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High-frequency noise absorbing properties of nickel nanowire arrays prepared by DC electrodeposition

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Nickel nanowire arrays are fabricated by electrochemical deposition in highly ordered nanosized pores in AAO (anodized aluminum oxide) templates, and their static and high-frequency noise absorbing properties have been investigated. Using the channelled AAO templates, a nickel nanowires array was fabricated by DC electrodeposition. Magnetic hysteresis was observed with a coercivity of 250~ 300 Oe depending on the field orientation with respect to wire axis. Noise absorbing properties of the nickel nanowires array was measured using the microstrip line. S_{11} parameter increases with frequency and reaches a saturated value of about -10 dB. The reflected power (about 10%) is much less than that of nickel thin film (about -3 dB), which is due to higher in-plane electrical resistance of the nanowire array structure. S_{21} decreases with frequency and has a value of -3 dB at 2 GHz. The attenuation of conduction noise through microstrip line is due to the magnetic loss of individual nickel nanowires. Power absorption of the Ni nanowire array was estimated to be 50% in the frequency range above 2 GHz.

1 Introduction

An interest is growing in the fabrication of nanostructured magnetic materials because of their unusual properties compared to bulk materials. Creation of well-ordered magnetic nanowire arrays may have promise in applications in recording media, sensors, and other devices [1–3]. Noise absorber in micro-EMC (electromagnetic compatibility) is one of the potential applications of the magnetic nanowires array due to their distinguished electrical and magnetic properties [4, 5]. Almost infinite in-plane electrical resistance and high magnetic permeability as well can be obtained from the periodic array structure of individual nanomagnets with high aspect ratio and nanometer-scaled diameter which is much smaller than skin depth in microwave frequency range. The purpose of this study is to investigate the potential application of the magnetic nanowire arrays in high-frequency noise absorbers. Ni nanowire arrays are fabricated by electrochemical deposition in highly ordered nanosized pores in AAO (anodized aluminum oxide) templates, and their static and high-frequency noise absorbing properties have been investigated using the microstrip line.

2 Experimental procedure

Electrodeposited Ni nanowires were fabricated in the porous alumina template with 200 nm pore diameter and 60 μm in thickness following the procedure described in the previous study [6]. For DC electro-

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deposition of Ni, Ag thin film was deposited on one side of the through-hole AAO template by sputtering. Ni was electrodeposited into the channelled pores using an electrolyte of Watts bath solution (300 g/*l* $NiSO_4 \cdot 6H_2O$, 45 g/*l* $LiC1_2 \cdot 6H_2O$, 45 g/*l* H_3BO_3). The electrolyte temperature was 57 °C and pH was adjusted at 3.8. Ni sheet was used as the counter electrode. The electrodeposition was carried out under the constant cathodic current of 10 mA.

The morphology of the deposited nanowires was observed by scanning electron microscope (SEM). The phase and crystallographic structure of the Ni nanowires was analyzed by X-ray diffraction (XRD). The magnetization hysteresis was measured by vibrating sample magnetometer (VSM). Conduction noise attenuation was measured in the microstrip line with 50 Ω characteristic impedance. Attaching the nickel nanaowire array sample (with size of 20 mm × 20 mm) in the central part of microstrip line whose schematic description is shown in Fig. 1, reflection and transmission parameters (S_{11} and S_{21}, respectively) were measured by HP8722D network analyzer in the frequency range of 0.5–3 GHz.

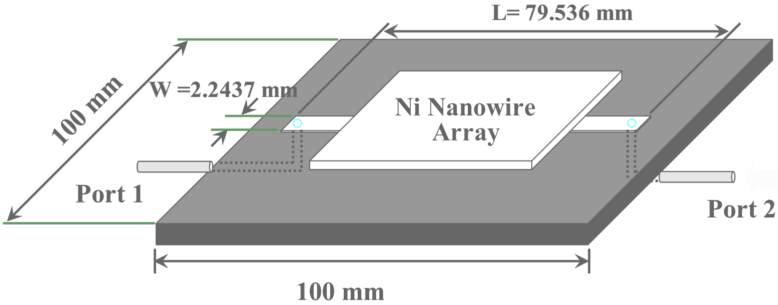


Fig. 1 Microstrip line used for determination of conduction noise absorption.

3 Results and discussion

Morphology of the electrodeposited Ni nanowire arrays is shown in Fig. 2. Well-aligned Ni nanowires (as long as 12 µm with diameter of 200 nm and wire density of 1.6×10^9 wires/cm^2) are observed in the pores of the channelled AAO template. Figure 3 shows the X-ray diffraction pattern obtained for the Ni nanowires array sample. FCC-Ni phase peaks with dominant (111) texture were assigned in the figure. Other peaks are from the Ag film sputtered on the anode side of AAO template.

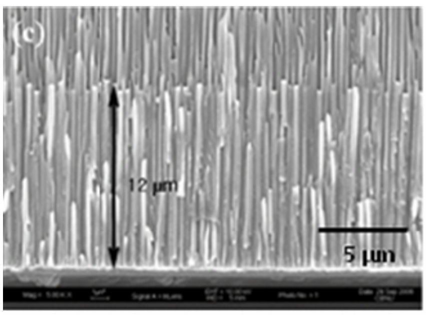


Fig. 2 SEM morphology of Ni nanowire arrays prepared DC electrodeposition in AAO template.

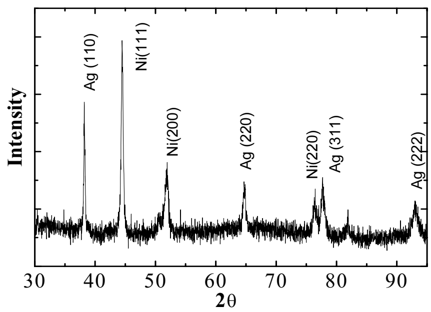


Fig. 3 X-ray diffraction patterns of Ni nanowires array.

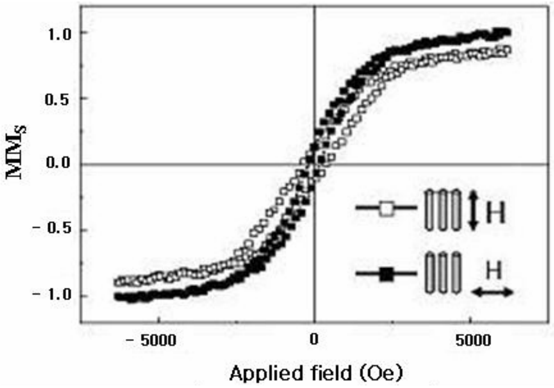
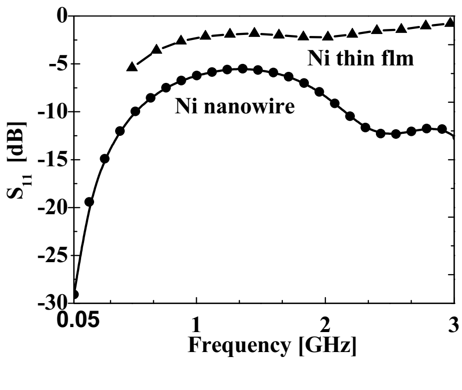
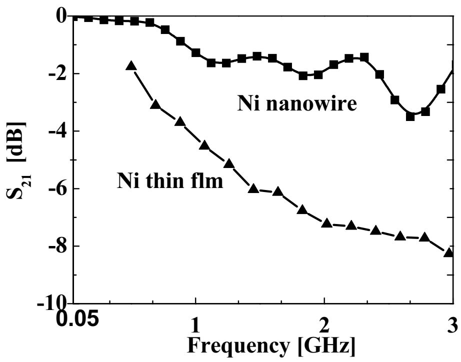


Fig. 4 Magnetic hysteresis loops of Ni nanowires array.

Figure 4 shows the M-H loops measured with the sweeping magnetic field parallel and perpendicular to the wire axis. The coercivity values were extracted from the hysteresis loops by applying field in the parallel and perpendicular directions were found to be 300 Oe and 250 Oe, respectively. Magnetic anisotropy was not significant because of large diameter of Ni nanowires (about 200 nm). Whitney et al. [7] found that multidomains formed for the large-diamerter Ni wires degrades the coercivity and also the degree of magnetic anisotropy is reduced with increasing wire diameter.

Figure 5 shows the noise absorbing properties of the Ni nanowires array determined by using the microstrip line. For comparison, high-frequency results of a continuous Ni thin film (size = 20 mm × 20 mm,





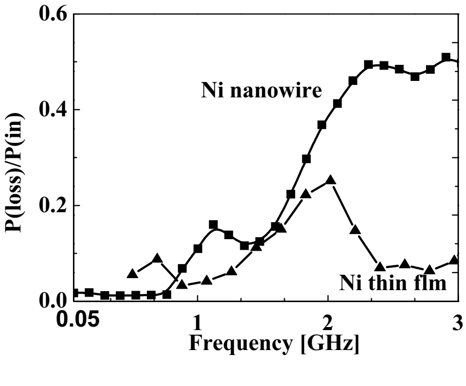


Fig. 5 S-parameters and power absorption determined in the microstrip line attached with Ni nanowires: (a) S_{11}, (b) S_{21}, and (c) PA.

thickness = 2 μm) are also inserted in the figure. S_{11} parameter of Ni nanowires array sample increases with frequency and reaches a saturated value of about -10 dB. The reflected power (about 10%) is much less than that of Ni film (about -3 dB), which is due to higher in-plane electrical resistance of the Ni nanowires array. S_{21} decreases with frequency and has a value -3 dB (50% power dissipation) at 2 GHz. The attenuation of conduction current through microstrip line is due to magnetic loss of individual Ni nanowires. A much reduced value of S_{21} observed in Ni thin film is considered to be due to eddy current loss in addition to their higher magnetic loss.

Power absorption (*PA*) is defined by the ratio of power loss to input power and calculated from the measured S_{11} and S_{21} values, which is given by Eq. (1):

$$PA = 1 - \left(|S_{11}|^2 + |S_{21}|^2 \right). \tag{1}$$

Power absorption by Ni nanowires array sample is increased with frequency and saturates to a value about 0.5 in the frequency region above 2.5 GHz. A much higher value of power absorption is predicted in Ni nanowires array in comparison with continuous Ni thin film. The result is attributed to smaller reflection loss coming from higher in-plane electrical resistance of nanowires array structure. It is, therefore, suggested that the magnetic nanowires array with higher in-plane resistance and appreciable magnetic loss can be a potential material as noise absorbers in GHz frequencies.

4 Conclusion

Noise absorbing properties of Ni nanowires array (diameter 200 nm, length 12 μm) prepared by DC electrodeposition was measured in the microstrip line. Appreciable value of noise absorption was estimated in GHz frequencies. S_{11} parameter increases with frequency and reaches saturated value of about -10 dB. The reflected power (about 10%) is much less than that of Ni thin film (about -3 dB), which is due to higher in-plane electrical resistance of the nanowires array structure. S_{21} decreases with frequency and has a value -3 dB at 2 GHz. The attenuation of conduction current through microstrip line is due to magnetic loss of individual Ni nanowires. It is suggested that the magnetic nanowires array with higher electrical resistance and appreciable magnetic loss can be a potential material as noise absorbers in GHz frequencies.

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