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A benchtop induction-based AC magnetometer for a fast characterization of magnetic nanoparticles

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Abstract

In this study, we report a development of a benchtop induction-based AC magnetometer to realize a simple, wideband, and sensitive AC magnetometer for bio-sensing applications and characterization of magnetic nanoparticles (MNPs). We investigate the inductance and parasitic capacitance of six different pickup coil geometries and compare their sensitivity and usable frequency range. In the pickup coil design, the number of turns and coil section separation are varied from 200 to 400 turns, and 1 to 4 sections, respectively. We find that the usable frequency range is greatly affected by the pickup coil's inductance due to the self-resonance phenomena compared to their parasitic capacitance. A low noise instrument amplifier circuit (AD8429, Analog Devices, USA) was integrated and fabricated on a printed circuit board to amplify the weak signal from the pickup coil. We also implement a generalized Goertzel algorithm to achieve fast signal amplitude and phase extractions at a frequency. The developed magnetometer shows a sensitivity of 10^{-8} $Am^2/\sqrt{Hz}$ at 6 Hz and a frequency range of up to 158 kHz. Using the developed AC magnetometer, we demonstrate the viscosity effect on the frequency response of thermally blocked, single-core nanoparticles (SHP30, Ocean Nanotech, USA) in glycerol solutions. The excitation frequency is swept from 5 Hz to 158 kHz at a field amplitude of 0.55 mT_{pp} within the acquisition time of 5 min (51 points). As a result, the viscosity change is confirmed by the peak shifting in the imaginary magnetization curve towards lower frequency values when the wt/V% of the glycerol solution is increased. The hydrodynamic size and the average anisotropy energy ratio σ are estimated to be 60.6 nm and 25, respectively, from the complex AC magnetization. It can be expected that the developed AC magnetometer can be a valuable tool in providing a fast and reliable assessment of MNPs for bio-sensing applications.

1. Introduction

Magnetic susceptibility methods have shown high potential to provide a fast characterization and standardization technique of magnetic nanoparticles (MNPs) [1, 2]. Particularly in biomedical applications, AC magnetometers have been developed to measure magnetic responses from MNPs where Neel and Brown relaxation parameters are characterized and utilized [3]. From the Brownian and Neel relaxations, geometrical and magnetic properties of the MNPs can be estimated, such as the hydrodynamic size and magnetic anisotropy energy ratio. During the analysis of the Brownian and Neel relaxation, it was shown that the characterization frequency range to observe these relaxations plays an important role where a broader frequency range is desired to reveal further information on the MNP properties [2].

The magnetic response produced by the time-dependent magnetization $M(t)$ of MNPs can be measured by using magnetic sensors such as superconducting quantum interference devices (SQUIDs) [4–6], optically pumped magnetometers [7], fluxgates, and giant magnetoresistance sensors [8]. However, compared to other magnetic