Spatially Distributed Annealing as a New Tuning of Magnetic Microwires

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***Abstract*—Spatially distributed annealing shows a new way of microwires tuning for sensors application. In this paper, we are dealing with a new, original annealing treatment. Our solution is related to the fact that, after the annealing, the distribution of magnetic properties is preserved. A gradient of internal stresses, ranging from tension to compression, was present across the sample's cross section, with the stress gradient smoothly varying along its length. Magnetic and magneto-optical studies revealed a transformation in both the magnetization reversal process and the domain structure as the measurement location shifted along the sample.**

Keywords- soft magnetic materials; amorphous magnetic microwires; magnetic domains; magneto-optic Kerr effect; magnetic anisotropy.

I. INTRODUCTION

Regarding the motivation of the presented research, there were recent studies on stress annealing on magnetic structure and Giant Magneto-Impedance effect (GMI) as well as Matteucci effects in bent microwires [1].

Our research can be considered within the framework of the idea of studying magnetic properties distributed along the length of a long sample. In addition to the distribution that was caused by annealing at temperatures distributed along the length of the microwire [2], we are now expanding this direction by adding external influences, such as distributed bending stress, along the length of the microwire, including the spiral bending. The main feature of this type of research is the smooth transition of magnetic properties along the sample, which provides great opportunities for analyzing the physical processes occurring in the sample. The original idea implemented in the presented study is that, after bending annealing and subsequent straightening of the sample, the induced magnetic properties are retained in the microwire.

II. EXPERIMENTAL TECHNIQUES

After the manufacture, the samples were bent and annealed in the bent state (T_{ann} = 300 °C (45 min)) (Figure 1). The hysteresis loops were obtained using the fluxmetric method, previously used for characterization of magnetically soft microwires. A thin (about 8 mm in diameter) 12 cm long solenoid creates a rather uniform axial magnetic field in the region where a sample of 10 cm long is inserted. The fluxmetric method allows the measurement of hysteresis loops up to H=3 kA/m. A short (2 mm long) pick-up coil was used to characterize the bending-annealed microwires, which can show hysteresis loops with different shapes for different regions of the microwire. Such setup allowed us to measure the hysteresis loops in different longitudinal regions of the microwire by moving the short pick-up coil along it.

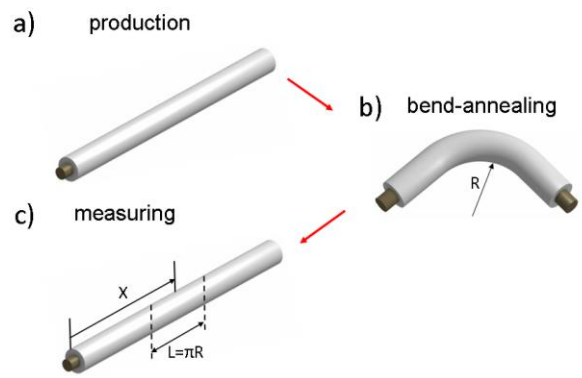

Figure 1. Schematic picture of the samples preparation for the measuring

The Magneto-Optical Kerr Effect (MOKE) technique has been applied as a method to acquire the contrast images of the surface magnetic domain structures. The experiments were performed by means of a high-resolution, wide-field, optical polarizing microscope based on a commercial one (Carl Zeiss) working in reflective mode using the longitudinal MOKE configuration. Also, the MOKE technique has been applied as a method to retrieve the information about the magnetization reversal (surface hysteresis loops).

III. RESULTS AND DISCUSSION

The effect of bending annealing-induced magnetic bistability was discovered in Fe rich microwires [3]. Without annealing and after the annealing without bending, this effect was not observed. The induced bistability effect was accompanied by the rapid movement of a single longitudinal domain wall along the surface of the microwire that was not

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observed in the classical bistability effect. The existence of the longitudinal magnetic domain structure is the result of a

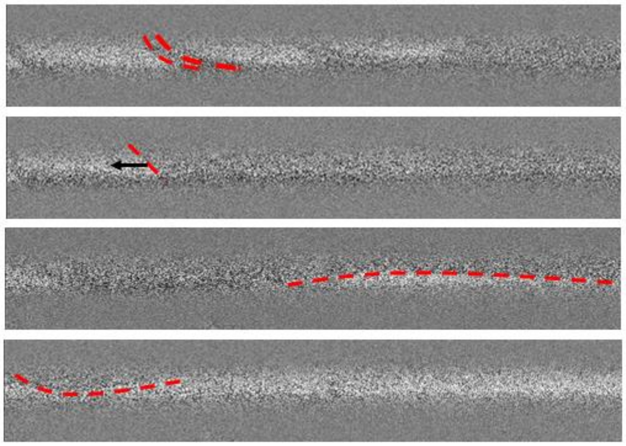

Figure 2. Samples of MOKE images of surface domain structure observed in different locations.

particular distribution of internal stress. This distribution represents a gradual transition from compression to tension across the microwire diameter.

The external mechanical bending stress also results in an internal stress distribution within the Co-rich microwire: from maximum tensile stress at the upper side to maximum compressive stress at the bottom side [4]. Consequently, a specific line within the sample corresponds to a zero value of internal stress where tension transitions to compression. This stress distribution across the sample diameter would consequently lead to the formation of a corresponding magnetic domain structure (Figure 2).

IV. Conclusion

The presented investigations were devoted to the studying of the magnetic properties of Co-rich microwires subjected to the so-called spiral annealing. Before annealing, the sample was laid in the form of a flat spiral. The curvature value at each point of the sample was known. The main idea was that, after annealing, we had a sample with magnetic properties continuously distributed along the length of the sample. As expected, we found a smooth change in the magnetic properties as the measurement point shifted along the sample. Changes were observed both in the sample volume and on the surface. Particular attention was paid to the induced change in the anisotropy field. A direct dependence of this effect on the value of the changing curvature of the sample was found.

Future research in this area involves expanding the pre-treatment methods, including a type of annealing called spiral annealing, which allows for mechanical stresses to be created not only along but also across the microwire. This will allow advances in optimizing the parameters of magnetic sensors.

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