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Domain Observation of Amorphous Wire with Large Diameter for Micro-Sensor and Micro-Motor Application

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Abstract. Domain structures of Fe-Si-B-Nb amorphous wires with a large diameter were investigated. A 10% increase of pulse output voltage due to large Barkhausen jumps in the Fe-Si-B-Nb wire at the diameter of 200 μm has been obtained which is less than expected due to decreased saturation and small domain size. Domain observation results indicate that the increase of the domain size in the inner core of the wire is important for high sensor output.

Keywords: Amorphous wire, domain structure, large Barkhausen jump, micro-motor

1. Introduction

In-water-quenched amorphous magnetic metal wire has been investigated owing to its unique properties that have initiated micro-sensor and micro-motor applications, such as RFID tags [1,2]. Since the intensity of sensor output using the amorphous wire depends on the diameter of the wire, the increase in the wire diameter has been required. In general, the quenching rate of molten alloy in the rotating water quenching technique decreases with increasing wire diameter. The diameter of amorphous wires obtained so far is limited to less than about 125 μm. In this study, efforts were made successfully to fabricate 200-μm-diameter amorphous wires by modification of alloy composition so as to increase formation ability of amorphous phase. Magnetic domain observation was performed to investigate the magnetic reversal process of the wires with increased diameter.

2. Experimental

Amorphous wires were prepared by in-rotation water quenching technique. Figure 1 shows a schematic view of a machine for fabrication of amorphous wires. The composition of the alloys is Fe-Si-B-M with M=Zr, Ta, Nb, and Ni. Magnetic hysteresis loops were measured at 100 Hz to detect large Barkhausen jumps and the voltage generated by the re-entrant flux reversal in a pick-up coil was measured. Magnetic domains of as-quenched and polished wires were observed using a Kerr microscope employing an image processor.

3. Results and Discussion

To increase formation ability, as a fourth or fifth elements Zr, Ta, Nb, and Ni were added to the Fe-Si-B ternary alloys[5]. The 200-μm-diameter wire with full amorphous phase was obtained with the composition $Fe_{73}Si_{15}B_{10}Nb_2$. Figure 2 shows the comparison of major and minor hysteresis loops for $Fe_{73}Si_{15}B_{10}Nb_2$ and $Fe_{77.5}Si_{7.5}B_{15}$ wires with the diameter of 200 μm. The maximum applied field of minor loop measurement is 0.1 Oe. As seen on the minor loop in Fig. 2(b), the $Fe_{73}Si_{15}B_{10}Nb_2$ wire exhibits a rapid flux change characteristic of re-entrant reversal. However, the rapid flux change cannot be seen on the minor loop of $Fe_{77.5}Si_{7.5}B_{15}$ wire in Fig. 2(a). The difference of flux change between two wires may be due to the precipitation of crystallites in the large-diameter $Fe_{77.5}Si_{7.5}B_{15}$ wire. By comparing the two loops, it is clear that the re-entrant characteristics can be obtained by adding Nb to large-diameter Fe-Si-B ternary alloy wire.

Domain patterns of as-quenched $Fe_{73}Si_{15}B_{10}Nb_2$ wire are shown in Fig. 3. The surface of the wire exhibits a maze domain configuration at the remanent state, as seen in Fig. 3(a). The width of the maze domain decreases with increasing applied field. When a dc field reaches 100 Oe, the maze domain width become very small and the wire is almost configured a saturation state, as shown in Fig. 3(d). This domain change caused by an applied field is different from that of the Fe-Si-B amorphous wire with 125 μm diameter, but very similar to that of the Fe-Co-B amorphous wire with low positive magnetostriction [3,4]. It seems that the change in domain configuration indicates the decrease in saturation magnetization due to the replacement of Fe with Nb.

The voltage generated by the re-entrant flux reversal of $Fe_{73}Si_{15}B_{10}Nb_2$ wire with 200 μm diameters in a pick-up coil is compared to that of $Fe_{77.5}Si_{7.5}B_{15}$ wire with 125 μm diameters. The re-entrant reversal process induces large Barkhausen discontinuities (BHD) that is the key technologies for sensor applications [1,2]. It was found that re-entrant flux reversal of $Fe_{73}Si_{15}B_{10}Nb_2$ wire generates the voltage of 11 mV that is 10% higher than that of $Fe_{77.5}Si_{7.5}B_{15}$ wire, as shown in Fig. 4. This value of induced voltage is much lower than the value expected from the increase in the wire diameter. One of the reasons for this is the decrease in the saturation magnetization due to the replacement of Fe with Nb. The inductance voltage is also influenced by the size of the inner core domain [3,4]. To evaluate core domain size, the wire was polished by approximately 40 μm from the surface. The domain patterns of polished surface are shown in Fig. 5. It is seen that the core domain appears when the field of 40 Oe is applied. From this domain configuration, the radius of the core domain is evaluated to be less than 60 μm, being smaller than a core domain size of about 70 μm for a 125-μm Fe-Si-B amorphous wire.

4. Conclusion

The Fe-Si-B-Nb amorphous wire having 200 μm diameter was fabricated successfully by the in-rotating water quenching technique. The wire has core and shell domain structure and exhibits the re-entrant flux reversal. Voltage generated by the Barkhausen discontinuities in a pick up coil is lower than that expected from the wire volume. This is partially due to the decreased saturation magnetization and partially due to the domain structure with smaller core domain size.

References

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FIGURE CAPTIONS

Fig. 1. A schematic view of machine for fabrication of amorphous wires.

Fig. 2. Major and minor hysteresis loops of amorphous wires.

Fig. 3 Domain patterns of as-quenched $Fe_{73}Si_{15}B_{10}Nb_2$ wire.

Fig. 4 Pulse output voltage applying an ac field.

Fig. 5 Domain patters of polished $Fe_{73}Si_{15}B_{10}Nb_2$ wire.

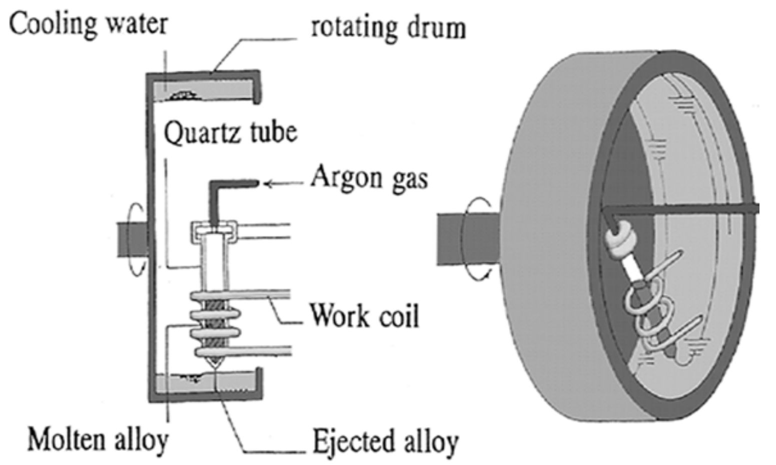
Cooling water
rotating drum
Quartz tube
Argon gas
Work coil
Molten alloy
Ejected alloy

Fig. 1

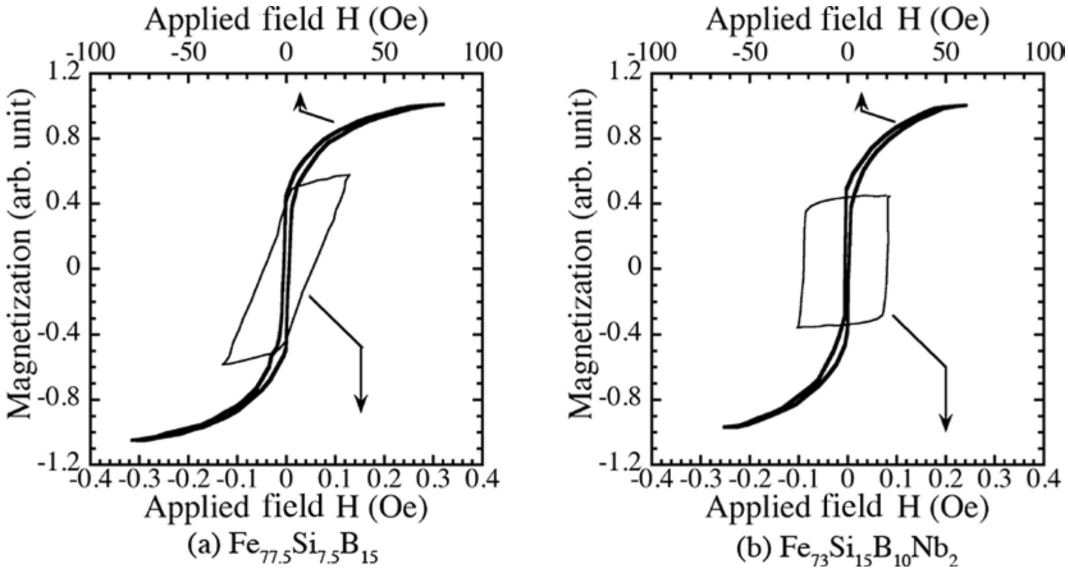
Applied field H (Oe)
-100
-50
0
50
100
Magnetization (arb. unit)
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4
Applied field H (Oe)
(a) $Fe_{77.5}Si_{7.5}B_{15}$
(b) $Fe_{73}Si_{15}B_{10}Nb_2$

Fig. 2

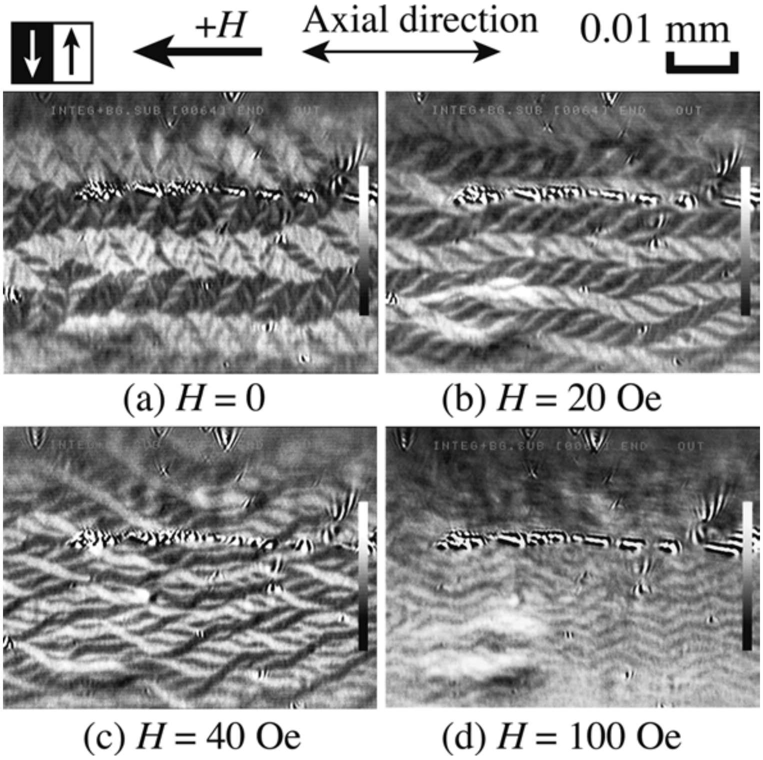
+H
Axial direction
0.01 mm
(a) H = 0
(b) H = 20 Oe
(c) H = 40 Oe
(d) H = 100 Oe

Fig. 3

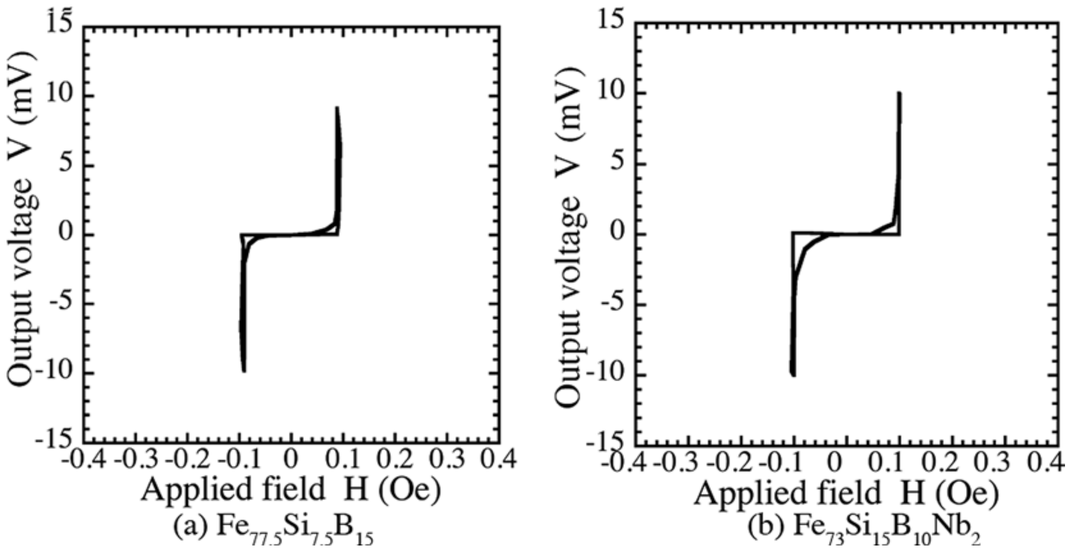
Output voltage V (mV)
15
10
5
0
-5
-10
-15
-0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4
Applied field H (Oe)
(a) $Fe_{77.5}Si_{7.5}B_{15}$
(b) $Fe_{73}Si_{15}B_{10}Nb_2$

Fig. 4

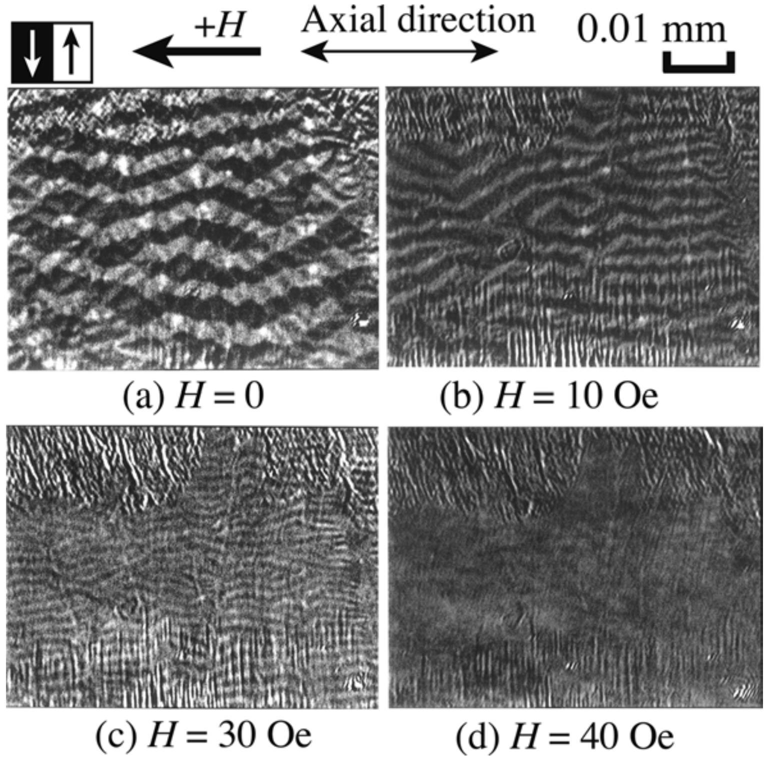

Fig. 5