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Giant magnetoimpedance for biosensing: Advantages and shortcomings

G.V. Kurlyandskaya [a,b,*]

[a] Ural State University, Department Magnetism and Magnetic Nanomaterials, Lenin Ave. 51, 620083 Ekaterinburg, Russian Ferderation
[b] Universidad del País Vasco, UPV/EHU, Dpto. de Electricidad y Electrónica, PO Box 644, Bilbao 48080, Spain

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ABSTRACT

Biosensors are an important area of modern sensor applications. Magnetoimpedance (MI) phenomenon was proposed for biosensing in 2003. Since that MI biosensor prototypes based on amorphous ribbons, multilayered structures, amorphous rapidly quenched wires and glass covered microwires were designed and tested. In this paper the advantages and shortcomings of MI-based devices for magnetic labels or label-free biodetection are discussed in view of recent results.

A biosensor is a compact analytical device incorporating a biological or biologically derived sensitive element integrated in or associated with a physicochemical transducer [1]. Magnetic biosensors are well suited to the requirements of medical diagnostics with increasing number of tests. There are different types of magnetic effects capable of creating magnetic biosensors: magneto- and giant magnetoresistance, spin-valves, inductive, magneto-elastic and Hall effects, magnetoimpedance (MI) [2–5]. Magnetoimpedance phenomenon consists in the change of the total impedance, $Z = R+jX$ (where R is a real and X is an imaginary components), of a ferromagnetic conductor in a magnetic field, H_{ext}, when a high-frequency alternating current $I = I_0 e^{-i\omega t}$ flows through it [5–7]. In all magnetic biosensors magnetic field plays role of a transducer. They can be divided in two groups in accordance to working principle: biosensors based on magnetic marker and label-free detection. Fig. 1(a) shows the general scheme of testing with magnetic markers. The functionality basis is supposed to be similar to that proposed earlier for biosensors working on the principle of magnetoresistance or spin-valve [2,3]: the fringe fields induced by the magnetic markers employed as biomolecular labels provide a means for transfer of information. In MI biosensors of the first type, the change of the impedance of the sensitive element under the application of a magnetic field is compared for two states: without magnetic markers in a test solution and with them. In the case of the magnetic labels detection, the sensitive element is required to keep the same geometry over the testing time and therefore it is separated from the analyte by a protecting layer [2–4] or material of the sensitive element is selected to be very stable to the biocorrosion [8]. Fig. 1(b) shows the way of testing without magnetic markers. The label-free detection of the components of the biological substances using the MI effect is based on the monitoring of changes of the MI under surface modification which can be caused by changes of the geometry of the sensitive element, surface morphology and/or surface anisotropy.

In the following, an overview of the various MI biosensor prototypes will be given together with their short description. MI magnetic field sensors adapted for the detection of magnetic markers are still under development: all prototypes which have been reported until now, instead of employing of a suitable biochemistry to count the selectively attached markers, deal with free beads immersed in a buffer [9–13] or spread on the surface of the MI sensitive element "in dry" [14]. These prototypes were based on rapidly quenched amorphous ribbons [9,11,13], rapidly quenched wire [14], glass covered microwires [12,14] or MI multilayers [10]. Ribbon-based MI elements, which are inexpensive, very sensitive to external field detectors work in relatively low-frequency range well adapted to standard electronic circuitry solutions of 1–10 MHz. They exploit an idea of a disposal stripe sensitive element without a protecting layer. Such a design not only simplifies a microdevice architecture but also prevents MI element from contamination contributing to the possibility for tests to be undertaken by non-skilled personnel. Only

* Corresponding author at: Ural State University, Department Magnetism and Magnetic Nanomaterials, Lenin Ave. 51, 620083 Ekaterinburg, Russian Ferderation. Tel.: +7 3432615705; fax: +34 946013071.
E-mail address: galina@we.lc.ehu.es

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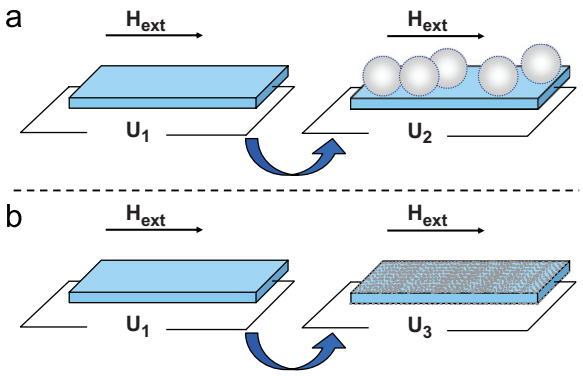

Fig. 1. General schemes of MI-biosensors: (a) testing with magnetic markers and (b) label-free detection.

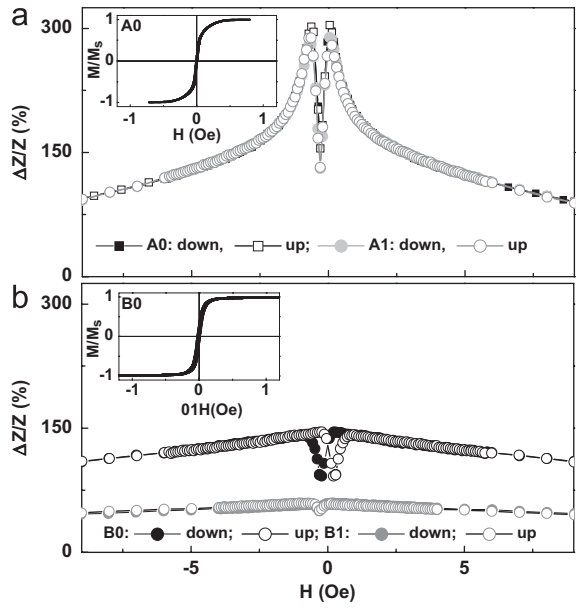

Fig. 2. Insets show the hysteresis loops corresponding to the samples A0 and B0 without treatments. MI responses of FeCoCrSiB (a) and FeCoSiB (b) samples before and after the electrochemical treatment in PBS: $f = 7$ MHz, $I_{rms} = 20$ mA.

ribbon-shaped MI elements have until now been tested in the label-free detection of the components of the biological substances by MI detectors [8,15,16].

Co-based amorphous ribbons apart from having high sensitivity of MI to a magnetic field offer huge variety of anisotropies and corrosion stabilities studied by standard techniques. Fig. 2 shows a comparison of magnetic inductive hysteresis loops of $Fe_3Co_{67}Cr_3Si_{15}B_{12}$ (A0 sample) and $Fe_5Co_{70}Si_{15}B_{10}$ (B0 sample) amorphous ribbons before and after conventional electrochemical treatment in a three-electrode glass cell. MI ratio was defined as follow: $\Delta Z/Z = (Z(H) - Z(H_{max}))/Z(H_{max})$, $H_{max} = 70$ Oe. A phosphate-buffered saline (PBS) was used as an electrolyte at the temperature of 37 °C aiming to simulate the living body conditions [8]. The working electrodes were polarized from the corrosion potential (250 mV) in the anodic direction up to the value of 0.6 V for FeCoCrSiB (A1) and 0 V for FeCoSiB (B1) ribbons. Hysteresis loops show that A and B samples are typical soft ferromagnets with high magnetic permeability. The effective magnetic anisotropy is not purely longitudinal with a clear contribution of the surface anisotropy [15,16]. The MI responses of A0 samples are much higher comparing with B0 samples. Electrochemical treatments leads to a very small change of the A samples MI indicating very high corrosion stability to the treatment conditions. MI of sample B is highly affected by the treatment leading to a significant decrease of the MI and change of the shape of the MI curve. Due to the biocorrosion stability and high MI, FeCoCrSiB ribbons were proposed for applications in magnetic labels detectors. FeCoSiB ribbons have low corrosion resistance, smaller MI response and therefore cannot be employed for applications in magnetic label detectors without protective covering.

Fig. 3 shows MI responses of B0 ribbons after surface treatments in human urine. In the first case after the treatment for 7–460 h, MI of each sample after cleaning and installation into the imprinted circuit board was measured in a frequency range 0.5–10 MHz. Fig. MI responses are clearly dependent on the

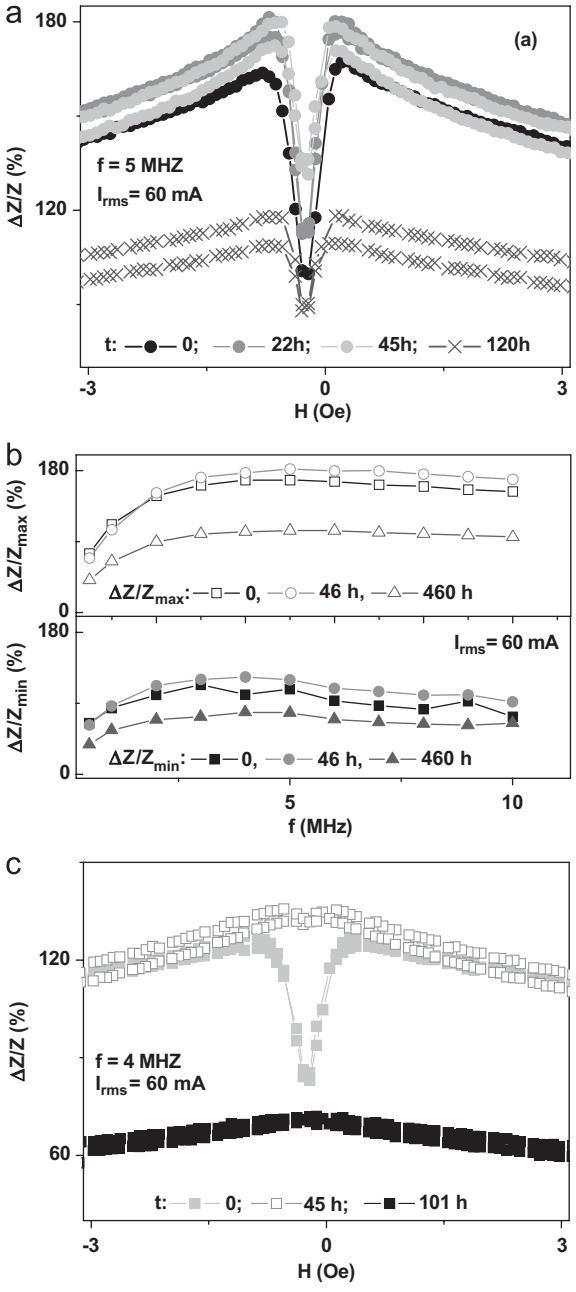

Fig. 3. FeCoSiB ribbons. Passive surface modification in human urine: (a) MI responses for selected time of treatment; (b) frequency dependence of the MI maximum, $\Delta Z/Z_{max}$, and response in zero field, $\Delta Z/Z_{min}$, for selected times. Active surface modification in urine: MI responses for selected times (c).