Nanowire GMR Thin Films for Magnetic Sensors

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ABSTRACT

We present an appealing technique for the fabrication of nanowire-GMR thin films for magnetic sensors. Using this technique, magnetic sensors can be created that are transparent, flexible, and can have a size from square microns to square meters with no exponeitial cost increases. The electrical sheet resistance of these sensors are between 100-100k Ω/□, with a %GMR on the scale of 10%. A electrodeposition technique is used to create current perpendicular to plane (CPP) multilayer GMR nanowires inside of aluminum oxide templates. After fabrication, the nanowires can be transferred to substrates using a variety of techniques including vacuum filtration, metering rod, and spray coating methods. The operational parameters of the magnetic sensors are determined by the characteristics of the nanowires, which include their chemical makeup, length, density, amount of oxidation removal and annealing.

Keywords: giant magnetoresistance**,** GMR, magnetic sensors, nanowires, thin films

1 INTRODUCTION

Material that exhibit a GMR response can be fabricated from a number of thin film fabrication techniques, which can be broadly classified into physical and chemical processes. Physical processes entail emitting charged atoms from a target by means of high-speed electrons, ions, or molecules and then directing the material to a substrate. Alternatively, chemical and electrochemical processes are characterized by the occurrence of chemical reaction at the substrate surface. Each fabrication method has its advantages and disadvantages, with the cost of fabrication and quality of the GMR material both being affected by the fabrication method [1-4].

This paper details the fabrication of thin film magnetic sensors from GMR nanowires. Using a pulsing electrodeposition technique, multilayer nanowires are fabricated inside of aluminum oxide templates. Parameters, such as electrolyte concentration, current density, and deposition times determine the magnitude of the GMR effect exhibited by the nanowires [5]. After the GMR nanowires are fabricated inside the template, they are removed and transferred to flexible and transparent PET substrates using a variety of techniques including a PDMS stamp, metering rod, and spray coating methods. Magnetic sensors created using this technique can be used to create large inexpensive magnetic sensing arrays for a variety of applications.

2 THEORATICAL AND EXPERIMENTAL

Using a pulsing electrodeposition technique, CoNiFeCu/Cu multilayer GMR nanowires were fabricated inside of 20nm pore Anodisc aluminum oxide (AAO) templates (6809-6002 Anodisc™, Whatman) . First, a 200nm gold layer was deposited onto the template followed by a coating of the liquid metal GaIn. The membrane was then placed into a specially designed holder, with the conductive side acting as a cathode. An anode and reference electrodes were added to the electrolyte solution creating a standard electrochemical setup. Multilayer GMR nanowires were electrodeposited inside the pores of the template using a pulse deposition technique controlled by a computer. After deposition the GaIn and gold was removed with concentrated nitric acid and then finally the template was dissolved with a 6 M NaOH solution. The NaOH solution was removed from the nanowires and they were then rinsed multiple times with DI water and finally suspended in isopropanol alcohol [6]. Figure 1 highlights the nanowire fabrication steps.

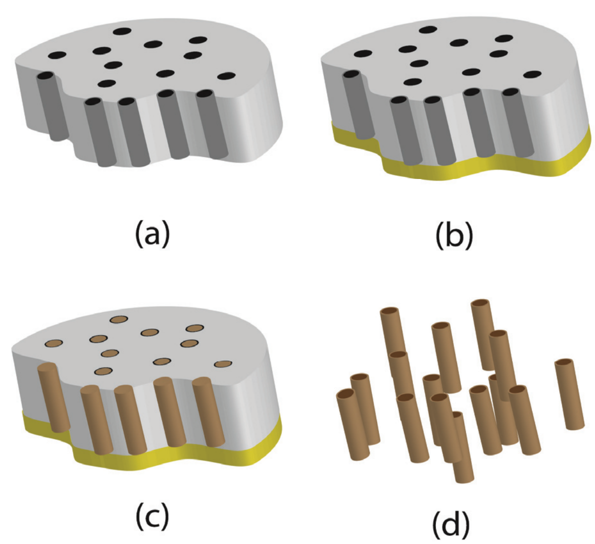

Figure 1: Template Assisted Nanowire Fabrication (a) Empty template membrane (b) Template membrane coated with conductive metal on bottom (c) Nanowires electroplated inside template membrane (d) Nanowires released from template

2.1 Thin Film Fabrication

Once the GMR nanowires were fabricated and suspended in a buffer solution, they were be turned into thin films for magnetic sensors. Three sensor fabrication techniques were explored that had the ability to produce low power, inexpensive, transparent and flexible magnetic sensors on a large scale. Before each of the following thin film fabrication techniques, the suspended GMR nanowires were ultrasonicated for 20 minutes to decrease nanowire aggregation.

Vacuum Filtration Thin Film Fabrication Method

GMR nanowires (20-60μm in length) were vacuum filtered onto 200nm pore aluminum oxide membranes with a vacuum flask and pump. Once a thin film of nanowires formed on the AAO filter, a cylindrical PDMS stamp was used to collect the GMR nanowires from the membrane by forming secure contact between the stamp and nanowires. After collecting the nanowires the PDMS stamp was used to transport the nanowires to a 120°C heated PET plastic receiving substrate. Figure 2 highlights the vacuum filtratioin thin film fabrication steps.

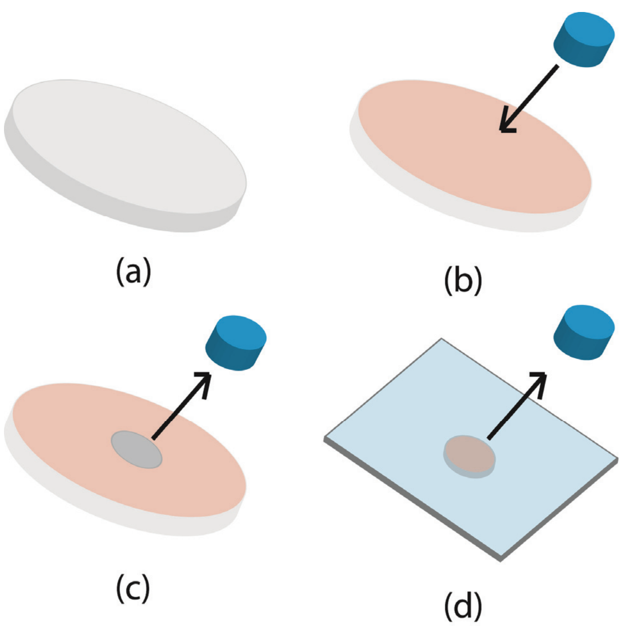

Figure 2: Vacuum filtration thin film fabrication (a) empty membrane (b) membrane after GMR nanowires are vacuumed filter on top (c) PDMS stamp being used to transfer GMR nanowires (d) PDMS stamp transferring nanowires to a receiving substrate

Metering Rod Thin Film Fabrication Method

The second method attempted to create GMR nanowire thin films was a metering rod coating technique. A 16" long #10 metering rod was purchased from Diversified Enterprises. The #10 metering rod is designed to give a 25.4μm film thickness and has a coverage area of 39.4 m^2 per liter of liquid. GMR nanowires suspended in isopropyl alcohol were dispensed onto a PET plastic substrate before the metering rod was used to spread the solution uniformly over the PET surface. As the PET film was allowed to dry, a GMR nanowire film adhered to the PET substrate. Multiple coatings of GMR nanowires could be applied using the metering rod. Once the desired thickness of GMR nanowires was reached, the PET film was allowed to completely dry before PDMS stamps were used to collect the nanowires onto their surfaces for transfer to a receiving substrates. Figure 3 shows the process steps for the metering rod method.

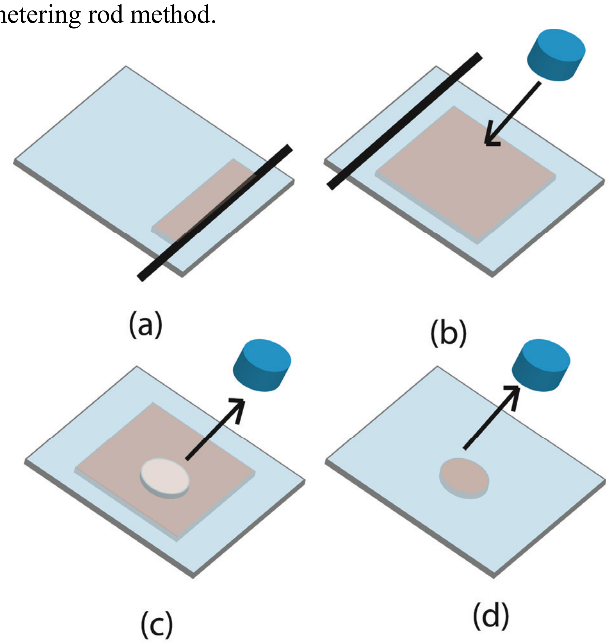

Figure 3: GMR thin film applied with a metering rod method: (a)-(b) GMR nanowire thin film being applied to a PET substrate with metering rod (c) PDMS stamp being used to transfer nanowires (d) PDMS stamp transferring nanowires to a receiving substrate

Spray Coating Thin Film Fabrication Method

Two simple spray coating method were also explored as a large scale production method of creating GMR nanowire thin films. First, an airbrush was used to coat a layer of masking tape that had a pattern cut out. The tape was ontop of PET plastic. After the tape is removed a GMR nanowire thin film is left on the PET. A blank PDMS stamp is then used to transfer the nanowires to a receiving substrate. The second spray coating method uses a patterned PDMS stamp with a layer of GMR nanowires applied by an airbrush. The stamp is used to transfer the GMR nanowires to a receiving substrate to create magnetic sensors of various line widths and geometries. Figures 4 and 5 shows the process steps for the spray coating methods used to create GMR nanowire thin films for magnetic sensors.

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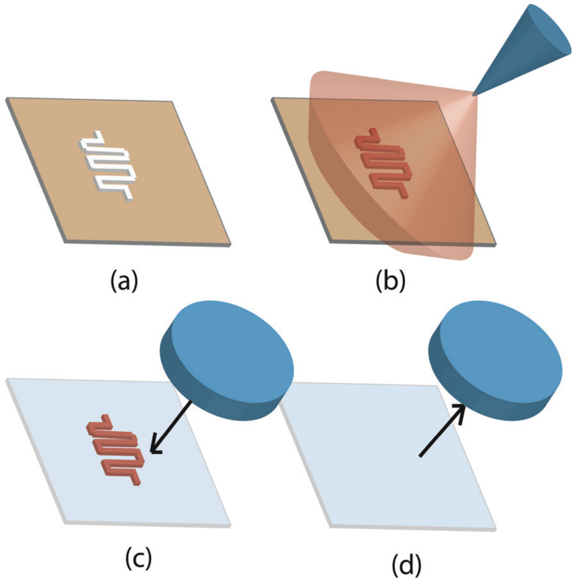

Figure 4: Spray coating thin film method 1 (a) PET substrate covered with pattered Kapton tape (b) GMR nanowires being spray coated over the PET substrate (c) PET substrate with the Kapton tape removed, leaving behind the patterned nanowires (d) blank PDMS stamp transferring the nanowire thin film pattern

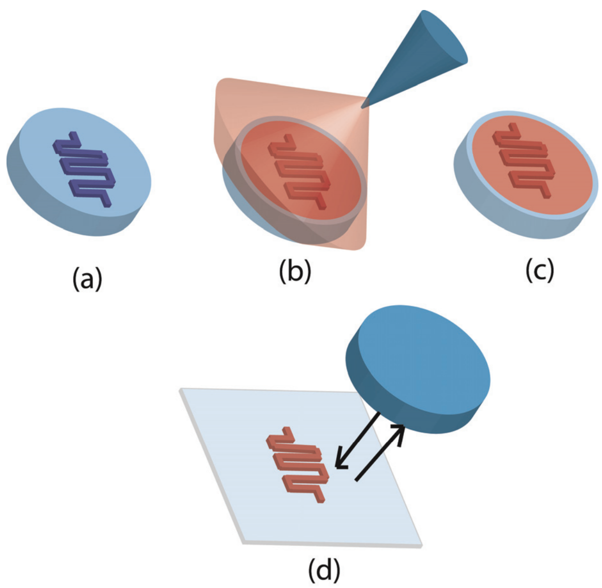

Figure 5: Spray coating method 2: (a) Patterned PDMS stamp (b) PDMS stamp being spray coated with GMR nanowires (c) PDMS stamp with GMR nanowire thin film (d) PDMS stamp transferring nanowires to PET substrate

Assembly and Testing

After the GMR nanowires are transferred to a substrate, electrodes are fabricated for turning the nanowire thin films into magnetic sensors. Silver conductive paint was used to create electrodes. The silver paint was applied to the film and allowed to dry before the electrodes were used for testing the resistance of the sensors.

The conductivity of the GMR nanowire thin films depends profoundly on the amount of oxidation present. Oxidation of the nanowires leads to high resistance films. Routinely, after a GMR nanowire thin film was fabricated its resistance was above the limits of a standard multimeter (>80MΩ). However, after a dilute acid is applied to the film and a current is allowed to flow through the film, the resistance decreases dramatically. This difference in resistances can be attributed to the removal of oxidation and fusion of the GMR nanowires. Care has to be taken not to destroy the multilayers in the nanowires by over etching with the acid or burning them with excessive current. After fabrication, the GMR thin films were tested with a standard multimeter and neodymium magnet as well as a Lakeshore 7603 Hall Measurement System.

3 RESULTS AND DISCUSSION

Figure 6(a) shows an image of four GMR thin film magnet sensors deposited on a PET plastic substrate using the vacuum filtration method described previously. Figure 6(b) shows a SEM image of a sensor.

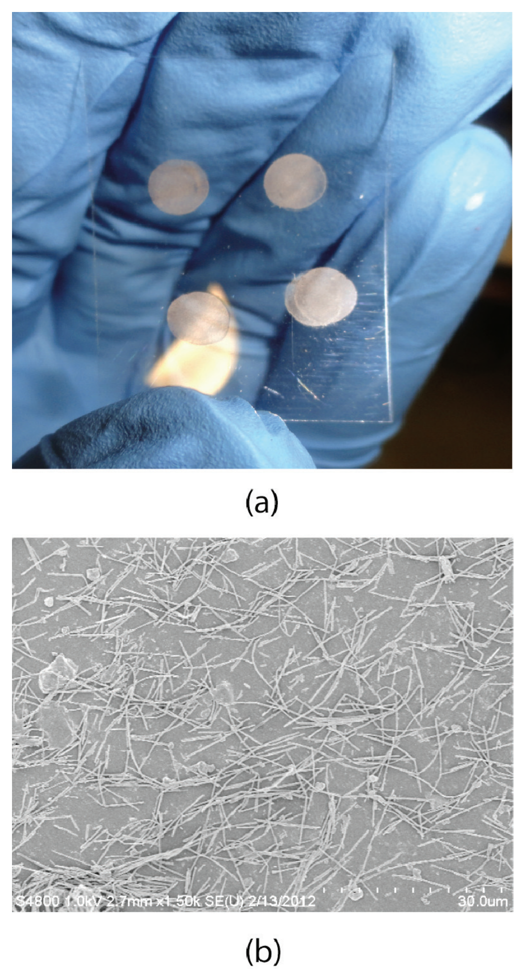

Figure 6: (a) Four nanowire-GMR thin films (b) SEM image of GMR nanowries on PET substrate

Figure 7 shows the output voltage and resistance change of the GMR thin film when a constant 0.5mA current was passed between the electrodes of the thin film. The square wave represents a small neodymium magnetic being brought in close proximity (2mm) and removed from the magnetic sensor in 1 minute intervals. Figure 8 shows a GMR curve of a GMR thin film obtained by varying a magnetic field from ± 1 Tesla. The graph is not completely symmetric due to hystersis but there is a clear correlation between the magnetic field and resistance.

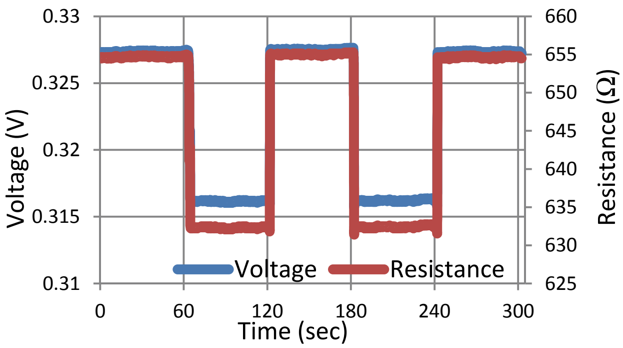

Figure 7: Voltage output and resistance of a GMR thin film when a .5mA current passes between the electrodes. A small neodymiumm magnet was brought in close proximity (2mm) to the sensor and removed in 1 minute intervals.

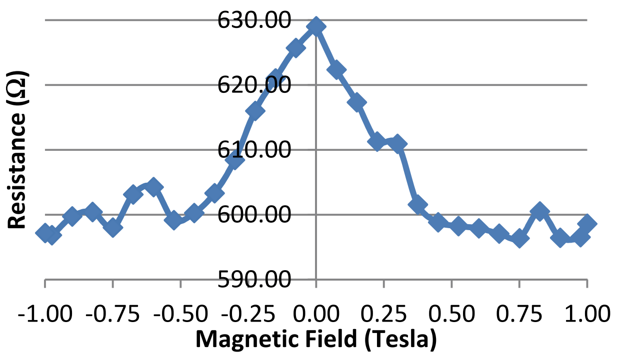

Figure 8: %GMR curve of nanowire-GMR magnetic sensor

4 CONCLUSION

This research demonstrates the feasibility of creating transparent, flexible, low-cost magnetic sensors based on nanowire-GMR thin films. Applications for these magnetic sensors include non-contact position sensors, proximity sensors, and magnetic anomaly detection. Future research includes studying how oxidation removal techniques, length and density of nanowires, nanowire composition, and annealing affect the performance of the magnetic sensors.

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