Magnetic amorphous wires in magnetoelastic sensors for biomedical applications

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Magnetoelastic sensors are magnetic devices that use magnetostrictive materials, which produce mechanical vibrations when exposed to a magnetic field at their resonance frequency. In this study, amorphous wires were fabricated by rapid quenching in rotating water and tested in a magnetoelastic sensor setup. A custom test stand was developed to assess performance, including for biomedical applications. FeSiB amorphous wires and annealed FeSiBCuNb nanocrystalline wires demonstrated high sensitivity and resolution in compact configurations. The use of amorphous wires enhances sensor performance and enables miniaturization, supporting new biomedical sensing technologies.

Keywords: magnetoelastic sensors; amorphous wires; biomedical applications; regenerative medicine.

1. Introduction

Magnetoelastic sensors are a class of magnetic sensors composed of magnetostrictive materials that undergo mechanical vibrations when subjected to a magnetic field at their resonance frequency [1]. These sensors are typically engineered or functionalized such that the parameters of interest induce measurable changes in either the resonance frequency or the amplitude of the vibrations. In this study, we present a magnetoelastic sensor developed in-house, utilizing amorphous magnetic wires as the magnetostrictive material.

2. Results and discussion

Amorphous magnetic wires with a diameter of 120 μm and compositions of FeSiB, CoSiB, and FeSiBCuNb were prepared by rapid solidification in a rotating water layer. Their amorphous structure was confirmed via X-ray diffraction (XRD) and high-resolution scanning electron microscopy (HR-SEM). Among the compositions studied, $Fe_{77,5}Si_{7,5}B_{15}$ and $Fe_{73,5}Cu_{1}Nb_{3}Si_{13,5}B_{9}$ (FINEMET) exhibited higher saturation magnetization, relative permeability, and positive magnetostriction, as shown in Figures 1c and 1d.

A dedicated experimental setup was constructed to test the functionality of the magnetoelastic sensor, incorporating the amorphous wire mounted freely within a support structure. The system includes a set of coils that generate an alternating magnetic field with frequencies ranging from 10 to 200 kHz and a static magnetic field with intensities between 10 and 100 A/m. A pickup coil detects the signal generated by the wire's vibration. A diagram of the setup is provided in Figure 1a.

The measurement system is based on the AD5933 impedance converter, which integrates a signal generator, DAC, and DSP. Controlled via LabVIEW, it sets excitation frequency and records data. A microcontroller communicates with the AD5933 via I²C and interfaces with the computer. The resonance signal reflects changes in both the wire and surrounding medium, enabling environmental assessment.

The observed resonance frequencies ranged from 50 to 70 kHz, with amplitudes between 1 and 10 ohms. The highest sensitivity, resolution, and reproducibility were achieved using FeSiB amorphous wires and FeCuNbSiB wires thermally treated for 1 hour at 510 °C to induce a nanocrystalline structure (Figure 1b). Both wires were 15 mm in length.

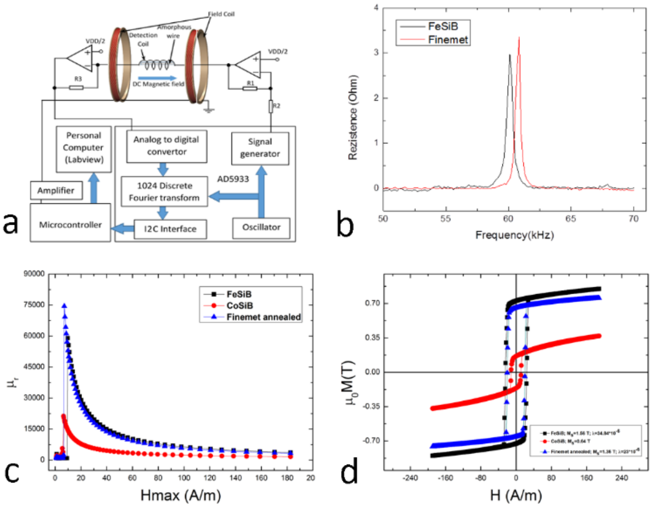

Figure 1: (a) Schematic diagram of the setup; (b) Resonance curves of amorphous FeSiB and FeCuNbSiB (FINEMET) wires in the frequency range of 50–70 kHz.; (c) The variation of saturation magnetization with temperature for FeSiB, CoSiB, and FeSiBCuNb wires; (d) Magnetic hysteresis loop for the FeSiB, CoSiB, and FeSiBCuNb wires.

The sensor was successfully used to monitor consistency changes in a bone tissue–mimicking medium. Its sensitivity to environmental conditions enables evaluation of properties such as viscosity and concentration. This type of sensor facilitates monitoring of changes in magnetic permeability under applied mechanical stress. Potential applications include monitoring bone plate strain and artificial bone degradation. The use of amorphous wires in the fabrication of magnetoelastic sensors significantly enhances their sensitivity while enabling miniaturization. The biocompatibility and small size of amorphous wires support their integration into implantable sensing elements for remote, non-invasive measurements.

References

[1] B. D. Nelson et al, Sensors, 20 (2020), 4604.

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