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LETTER TO THE EDITOR

Glass-coated hard-magnetic Fe–Co–Cr microwires

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Abstract. Glass-coated hard-magnetic Fe–Co–Cr microwires were prepared by Taylor's technique with subsequent annealing at different temperatures. The diameter of the metallic core is 3 μm. The annealing temperature dependence of the coercive force is reported; the maximum coercivity is about 200 Oe after an annealing at 600 °C for one hour. Such materials may be useful in locally magnetizing devices and magnetic force microscopy.

Glass-coated soft-magnetic microwires have attracted attention in recent years [1]. We newly reported that glass-coated hard-magnetic Fe–Ni–Cu microwires could also be prepared by Taylor's technique in [2]. The average diameter of the cores of those Fe–Ni–Cu microwires was 5 μm. Their coercivity reached about 600 Oe after an annealing at 700 °C for one hour. Such microwires might be useful in locally magnetizing devices and magnetic force microscopy.

In this work, we will report the formation of new glass-coated Fe–Co–Cr microwires, and the relationship between their coercivities and annealing temperature.

The Fe–Co–Cr master alloy (Fe 46%, Co 23%, and Cr 31%, by weight) was prepared by arc melting the appropriate amounts of the constituent elements Fe, Co, and Cr (Aldrich) in a water-cooled copper boat under an argon atmosphere. The button was melted several times to ensure homogeneity. Then it was put into a Pyrex glass tube and melted using an induction heating coil. A continuous kilometre-long glass-coated microwire was extracted from the lower end of the glass tube [1]. The uniformity of the diameter of the continuous wire was first checked by a contactless high-frequency technique. Some segments of the wire produced were observed with a conventional optical microscope (Carl Zeiss); they each had a diameter of about 3 μm. The annealing was performed in air for each of the different samples. X-ray diffraction was performed in a Siemens D5000 (Cu Kα) instrument on a group of cut wires. The magnetic hysteresis loop was recorded at room temperature in a vibrating-sample magnetometer.

Figure 1 shows x-ray diffraction patterns of (a) as-cast and (b) annealed samples. We can see that there is a sharp peak at $2\theta = 45.1^\circ$ whose intensity increases on annealing at 600 °C for one hour. The peak at $\sim 45^\circ$ may be a characteristic common to all Fe-based microwires [1]. For the present wires, we can logically regard it as the (110) diffraction peak of bcc crystallites, with the lattice parameter $a = 2.84$ Å. The increase of its intensity indicates the growth of the grain size.

Comparing with the diameter of hard-magnetic Fe–Ni–Cu microwires and other soft-magnetic microwires [1, 2], we have found that the outer diameter for the glass-coated

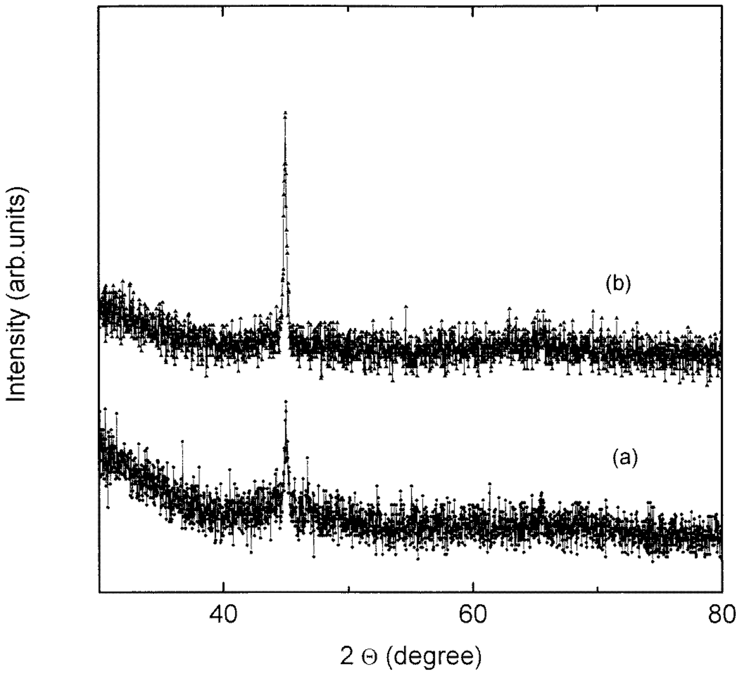

Figure 1. X-ray diffraction patterns of (a) as-cast and (b) annealed (at $T_a = 600$ °C) Fe–Co–Cr microwires.

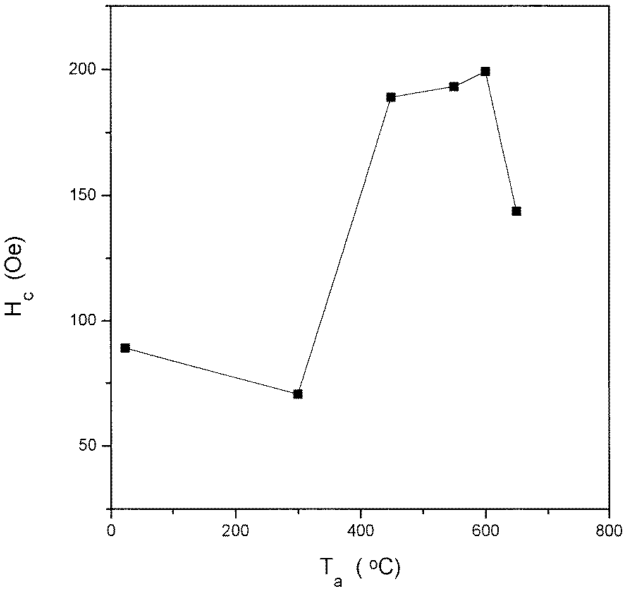

Figure 2. The relationship between the coercivity H_c and the annealing temperature T_a (the annealing duration was one hour) for Fe–Co–Cr microwires.

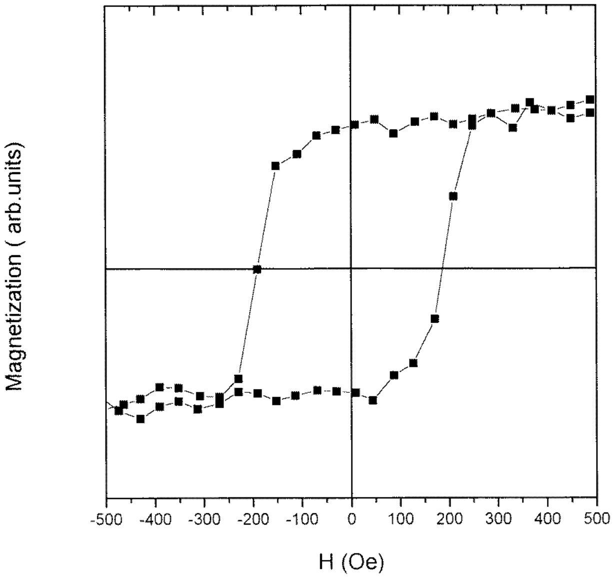

Figure 3. The hysteresis loop of Fe–Co–Cr microwires 8 mm long annealed at $T_a = 600$ °C for one hour. The magnetic field is along the length of the microwires, and the remanence $4\pi M_r \approx 5$ kG.

Fe–Co–Cr microwires (25 μm) is greater, but the diameter of the Fe–Co–Cr metallic core is less, being about 3 μm.

The relationship between the coercivity, H_c, and the annealing temperature, T_a (the annealing duration was one hour), is shown in figure 2. It can be seen that the as-cast wires are ferromagnetic with $H_c \approx 80$ Oe. H_c shows a small decrease to 60 Oe after an annealing at $T_a = 300$ °C. This trend was not previously observed for hard-magnetic Fe–Ni–Cu wires, which were weakly magnetic below $T_a \approx 500$ °C. H_c increases to 180 Oe as T_a increases to 450 °C for the present wires, and reaches 200 Oe at $T_a = 600$ °C, as seen from the hysteresis loop shown in figure 3. Further increasing of T_a leads to a drop in H_c. The mechanism of magnetic hardening in bulk Fe–Co–Cr materials was thought to be spinodal decomposition [3]. However, for our material, the change in H_c with T_a may be related to the increase in grain size; H_c shows a maximum when the grain sizes are close to the single-domain size.

Although H_c for the present wires is about a third of that for Fe–Ni–Cu wires reported earlier, their remanence, M_r, is greater by a factor of 2.5 with a reduced diameter. This is an advantage of the present material, considering that a large value of M_r and a small diameter are more important than H_c for locally magnetizing devices or magnetic force microscopy.

In summary, we have successfully prepared glass-coated hard-magnetic Fe–Co–Cr microwires. The diameter of the metallic core is about 3 μm. After an annealing at 600 °C for one hour, the coercivity is 200 Oe. This is lower than that of previously produced Fe–Ni–Cu wires, but since the ferromagnetic phase is more complete for the present wires, their remanence is higher than that of Fe–Ni–Cu ones.

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