SUMMARY OF Ph.D. DISSERTATION

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Title

Study of Oscillation Controlled Highly Sensitive Magnetic Sensing with Magnetoresistance Devices

Abstract

Highly sensitive magnetic sensing has been of great assistance to mankind in a variety of applications, ranging from magnetic force microscope for magnetic state observation to high-density magnetic card sensors. Recently, spin tunneling junctions have been attracted for highly sensitive magnetic sensing devices due to large tunnel magnetoresistance (TMR) ratio at room temperature. However, it is difficult to flow large current due to high resistance in junctions. This leads to difficulty for an achievement of a high signal-to-noise (S/N) ratio in the conventional magnetic sensing, such as a detection of dc voltage difference using magnetoresistance effect. In this paper, highly sensitive magnetic sensing using spin tunneling junction is proposed and the feasibility of this sensing is discussed.

This dissertation consists of six chapters.

In the 1st chapter, the background and the purpose of this study are described.

In the 2nd chapter, oscillation controlled highly sensitive magnetic sensing is described. In this new magnetic sensing, spin tunneling junction is constructed in the feedback loop of the Hartley oscillator. the oscillation voltage, noise, S/N ratio, time response, and error rate are calculated theoretically. As a result of a design of the magnetic sensing circuit based on this proposal, we confirmed the sensing performance of the oscillation controlled magnetic sensing having high S/N ratio.

In the 3rd chapter, fabrication methods of the spin tunneling junction and analysis methods of various properties, such as oxidation states of insulator, leakage current densities, and electronic structures of the interfacial atoms are described. Coercive differential spin tunneling junctions Co (10nm)/Al-oxide/Co (50nm) were fabricated on glass substrates by ion-beam mask sputtering. The sputtered Al film was oxidized in pure O_2 gas for 12 – 216 h at room temperature. Thickness and oxidation state of Al-oxide barrier were evaluated from X-ray photoelectron spectroscopy depth profiles. Electronic structures of Co/Al interfacial atoms were calculated by using the first principle band calculation. Leakage current densities were estimated from a fit to Stratton eq. and Schottky eq. of current-temperature characteristics. With respect to magnetoresistance of junctions, the sputtered Al thickness dependence an influence of anneal treatment were investigated.

In the 4th chapter, ac impedance characteristics of junctions are described. As a result of the investigation of ac impedance characteristics, not only real part but also imaginary part of impedance changes by the external magnetic field. This can be explained from an assumption of both dc TMR effect and RC parallel circuit of junctions. As the frequency approaches 0 Hz, the imaginary part of magneto impedance ratio exhibits two times of dc TMR ratio. As the frequency is higher than the roll-off frequency, the imaginary part approaches zero. As the spin tunneling junction showing the magnetoimpedance is used for the magnetic sensing, it is possible to detect the real and imaginary part of impedance by the external magnetic field without canceling out both of the part.

In the 5th chapter, experimental results of oscillation controlled magnetic sensing are described. In the sensing circuit using each of the spin tunneling junction and RC parallel circuit, the oscillation voltage, noise, S/N ratio, time response, and error rate are investigated. As a result, the oscillation voltage changes in accordance with the impedance change by the external magnetic field. High oscillation voltage is obtained even if the sensing current is small. Magnetoresistance dependence of output voltage is in good agreement with calculated results from F-matrix methods. Noise originated from the output in the sensing circuit can be explained from the thermal noise and shot noise of total output impedance. Based on these analyses, S/N ratio of the oscillation controlled magnetic sensing is found to be higher than those of conventional methods. Furthermore, error rate less than 10^{-7} is found to be obtained, and it can be explained from calculated results of normal distribution taking the crest value of total noise, summarized thermal noise and shot noise, and threshold voltage into account.

In the 6th chapter, conclusions in this paper are described.