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# Magnetization Dynamics and Magnetoimpedance Effect of Novel Fe–B–Si–M (M = Ta, Y) Amorphous Wires

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Amorphous wires of composition $Fe_{64}Co_8B_{19.2}Si_{4.8}M_4$ (M = Ta, Y) and 140 $\mu$m of diameter were obtained by rotating-water-bath-melt-spinning technique. Saturation magnetization ($M_s$) and coercivity values ($H_c$), at room temperature, were in the range of 1 T and 31 A/m, respectively, for the Ta samples, and $M_s = 1.32$ T and $H_c = 109$ A/m, respectively, for the Y samples. The magnetic permeability as a function of frequency showed a domain wall relaxation character, with relaxation frequency, of 3.5 kHz and 9 kHz for the Ta and the Y compounds, respectively. Magnetoimpedance (MI) measurements exhibited a MI factor $\Delta Z/Z_0 = 11\%$ for the Ta alloys, and 41% for the Y alloys. Results are interpreted in terms of magnetoelastic coupling differences in both alloys caused by distinctive frozen-in stresses for each case during the fabrication process.

**Keywords:** Ta- and Y-Amorphous Wires, Domain Wall Relaxation, Magnetoimpedance.

## 1. INTRODUCTION

Amorphous metallic materials occupy a prominent position among functional alloys because of their favourable combination of mechanical, electrical, magnetic and chemical properties derived from the absence of atomic long range order.[1] In particular, Fe-based amorphous alloys in the form of fine wires obtained by means of the rotating-water-bath-melt-spinning process, present an outstanding soft magnetic behavior including high magnetization saturation and permeability values besides a very low coercivity.

Fe–B–Si amorphous ribbons alloyed with elements with large atomic radius, relative to Fe atoms, have been reported as possessing high glass forming ability and thermal stability (with crystallization temperatures over 1100 K) together with an excellent combination of magnetic properties and mechanical strength.[2]

In this work, we present a systematic study on the magnetization processes and the magnetoimpedance (MI) response of Fe–B–Si amorphous wires alloyed with Y and Ta. Both alloys exhibited very soft magnetic properties, with high magnetization values. The differences among them can be attributed to the differences in atomic radii, since they are 13% (Ta) to 30% (Y) larger than Fe radius.

## 2. EXPERIMENTAL TECHNIQUES

Amorphous wires of composition $Fe_{64}Co_8B_{19.2}Si_{4.8}M_4$ (M = Ta, Y) and 140 $\mu$m of diameter were obtained by the rotating-water-bath-melt-spinning technique. The hysteresis $M$-$H$ curves were determined by an inductive method at 50 Hz. The magnetization process for both samples were monitored by spectroscopic permeability curves, $\mu_{re}(f)$, $\mu_{im}(f)$ determined in a HP 4192A impedance analyzer. This equipment was also used for magnetoimpedance (MI) measurements, for which an alternate $i_{ac}$ current of 20 mA (rms) of frequency $f = 5$ and 10 MHz was injected along the longitudinal wire axis. The amorphous wire was placed inside a 250-turns coil connected to a DC power source, which allowed the generation of a static magnetic field $H$ applied along the wire axis, with a maximum intensity of 80 Oe. The MI ratio $\Delta Z/Z$ (%) was calculated as follows: $\Delta Z/Z(\%) = [Z(H) - Z(80)]/Z(80)$. The impedance Z is calculated within the HP 4192A analyzer by means of a Wheastone bridge technique.

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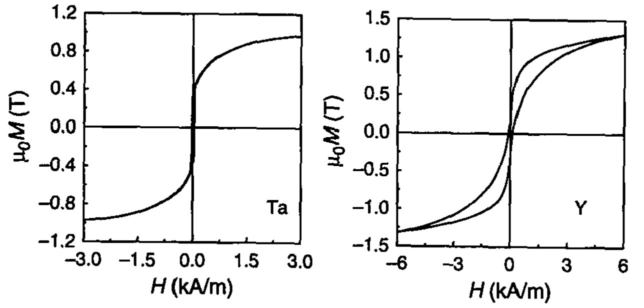

**Fig. 1.** Hysteresis loops of Ta alloys (left) and Y alloys (right), at room temperature.

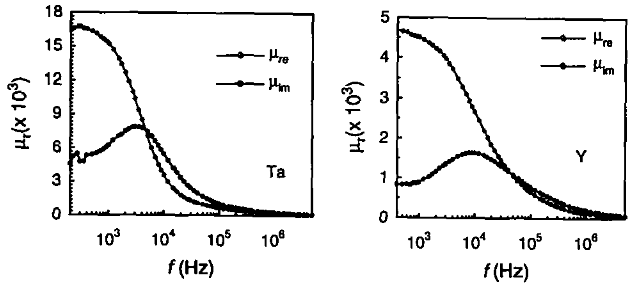

**Fig. 2.** Spectroscopic behaviour of real and imaginary permabilities of Ta alloys (left), and Y alloys (right).

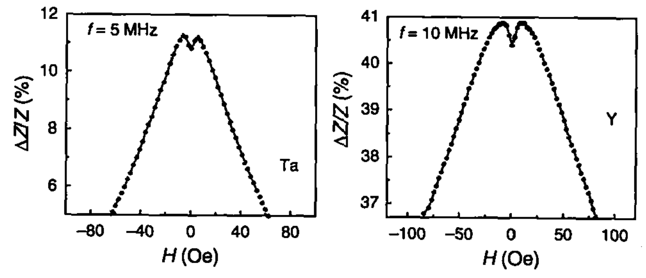

**Fig. 3.** Magnetoimpedance results in Ta alloys (left) and Y alloys (right).

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

$Fe_{64}Co_8B_{19.2}Si_{4.8}Ta_4$ showed saturation magnetization ($Ms$) and coercivity values ($H_c$) of 1 T and 31 A/m, respectively. $Fe_{64}Co_8B_{19.2}Si_{4.8}Y_4$ exhibited $M_s = 1.32$ T and $H_c = 109$ A/m, as shown in Figure 1. These are properties which correspond to very soft magnetic materials, with a high magnetization.

The dynamics of magnetization process, investigated by means of spectroscopic curves of the real and imaginary parts of complex permeability, is shown in Figure 2. The value for initial relative permeability, which is associated with the low frequency value of the real part of permeability, was 16,750 for the Ta-alloy and 4,650 for the $Y$-alloy. As frequency increases, the real part of permeability exhibited a decrease while the imaginary part went through a maximum.

This behavior is typical of a relaxation,[3] and is directly related to the dynamics of the reversible domain wall bulging. The observed relaxation frequency, indicated by the maximum in the imaginary part, was 3.5 kHz for the Ta alloy, and 9 kHz for the Y alloy, typical values for as-cast soft amorphous alloys.

These results are consistent with a general behavior of domain wall dynamics in soft ferromagnetic materials, which displays an inverse relation between initial permeability and relaxation frequency.

On the other hand, MI measurements showed significant values for $\Delta Z/Z$ of 11% for the Ta alloy and 41% for the Y alloy, as illustrated in Figure 3. In spite of the low Co-content, both samples exhibited non-negligible transverse anisotropy, as appears from the double-peak feature of MI plots. The anisotropy fields for each alloy, as deduced from the separation between magnetoimpedance peaks, were of 4.8 Oe and 7.2 Oe for Ta- and Y-containing wires, respectively, which makes these alloys (especially the Y alloy) potentially interesting for MI applications. The variable MI response in each case can be ascribed to magnetoelastic coupling differences in both alloys caused by distinctive frozen-in stresses during the fabrication process, as suggested by the higher anisotropy field observed for the M = Y alloys (compared with M = Ta), which is consistent with the higher coercivity field of the Y-containing wire. The stress variation between amorphous wires can be ascribed to the marked difference in atomic radii between Ta (0.143 nm[5]) and Y (0.180 nm[5]) atoms, since large variation in the atomic radius for the component elements in amorphous metals are expected to favour inner stresses due to mismatch effects.[6]

## 4. CONCLUSIONS

The magnetization dynamics for novel $Fe_{64}Co_8B_{19.2}Si_{4.8}M_4$ (M = Ta, Y) amorphous wires was described in terms of reversible bulging of magnetic domain walls, which is typical of very soft magnetic materials. The alloys studied displayed a noticeable magneto-impedance response, as a consequence of a well-defined transverse magnetic anisotropy, relative to the wire's axis.

## References and Notes

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