University Oral Examination

Spin Valve Sensor for Biomolecular Identification: Design, Fabrication and Characterization

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Biomolecular identification, e.g. DNA recognition, has broad applications in biology and medicine such as gene expression analysis, disease diagnosis and DNA fingerprinting. We have been developing a magnetic biodetection technology based on the giant magnetoresistive spin valve sensors and the magnetic nanoparticles (< 20 nm in diameter) as biomolecular labels in an effort to provide a highly sensitive, quantitative, portable and cost-effective biomolecular identification device. This dissertation is concentrated on the design, modeling, fabrication and characterization of the spin valve sensors, aiming to prove the magnetic biodetection concept and demonstrate the feasibility of the magnetic nanoparticle detection by the spin valve sensors.

The intended magnetic nanoparticle labels are superparamagnetic at room temperature with zero magnetic remanence. Therefore, the nanoparticles need to be magnetically excited in order to generate magnetic fringing fields detectable by the field-sensitive spin valve sensors. DC or AC magnetic excitation can be applied, for which we have designed several nanoparticle detection schemes. An analytical model has been developed for the magnetic nanoparticle detection, based on the two assumptions of (1) the equivalent average field of magnetic nanoparticles and (2) the coherent rotation of spin valve free layer magnetization. Micromagnetic simulations have also been performed for the spin valve sensors. The analytical model is found consistent with the micromagnetic simulations and can be used as an efficient design tool.

The prototype spin valve sensors have been fabricated at both micron and submicron scales. We first demonstrated that the micron-sized spin valve sensors successfully detected a single 2.8-μm magnetic microbead. To demonstrate the detection of magnetic nanoparticles, we developed a bilayer liftoff process, based on a polymer-mediated self-assembly and fine lithography, to deposit magnetic nanoparticles onto sensor surface in a controlled manner. With this liftoff process, we successfully detected the monodisperse 16-nm Fe_3O_4 nanoparticles in a quantity from tens to hundreds using submicron spin valve sensors at room temperature. A linear dependence of the spin valve sensor signal on the number of nanoparticles has been found, as desired for the quantitative biodetection. The detection limit was found to be 14 Fe_3O_4 nanoparticles with the current detection scheme. Preliminary detection results on the nanoparticle-labeled DNA hybridization events will also be presented.