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ANNEALING EFFECTS IN FERROMAGNETIC AMORPHOUS ALLOYS(U)

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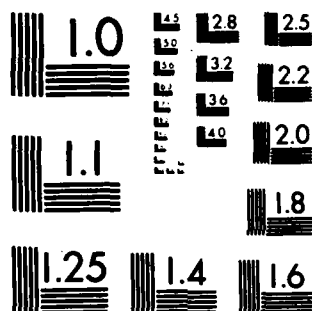
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INTRODUCTION

Ferromagnetic amorphous alloys, or glassy metals, have been under development as engineering materials for about ten years. They are now used commercially in various high-permeability applications such as recording heads and phonograph pickups. Large-scale application in power transformers, power switching devices, and similar equipment appears to be imminent.

In all these applications, heat treatment or annealing of the as-quenched alloys is normal practice. The properties of amorphous alloys, like those of crystalline alloys, are altered by annealing; this is true even when the annealing treatment is too short or at too low a temperature to cause crystallization. As might be expected, the structure-sensitive properties such as coercivity and permeability are strongly affected by annealing; sometimes they are greatly improved, but sometimes they are degraded. It is therefore important to understand the mechanisms of annealing so that heat treatments can be specified to give optimum properties with high reliability and reproducibility at the lowest possible cost.

RESEARCH RESULTS FOR THIS REPORTING PERIOD

Field-Induced Anisotropy and Curie Temperature

The kinetics of the formation and reorientation of the field-induced anisotropy K_u have been carefully studied in as-received samples and samples pre-annealed in various ways. We have established clearly that the kinetics can be described by a distribution of activation energies that depend weakly on the pre-annealing treatment. Changes in

Curie temperature caused by annealing show similar kinetics, and in one particular alloy ($\text{Fe}_{40}\text{Ni}_{40}\text{P}_{14}\text{B}_6$) we have determined that the kinetics of these two phenomena are identical. This implies that they result from the same microscopic mechanism. We have also made careful measurements of internal friction in amorphous alloys, and in another composition ($\text{Fe}_{32}\text{Ni}_{36}\text{Cr}_{14}\text{P}_{12}\text{B}_6$), we have established that the change in Curie temperature is proportional to the change in internal friction $1/Q$, as measured by the torsion pendulum method. Thus we conclude that changes in both K_u and T_C are caused by atomic level local shear transformations that change the local compositional short range order. The internal friction has been studied in considerable depth, and we now understand its behavior quite well even at a microscopic level.

Magnetic permeability after-effect

A time-decay of ac permeability after demagnetization, even at room temperature, is observed in some crystalline alloys. It is sometimes known as disaccommodation (DA), and is known to occur also in amorphous alloys. We have established that DA in zero-magnetostriction amorphous alloys is caused by induced anisotropy in the domain walls, and have found that cooling an amorphous alloy through the Curie temperature in a field applied perpendicular to the ribbon axis reduces the DA and at the same time increases the permeability. The field annealing induces a weak anisotropy perpendicular to the ribbon axis, causing magnetization to occur by spin rotation rather than domain wall motion.

In magnetostrictive alloys, we have confirmed the theory of Allia and Vinai (P. Allia and F. Vinai, Phys. Rev. B26 (1982) 6141) that DA is due to internal friction coupled to domain wall motion via the magnetostriction.

Flash annealing

A new technique of heat treatment of amorphous alloys, called flash annealing, has been developed and investigated. The sample ribbon is immersed in liquid nitrogen, and a dc pulse current up to several amperes is passed through the ribbon for a controlled time period of 80 msec to 1 sec. The sample temperature can be indirectly monitored by observing the change of magnetization when the sample passes through the Curie temperature. Because of the high heating and cooling rates, it is possible to heat samples to 1200 K without causing crystallization. Even when crystallization does occur, the sample surface remains shiny (unoxidized), and the sample remains ductile, presumably because the crystalline grain size is very small. This technique permits annealing treatments which have not previously been possi-

ble. One effect that we have observed is that flash annealing "rejuvenates" a sample previously relaxed by annealing treatments below T_c ; that is, the slow annealing kinetics become fast again, as in an as-quenched sample. We are continuing to investigate this annealing technique.

Theory of magnetostriction

Magnetostriction is clearly an important phenomenon controlling the low-field properties of amorphous alloys. However, the origin of magnetostriction in amorphous alloys is not well understood at the microscopic level. We have developed a microscopic theory of magnetostriction within the screened point charge model. We find that if the point charges are not screened, the linear magnetostriction is always zero, and that the screening condition determines the sign of the magnetostriction. We have also made an atomistic computer simulation of magnetostriction during deformation.

PUBLICATIONS

Details of the results summarized above are contained in the publications that have appeared in the technical literature. A list of these publications is given at the end of this report. The identification numbers are the same as those used in our previous reports. Papers with numbers 10 and above were prepared during this reporting period.

Publications Resulting from
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1. Structure and Magnetism of Amorphous Alloys
T. Egami
IEEE Trans. Magn. MAG-17 (1981) 2600.
(Invited paper at INTERMAG, Grenoble, France)
2. Kinetics of Formation of Induced Magnetic Anisotropy in
a Zero-Magnetostriction Amorphous Alloy
Kai-Yuan Ho, P. J. Flanders, and C. D. Graham, Jr.
J. Appl. Phys. 53 (1982) 2279.
3. Physical Origin of Losses in Conducting Ferromagnetic
Materials
C. D. Graham, Jr.
J. Appl. Phys. 53 (1982) 8276.
(Invited paper at Conf. on Magnetism and Magnetic
Materials, Montreal)
4. Isotropic Behavior of the Kinetics of Reorientation of
Induced Anisotropy in Amorphous and Crystalline Alloys
Kai-Yuan Ho
J. Appl. Phys. 53 (1982) 7828.
5. Kinetics of Reorientation of Induced Anisotropy in
Amorphous and Crystalline Alloys
Kai-Yuan Ho
J. Appl. Phys. 53 (1982) 7831.
6. Kinetics of Changes in Initial Permeability Produced by
Magnetic Annealing in a Zero-Magnetostrictive FeCoSiB
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T. Jagielinski
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7. Elimination of Disaccomodation in a Zero-
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T. Jagielinski
J. Appl. Phys. 53 (1982) 7852.
8. Structural Relaxation and Magnetism in Amorphous Alloys
T. Egami
J. Mag. Magn. Mat. 31-34 (1983) 71.
(Invited paper, International Conf. Magnetism, Kyoto)

9. Single-Ion Anisotropy and Magnetostriction of Amorphous Alloys
Y. Suzuki and T. Egami
J. Mag. Magn. Mat. 31-34 (1983) 1549.
10. Internal Friction of a Glassy Metal $\text{Fe}_{32}\text{Ni}_{36}\text{Cr}_{14}\text{P}_{12}\text{B}_6$
During the Cross-Over Behavior of the Curie Temperature
N. Morito and T. Egami
IEEE Trans. Magn. MAG-19 (1983) 1898.
11. Correlation Between the Changes Due to Heat Treatment in the Curie Temperature and Internal Friction of a Glassy Metal $\text{Fe}_{32}\text{Ni}_{36}\text{Cr}_{14}\text{P}_{12}\text{B}_6$
N. Morito and T. Egami
IEEE Trans. Magn. MAG-19 (1983) 1901.
12. Field Induced Anisotropy in Zero Magnetostriction Amorphous Alloys Measured with a Rotating Sample Magnetometer
P. J. Flanders, T. Egami, and C. D. Graham, Jr.
IEEE Trans. Magn. MAG-19 (1983) 1904.
13. The Relationship Between Changes in Field-Induced Anisotropy and Curie Temperature for $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{14}\text{P}_6$
P. J. Flanders, N. Morito, and T. Egami
IEEE Trans. Magn. MAG-19 (1983) 1907.
14. Annealing Kinetics for Curie Temperature Changes in the Amorphous Alloy $\text{Fe}_{32}\text{Ni}_{36}\text{Cr}_{14}\text{P}_{12}\text{B}_6$
P. J. Flanders, N. Morito, and T. Egami
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15. Effects of Anisotropy on Domain Structure in Amorphous Alloys
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IEEE Trans. Magn. MAG-19 (1983) 1916.
16. Flash Annealing of Amorphous Alloys
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IEEE Trans. Magn. MAG-19 (1983) 1925.
17. Disaccommodation of Magnetic Permeability in Amorphous Iron-Nickel-Boron Alloys
T. Jagielinski
IEEE Trans. Magn. MAG-19 (1983) 1934.
18. Elastic Stress-Induced Coercive Field Changes in NiCo Films Used in a Rotating Disk
P. J. Flanders
IEEE Trans. Magn. MAG-19 (1983) 1680.

Closely-related work not paid for by the ONR Contract appears in:

- A. Magnetic After Effect in a Zero-Magnetostriction Amorphous Alloy
 T. Jagielinski
 J. Appl. Phys. 53 (1982) 1182.

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The kinetics, and therefore probably the atomic mechanism, of the annealing of field-induced anisotropy, Curie temperature, and internal friction have been shown to be the same in certain ferromagnetic amorphous alloys. Disaccomodation can be almost eliminated, and permeability increased, by annealing a zero-magnetostriction amorphous alloy in a perpendicular field. Flash annealing of amorphous alloys permits new annealing treatments			

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that are not otherwise possible. A model of magnetostriction in amorphous alloys relates the magnitude and sign of the magnetostriction directly to the magnitude and sign of the screening in a screened point-charge model. In particular, the linear magnetostriction is zero if there is no screening. ←

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