Elemental Giant Magnetoresistance (GMR) Sensors for Neuromorphical Applications

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***Abstract*—Neuromorphic (bio-inspired) strategies have demonstrated to improve the performance of vision sensors. With the recent advances in sensor integration, such a paradigm can be extended to novel applications. With such a purpose in mind, this paper reports on the design, manufacturing, and characterization of Giant MagnetoResistance (GMR) based magnetic sensor arrays. Preliminary experimental results show that the developed sensors can be integrated, for example, in event driven based magnetic particle tracking systems.**

***Index Terms*—Neuromorphic, GMR sensors, Event Driven (ED), magnetic particles.**

I. INTRODUCTION

Bio-inspired approach to sensor design is a new paradigm that is changing the way in which some traditional applications, like artificial vision, are defined [1]. Retinomorphic sensors try to mimic the whole human visual process by considering an Event-Driven representation (ED) of the vision instead of the classical Frame-Driven (FD) one. By following this approach, the output of ED sensors consists of serialized “spiking” signals, grouped in events, which are much more effective where the speed or the bandwidth are constraints. The neuromorphic strategy has already been successfully extended to other human senses such as auditory or olfactory [2]. Developing novel bio-inspired sensors for applications different from human senses is, nowadays, challenging.

The integration of common sensors in specific bio-inspired sensing platforms is not straightforward. Active ‘pixels’, composed by sensing elements together with the specific electronics are necessary. Consequently, their design involves both electronics and technological issues. In this sense, the potentiality of using resistive sensors (with variations below 1% in sensors for nominal resistances ranging from 100 Ω to 10 kΩ) in ED strategies has been recently demonstrated [3].

The use of Giant MagnetoResistance (GMR) sensors for bio-inspired magnetic field sensors is proposed in this work. GMR sensors are high sensitivity resistive magnetic sensors, CMOS compatible, suitable for low-field detection applications. Their design, fabrication and fundamental characterization is described in the following sections. As preliminary test-benches, current sensing and magnetic particle movement tracking will be explored.

II. SENSOR DESIGN

8-element arrays of GMR sensors have designed and microfabricated for preliminary testing the potential of the approach, as described in Figure 1. The sensors were manufactured at the clean-room facilities of the INESC-MN, following a typical four-masks five-lithography-steps, as described in [4]. *Spin-valves* were considered as the sensing elements. Sensors included integrated current strips, aligned with the sensors, for testing purposes. A photograph of a sensor is included as an inset in Figure 1.

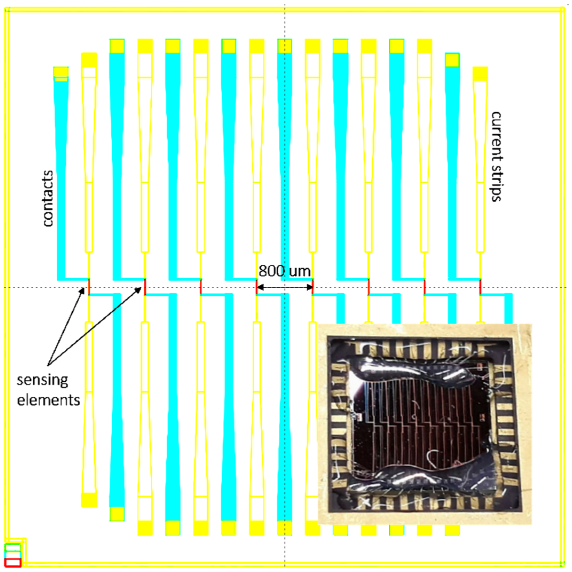

Fig. 1. Scheme of the considered GMR (spin-valves) sensing array with a photograph of an encapsulated sensor.

III. RESULTS

Preliminary tests on so obtained sensors included static characterization (magnetic field and electric current), dynamic measurements, and a scaled proof-of-concept.

A. Static characterization (magnetic field, electric current)

The response of sensing elements versus the applied magnetic field was measured with the help of an automated (GPIB based) testbench, including an electromagnet and a PC. The obtained results are shown in Figure 2. A clean linear behavior is observed in the range of interest, with values of (1160 ± 10) Ω and sensitivities of about (1.65 ± 0.05) Ω/Oe. Analog experiments were performed for measuring the resistance of the sensing elements as a function of the electrical current driving through the integrated strips ($10\ \mu$m width). In this case, the measured sensitivity was about (1.00 ± 0.05) Ω/mA. Then, 1 mA flowing through a current strips is generating about 0.6 Oe on the below sensing element.

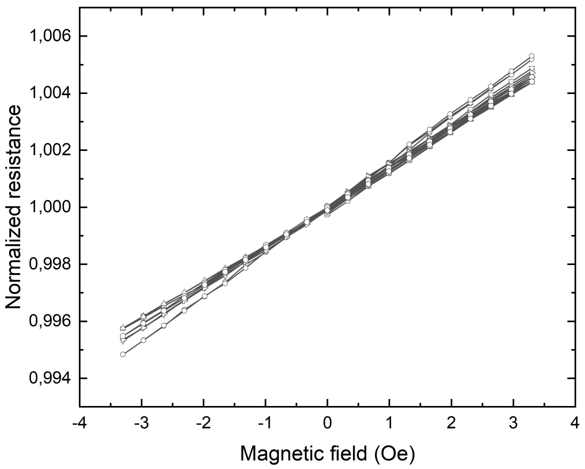

Fig. 2. Typical normalized resistance versus magnetic field of the sensing elements.

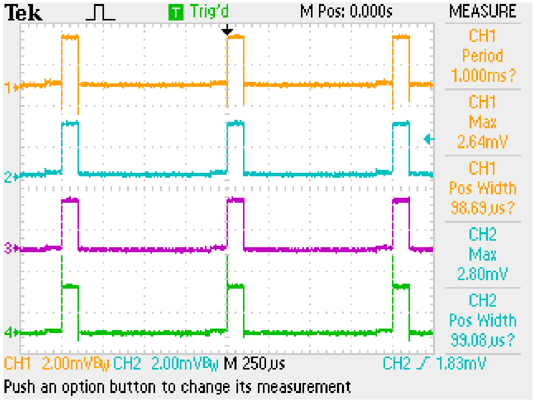

Fig. 3. Oscillograms from the sensing elements being excited by electrical current pulses.

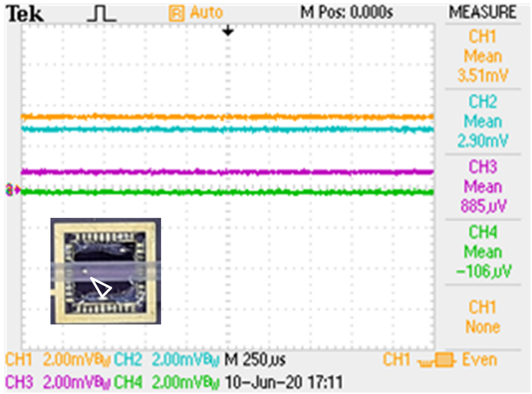

Fig. 4. Detection of a small spherical neodymium magnet ($\varnothing = 1$ mm).

B. Current pulses

Dynamic characterization was carried out by applying current pulses to the current strips and measuring the change of the sensing resistors, connected as voltage dividers, with an oscilloscope. Rectangular current pulses (10 mA amplitude, 100 us width) were applied, being the sensing elements biased with a 3.75 mA DC current. Typical results are shown in Figure 3 (four-channels oscilloscope), which are consistent with the static characterization. Fabrication tolerance issues are slightly observed.

C. Small magnet measurements

Finally, small ($\varnothing = 1$ mm) spherical neodymium magnets were placed close to the sensors in order to qualitatively estimate the potentiality of the sensors for detecting moving magnetic particles. Output signals were collected with the oscilloscope, as displayed in Figure 4. The detected field by the sensing elements was in the order of 1 Oe (within its optimal range) and it was conditioned by the distance from the magnet and its orientation. Additional measurements are required in order to give a more precise characterization.

IV. CONCLUSIONS AND FUTURE WORK

Specifically designed spin valve based magnetic sensor arrays have demonstrated to fulfill the requirements for being integrated in sensor systems based on the neuromorphic strategy. The next steps should include a systematic characterization for optimizing their parameters, mainly those related to power consumption and dynamic response. The development of electrical models and the monolithic integration with specifically designed ASICs should be done in the next future.

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