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Magneto-resistance of NiFe nanowire with zigzag shape

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A B S T R A C T

The anisotropic magneto-resistance (AMR) contributions of a zigzag-shaped NiFe wire were investigated. The magneto-resistance (MR) behaviors in different magnetic-field directions clearly reflect the angular relationships between the directions of the current and magnetic moment in the subdivisions. The resistance in remanence after magnetization along 0° in respect to the longer direction of zigzag was larger than that along 90°. Assumed that the difference appears due to the AMR contribution in the domain wall trapped at the corner, the MR ratio was estimated to be 1.2%, which is in good agreement with the AMR of the NiFe film. We clearly showed that the domain-wall resistance originates in the AMR.

1. Introduction

The transport properties and magnetic domain structures in magnetic nanostructures have been extensively studied such as magnetic disks, wires, and rings, because of the interesting physics as well as the possible industrial applications. In particular, the magnetic wires have been investigated with regard to the relationship between the magneto-resistance (MR) and magnetic structures, for example, anisotropic magneto-resistance (AMR), domain-wall resistance (DWR) and their switching behaviors [1]. Taniyama et al. [2] suggested zigzag-shaped wires to control the domain-wall configurations. In the zigzag-shaped wire, in-plane magnetic field parallel and perpendicular to the longer direction of zigzag is expected to induce two different domain configurations in remanence. The MRs of Co zigzag wires at various field orientations were investigated and the configuration difference of the resistivity was observed. Recently, the nucleation and erasure of the domain walls were demonstrated using a current pulse in an NiFe zigzag-shaped wire, which is used for location control of the domain walls [3]. Furthermore, using some combinations of ferromagnetic wires instead of a zigzag wire, they have a potential of the domain-wall logic circuits [4]. Thus, the wires consisting of some subdivisions attracted considerable attention for both fundamental and applicable aspects.

In this paper, we report the transport properties of zigzag-shaped NiFe wires. The MRs in various magnetic field directions showed different field-dependences and the distinct difference in the resistance at the remanent state was also observed. These results are discussed from the aspect of the AMR and DWR with the calculated magnetic domain structures using the micromagnetic simulations.

2. Experimental procedures

The zigzag-shaped NiFe wires with a width of 400 nm were fabricated using electron-beam lithography and lift-off techniques. The subdivision length and thickness of the wires are 13 μm and 20 nm, respectively, and the bent angle is 90°. As shown in Fig. 1, there are 6 corners and some straight parts with a net length of about 6 subdivisions between electrical pads for a voltage measurement. The magneto-transport properties were investigated by the four-terminal method at 77 K. It was measured by means of low-frequency (50 Hz) and low-current ac techniques using an AC resistance bridge. The magnetic field was applied to various in-plane orientations by rotating a magnet, so that there was no ambiguity by the probe contacts and cable configurations of the sample.

The magnetic structures of the NiFe wires were simulated using the Landau–Lifshitz–Gilbert (LLG) micromagnetic simulator [5]. The cell size was 10 nm in the in-plane direction.

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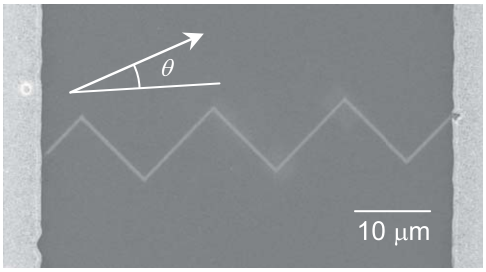

Fig. 1. SEM image of the zigzag NiFe wire. Six corners and some straight parts with a net length of about six subdivisions are included between electrical pads for a voltage measurement.

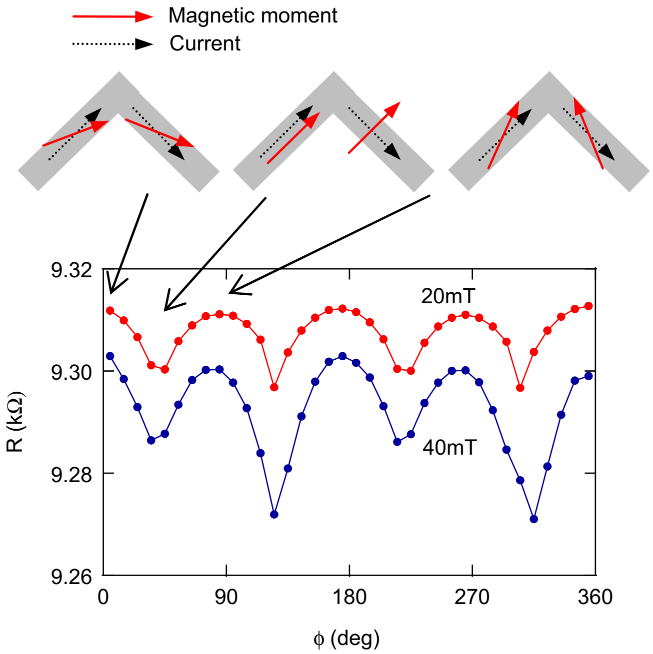

Fig. 2. The field angular dependence of the resistance in 20 and 40 mT. Schematic magnetic structures at typical angles are also depicted.

3. Results and discussions

The field angular dependence of the resistance in the constant magnetic fields is shown in Fig. 2. Approximate four-fold symmetry is observed in angle-dependent magneto-resistance. Schematic magnetic structures at typical angles are also depicted in Fig. 2. It is well known that the anisotropic magneto-resistance (AMR) has maximum value when the direction of current is parallel to that of the magnetic moment. For 0°, the magnetic moment direction in the straight subdivision is nearly parallel to the wire direction because of the shape-induced anisotropy of the wires and weak external magnetic field. Therefore large resistance by the AMR is observed at 0°. For 45°, on the other hand, the magnetic moment in one side of the subdivisions directs almost perpendicular to the wire, although that in another side directs parallel to the wire. In the former case, the current flow perpendicular to the magnetic moment, so that the resistance decreases by the AMR contribution. For 90°, the angle relationships between the current and magnetic moment directions are almost same as that for 0°. Therefore, the resistance has maximum again at 90°. The resistance dip of 135° and 315° is larger than those of 45° and 225° in 40 mT. This is because the length of straight parts is slightly different between two directions because of the limit of the patterning calibrations of the e-beam lithography.

Fig. 3 shows the MR behaviors along three magnetic-field directions: (a) 0°, (b) 45° and (c) 90°. The resistivity in remanence is approximately $95\times10^{-6}\,\Omega$ cm. Micro-magnetic simulations provide useful information to discuss these MR behaviors. The calculated magnetic structures are also shown, and the arrows of the solid line are the typical directions of the magnetic moments in the subdivisions for the guide of eyes. The calculated magnetic structures were obtained in a slightly larger field than the actual field, judging from a comparison with the actual MR behaviors. This appears to come from the slight difference in the actual size of the wire. Accordingly, dashed allowed magnetic field is a few mT different from the calculated field. For 0° and 90°, the MR

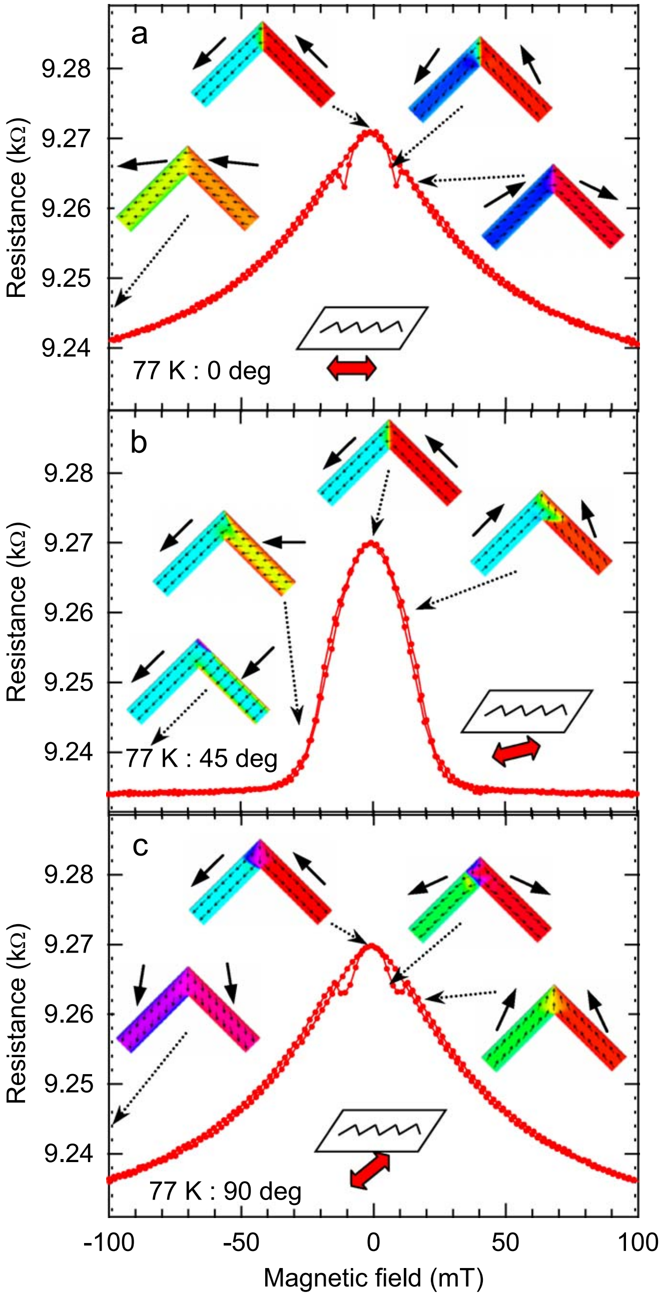

Fig. 3. Magneto-resistance along three magnetic-field directions: (a) 0°, (b) 45° (c) 90° in respect to the longer direction of the zigzag.