Development of Serial Magnetic Tunnel Junction Sensors for High Signal-to-Noise Ratio in Nondestructive Eddy Current Testing

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論文内容要約

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[Introduction and purpose]

Magnetic tunnel junctions (MTJs) are used as innovative spintronic devices such as highly sensitive magnetic sensors. MTJ-based magnetic sensors enable us to detect small defects by nondestructive eddy current testing (ECT) owing to their frequency independent sensitivity and small size of the devices. In particular, a serial MTJs sensor can provide excellent detectivity for detecting a weak variation in magnetic field from sub-millimeter sized surface cracks. In this study, I aimed to show that the MTJ sensors are greatly useful for the ECT by carrying out the following research contents.

1. Fabrication of a single MTJ device with excellent resistance response to external field
2. Design of MTJ sensors and excitation coils to realize effective sensing and high spatial resolution
3. Characterization and optimization of serial MTJ sensors to obtain high signal-to-noise ratio
4. Estimation of the size of surface cracks by developed serial MTJ sensors

[Experimental results]

Optimization of a single MTJ for ECT application (Chapter 3)

In order to realize the ECT with high sensitivity and high reliability, a single MTJ device with high sensitivity and small nonlinearity is required. I fabricated single MTJ elements with various aspect ratios and areas and investigated their magneto-resistive properties. A single MTJ with an area of 15 μm×60 μm was the most suitable MTJ element due to its high sensitivity (2.4 %/Oe) and small nonlinearity (4.3% FS) in a wide range of magnetic field (±33 Oe).

Characterization of serial MTJ sensors with various configurations (Chapter 4)

By analyzing finite element method (FEM) simulation, I found by the simulation that a serial MTJ sensor can effectively detect a variation of a perpendicular component of magnetic field from surface cracks with high spatial resolution, when it is patterned into a compact area (100 μm width; 300 μm height). Furthermore, I fabricated five types of serial MTJ sensors with various numbers of MTJs (N=4, 16, 28, 40, and 52) arranged in 1, 4, 7, 10, and 13 rows. I found that high sensitivity can be obtained by increasing number of serial MTJ element N due to accumulated effect. I also determined an applied current of 0.1 mA to obtain a high sensitivity in serial MTJ sensors.

Detection of surface cracks by probes with fabricated MTJ sensors (Chapter 5)

I investigated the performance of fabricated serial MTJ sensors for the ECT. Although all of the sensors detected sub-millimeter sized surface cracks, a sensor with 28 serial MTJs in 7 rows exhibited the highest signal to noise ratio (SNR). By using this sensor, the high SNR of 116 dB was obtained in an inspection of a small crack with 0.1 mm width and 0.1 mm depth.

Estimation of surface crack dimensional characteristics by an ECT probe with a developed serial MTJs sensor (Chapter 6)

I measured magnetic field from small surface cracks with various dimensions by a developed serial MTJ sensor (N = 28) to determine the size of cracks. The width and depth of cracks were successfully estimated by analysis of the ECT signals.

[Achievement]

This study demonstrated that the developed serial MTJ sensors can detect sub-millimeter sized surface clacks of metallic specimens with high SNRs and high spatial resolution in the ECT. This technology will be used as a safety inspection method in the construction and airplane manufacturing industries. In addition, the knowledge obtained in this study can greatly contribute to the progress of applied physics field.