnetic Curie temperatures $\theta_p(x)$ which vary strongly with concentration. The $T_c(x)$ values are enhanced over the AG values above 0.6 at.% Gd. The results are compared with 'pair-breaking' theories. The role of the electronic mean free path on the RKKY interaction is also investigated.

6. FLUX PINNING BY CRYSTALLINE PHASE PRECIPITATES EMBEDDED IN AN AMORPHOUS SUPERCONDUCTING MATRIX

(continuing)

W. L. Johnson

The upper critical field H_{c2} for a number of amorphous superconductors has been measured and found to be large. The formula

$$H_{c2}(T) = H_{c2}(0) \left[(T_c - T)/T_c \right]$$

where T_c is the transition temperature and $H_{c2}(0)$ the linearly extrapolated critical field at $T = 0$ describes the temperature dependence of H_{c2} over the measured range of H and T . The values of $H_{c2}(0)$ obtained for liquid-quenched amorphous alloys range from 60 KOe to 200 KOe. Values of T_c ranging up to 9°K have been measured for amorphous Mo-base alloys. Together with the desirable mechanical properties and comparatively high crystallization temperatures (700°C to 800°C for Mo-base amorphous alloys). The above properties make these materials attractive for high field superconducting magnets. This possibility is more promising when one considers the degrading effects of irradiation on crystalline high-field superconductors and the prospect of avoiding such degradation using amorphous superconductors.

The principle drawback to using amorphous superconductors for such applications is their characteristically low critical current density in fields of the order of H_{c2} ($\lesssim 10^3$ A/cm² for $H \sim \frac{1}{2} H_{c2}$). Preliminary study of liquid-quenched amorphous alloys shows that critical current densities in high magnetic fields are significantly enhanced by the presence of crystalline precipitates in the amorphous superconducting matrix. The strength of flux pinning forces induced by such precipitates depends on their size, number, and distribution. A systematic study of this dependence is in progress and is

directed at providing criteria for optimizing pinning force profiles and thus critical current density in high magnetic fields. Techniques used to produce and vary the distribution of precipitates include heat treatment and choice of alloy compositions slightly outside the phase field for a homogeneous amorphous phase. The precipitate distributions are studied by x-ray diffraction, electron diffraction, and scanning electron microscopy. This information is correlated with flux pinning data deduced from measurements of critical current density vs. field and data from magnetization vs. field. It is hoped that both a better basic understanding of the mixed state in high κ type II superconductors and progress toward fabricating useful high-field magnet materials will result from this study.

7. KINETICS OF CRYSTALLIZATION OF AMORPHOUS ALLOYS

(continuing)

Pol Duwez

Many studies of crystallization of amorphous alloys have been published in the literature. Practically all these studies, however were carried out at temperatures between the glass transition temperature and the rapid crystallization temperature. At these relatively high temperatures the time required for complete crystallization is relatively short and no studies have been published with heat treatment times longer than about 1000 hours. Preliminary studies in this laboratory have been carried out during the last five years at constant heat treating temperature as low as 200°C . It is quite clear that many interesting phases can be obtained by very long time treatment at moderately high temperature. Very often a pseudo equilibrium is reached and the crystallization process is entirely stopped.

Kinetics studies of crystallization of amorphous alloys are also of practical interest. Low hysteresis losses magnetic metallic glasses are now used in transformer cores. These materials must remain stable for many years and may be at temperatures as high as 150°C . Very little is known about this type of long time stability. Transformation kinetics studies of amorphous superconductors are also important. In this case very small and evenly dispersed microcrystals must be obtained in order to produce pinning centers necessary to increase the critical current density.

8. PROPERTIES OF THE FLUX LATTICE IN AMORPHOUS
SUPERCONDUCTORS

(continuing)

E. R. Domb and W. L. Johnson

Amorphous superconductors can be characterized by a comparatively large value of λ the London penetration depth and a small value of ξ the coherence length. The ratio of these lengths $\kappa = \lambda / \xi$ is called the Ginzburg-Landau parameter and determines the detailed properties of the mixed state in a type II superconductor. Values of κ ranging up to ~ 100 found in amorphous superconductors represent the largest values observed among all superconducting materials. A program to study the mixed state of these large κ superconductors is in progress.

Measurements of the lower critical field H_{c1} have been carried out using a small dc superconducting coil which encloses an inductance bridge. The H_{c1} data can be combined with measurements of the upper critical field H_{c2} (using a high field superconducting magnet) to yield information regarding the behavior of κ . Direct observation of the flux lattice in type II superconductors is possible through use of a magneto-optic film and polarized light. An apparatus designed to carry out such observations is being set up in an optical dewar. It is expected that the large λ values of amorphous superconductors will permit observation of the single flux quanta which comprise the flux lattice. Flux line density in an applied field, density gradients in the presence of a transport current and pinning forces, and other phenomena are directly observable using this technique. Data obtained will provide a useful comparison with theoretical models for behavior of type II superconductors in the high κ limit.

9. LOW TEMPERATURE CALORIMETER

(new)

R. D. Shull

In any thorough study of low temperature phenomena, a knowledge of the material's specific heat is required. The investigation of superconducting and magnetic properties of amorphous alloys, in which this laboratory is primarily involved, is no exception. Consequently a project has been initiated to build an apparatus for use in making such measurements at temperatures between 1.5 and 40 K. Because of the small mass (approximately 20 mg) of the amorphous specimens to be studied, the relaxation time technique will be used. By this technique, a measurement is made of the time, τ , it takes the specimen (initially heated to some small constant temperature, ΔT , above the temperature, T_0 , of a thermally connected heat reservoir) to relax to a temperature $T = T_0 + 1/e (\Delta T)$. This relaxation time is directly related to the specimen's heat capacity, C , by the expression $C = k\tau$, where k is the thermal conductance of the specimen-reservoir linkage. The addenda heat capacity will be kept small by using a doped silicon chip as the specimen holder, heater, and thermometer. According to this arrangement, the addenda heat capacity is calculated to be at most only 10% that of the specimen. Additionally, the frequently encountered problem of adsorbed helium on the specimen at low temperatures is eliminated in this setup by both the inclusion of a continuous metallic heat link with the outside helium bath and the maintenance of a high vacuum around the specimen at all times. In order to make measurements in the presence of an applied magnetic field, this apparatus is being constructed to fit inside the bore of a 45 kG Ni-Ti superconducting magnet. All parts will be machined from non-ferromagnetic materials and the heat reservoir heating coil will be noninductively wound about an axis directed away from the specimen. Following the

construction of the above equipment, the apparatus will be calibrated by making measurements on a small foil of high purity copper. The calibration will subsequently be checked, using a thin foil of indium as the specimen. According to previous investigators using this method, a precision of 1% on samples as small as 1 mg is normal.

10. LOW TEMPERATURE HEAT CAPACITY OF METASTABLE
SUPERCONDUCTORS

(new)

R. D. Shull and W. L. Johnson

Low temperature specific heat measurements are being carried out on a series of Zr, Nb, and Mo-base amorphous superconducting alloys. Data from these measurements will be used to obtain estimates of the electronic density of states, and Debye temperatures of these alloys. Using this information together with the strong-coupling theory of superconductivity, one can determine the variation of fundamental parameters which govern superconductivity. Together with measurements of resistivity, critical field, and results of tunneling experiments, this data will give comprehensive information concerning the nature of electronic states and electron-phonon interactions in this class of materials. By better understanding amorphous transition metal alloys, it is anticipated that new insights into the nature of superconductivity in crystalline transition metals and compounds will be obtained.

11. THERMAL RELAXATION EFFECTS AND CRYSTALLIZATION OF AMORPHOUS ALLOYS

(new)

W. L. Johnson and A. Drehman

It has been found heat treatment of amorphous alloys at temperatures below those required for crystallization can lead to irreversible changes in electronic properties. For example, the superconducting transition temperature of amorphous $Zr_{75}Rh_{25}$ is observed to decrease from $4.5^{\circ}K$ to $3.8^{\circ}K$ after heat treatment for several hours at $340^{\circ}C$. Crystallization occurs during comparable time periods for temperatures above $370^{\circ}C$. A systematic study of such effects has been initiated. Structural investigation by x-ray diffraction, density measurements, and data involving electronic and superconducting properties are used to evaluate the effects of such heat treatment. It is believed that thermal relaxation of the amorphous structure is responsible for the changes observed.

Crystallization of amorphous metals frequently results in the formation of metastable crystalline modifications of the alloy. This technique is being studied as an approach to obtaining metastable superconducting alloy phases of the A-15 type. Several alloys containing Mo, Zr, and Nb are being investigated for this purpose.

12. FUNDAMENTAL STUDIES OF AMORPHOUS SUPERCONDUCTORS USING SUPERCONDUCTIVE TUNNELING

(new)

W. L. Johnson and A. Williams

Superconductive tunneling provides a method of obtaining fundamental data concerning the phonon spectrum, the electron-phonon interaction, and microscopic parameters which characterize a superconductor. Methods of fabricating superconducting tunnel junctions on bulk amorphous samples are being studied and some preliminary junctions have been made which show tunneling features. Growth of an oxide barrier with subsequent vapor deposition of Al and Pb counterelectrodes along with the point contact tunneling method are being used. Circuitry to measure I-V characteristics has been built and other circuits to measure the derivatives of the I-V curves are being designed.

The goals of this study are: (1) To provide a comparison of the phonon spectrum and electron-phonon interaction in amorphous superconductors and their crystalline counterpart. (2) To compare the properties of amorphous superconductors prepared by liquid-quenching to those of vapor-quenched materials which are being studied elsewhere. (Vapor-quenched materials are known to have significantly smaller density than liquid-quenched materials. Such a density difference will effect, for example, the phonon spectrum,) (3) To compare results with the predictions of the BCS theory and its strong-coupling modifications. The above comparison should provide information concerning what, if any, properties of these alloys are linked to the amorphous structure.

13. LOW TEMPERATURE CALORIMETRY OF BULK AMORPHOUS METALS

(new)

R. D. Shull

Exact comparisons of the amorphous and crystalline states in metallic alloys to date have been complicated by the fact that the crystalline counterparts of the bulk amorphous specimens have been comprised of a mixture of phases. Recently it was found that certain Zr-Rh alloys could be made amorphous by splat cooling; and when aged for several hours at temperatures around 370°C , the alloys crystallized into an E9_3 single phase structure. Further aging at higher temperatures resulted in a two phase equilibrium structure. Similarly, it was recently found that La_3Ni could also be produced in the amorphous state by splat cooling and crystallized into a single phase structure by high temperature aging. These two systems are therefore ideal for use in the study of the amorphous-crystalline relationship and a low temperature specific-heat investigation is proposed. Of particular interest is the manner in which the electronic specific heat coefficient (γ) and the lattice specific heat coefficient (β) vary with both the change in structure and the change in composition. In the rigid band model a change in γ with composition may be used to map the density of states curve. In the Zr-Rh system, the comparison between the amorphous and the two phase crystalline structures may also be made. Previous investigations of amorphous insulators have indicated the possibility of a temperature linear term in the lattice specific heat. If this phenomenon is a general consequence of the amorphous state, then it is expected that there should be an enhancement of γ in the amorphous metals. Comparison of the percentage change in density between the amorphous and crystalline states with the percentage change in β will additionally indicate the presence and degree of phonon softening. Whether or not

the softening is due to the introduction of localized phonon modes at low frequencies in amorphous materials will then be analyzed.

14. MICTOMAGNETISM IN AMORPHOUS ALLOYS

(new)

R. D. Shull

The occurrence of mictomagnetic (spin-glass) behavior at low temperatures in certain splat cooled amorphous alloys has been shown in several alloy systems. This fact is interesting in the respect that it shows the mictomagnetic state is to a first approximation independent of long range atomic order; that it is a local environment effect. Whether or not the amorphous mictomagnets also show an anomalously large specific heat coefficient (γ) linear in temperature, as is common in the case of crystalline mictomagnets, is not known; nor is it known whether these same amorphous materials possess a low temperature specific heat Schottky anomaly, indicative of the magnetic clustering thought to be responsible for mictomagnetic behavior. In the amorphous materials atomic clustering is prevented by the very fast cooling rate of the alloys from the melt and ordered domain boundaries are absent due to the non-crystallinity of the matrix. Consequently, in order for magnetic clusters to form in those amorphous materials which are more dilute in magnetic solutes, the interaction between magnetic atoms must extend over fairly long distances. It is planned to determine this distance by using both magnetic and low temperature specific heat measurements to find the number of atoms per magnetic cluster and calculating the distance under assumption of random atom occupation of the first few coordination shells. This distance may then be used to determine the distance apart the magnetic atoms must be before they become involved in the intercluster (as opposed to the intracluster) interaction. It is also planned to check whether the electronic specific heat of the amorphous alloys obey the scaling laws with concentration that the crystalline mictomagnets do at low

concentrations. If the scaling laws are obeyed, it is expected that the concentration range over which they hold will be more extensive in the amorphous materials than in the crystalline alloys.