# NEW EXPERIMENT FOR THE STUDY OF CRITICAL FIELDS IN BISTABLE FERROMAGNETIC MICROWIRES

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## 1. Introduction

Amorphous glass coated microwires are novel materials with outstanding magnetic properties from both physical and practical point of views. Taylor-Ulitovky method and rapid quenching used in microwire preparation result in characteristic mechanical stress distribution. This stress distribution combined with positive magnetostriction result in typical domain structure which consists of a large axial domain in the central part and radial domains in the outer shell of the wire. Due to stray field a closure domain structure is formed at wire ends. At some critical external magnetic field a free domain wall can be depinned from closure domain structure and subsequently it propagates along the microwire as a large Barkhausen jump. Usually this critical field is higher than the wall coercive fields and the microwire is re-magnetized by a single Barkhausen jump. This so called bi-stable behaviour results in a rectangular hysteresis loop and it gives a unique opportunity to study dynamics of a single domain wall (DW).

A free domain wall, which can propagate along the microwire, can be produced either by depinning from wire ends [1] or by nucleation of reversed domain in regions far from microwire ends [2, 3, 4]. A basic quantitative parameter of these processes is the magnitude of corresponding critical field. As we will show in this paper an analysis of dynamics of these processes can provide useful information about their mechanisms.

Dynamics of the release of a domain wall from natural (wire ends) [4] and artificial (external inhomogeneous magnetic field) potential well was studied in [5]. Critical parameters of rectangular magnetic field pulse (length, magnitude) for which the wall is released from potential well were determined experimentally and compared with theoretical model [6, 7, 8]. A model in which a reversed domain (domain wall) is present in remanent state was used in these studies. The main problem which we would like to solve in this study is whether this model is appropriate also for the process of reverse domain nucleation in regions far from wire ends. The other alternative is a model based on classical nucleation theory in which reversed domains (domain walls) are not present in zero external field.

## 2. Experimental

The measurements were carried out on glass-coated $Fe_{49.6}Ni_{27.9}B_{15}Si_{7.5}$ microwires prepared by the Taylor-Ulitovski method. Diameter of the metallic core was about 15 μm, the thickness of glass coating was about 8 μm and length of the sample was 12.5 cm.

Experimental set-up is shown in Fig. 1. Solenoid generated homogeneous magnetic field $H$ along the wire. The microwire was placed into two coaxial narrow coils with length of 1 cm and diameter of 1 mm. The position of these coils along the microwire was possible to change. The first coil (pulse coil) was connected to a function generator G and generated defined magnetic field pulses. It was connected in series with resistor. The voltage on this resistor was monitored by one channel of oscilloscope. In this way information about magnetic field pulse could be obtained. The second coil (pick-up coil) was connected to the input of an integrating amplifier (IA) which gave possibility to obtain information about magnetic state of the part of the wire inside the pick-up coil [9].

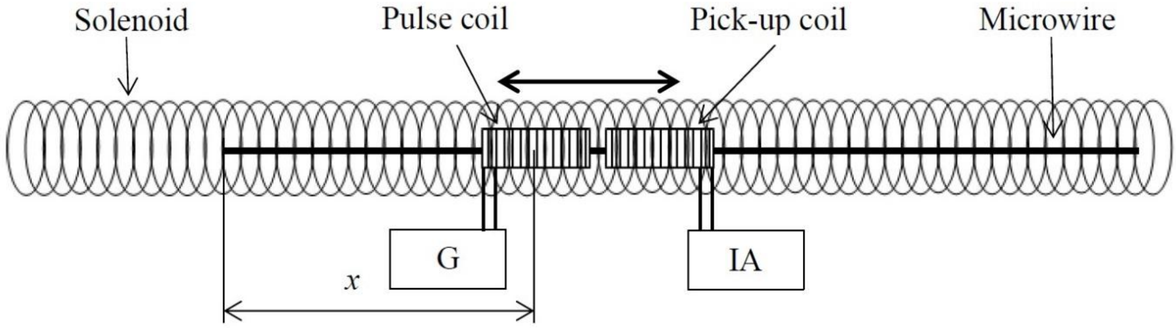


Fig.1: *Experimental set-up. G is a function generator and IA is an integrating amplifier. The coil generating magnetic field pulses and the pick-up coil can be displaced along microwire.*

The measurement procedure consisted of the following steps. First the sample was magnetically saturated in negative axial field generated by the solenoid. After switching off this field a defined remanent state was obtained. Then a region of the microwire inside the pulse coil was magnetized by a positive magnetic field pulse generated by the pulse coil (details of this pulse will be given in the following text). In the next step a low positive axial magnetic field was generated by the solenoid. The magnitude of this field was high enough to set the existing wall into motion along the wire and at the same time it was lower than the critical field needed for depinning the wall from the wire ends [9]. Finally the information about the wire magnetic state in the pick-up coil was obtained using IA. If a free domain wall was produced by a field pulse the magnetization reversal in the pick-up coil was detected.

## 3. Results and discussion

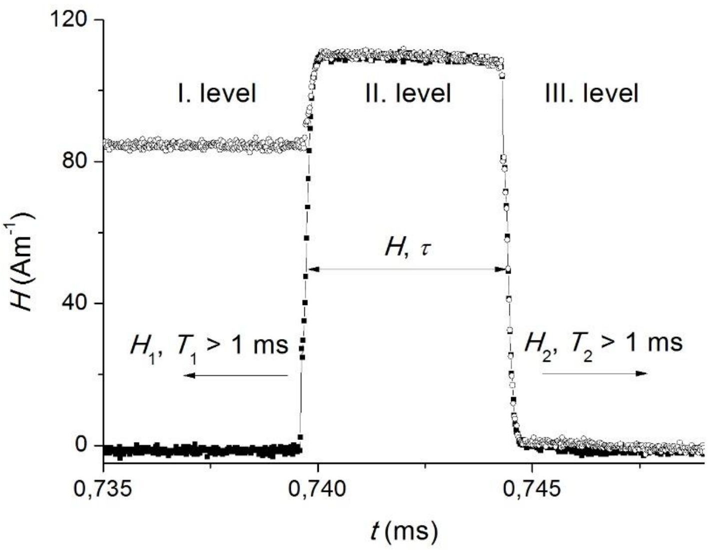


Fig.2: Three level field pulse generated by the pulse coil.

Recently we have developed a new experimental technique for the study of dynamics of a domain wall trapped in a local potential well [5, 9]. The basic idea of this technique consists in determining parameters of rectangular magnetic field pulse (magnitude - $H$, length - $\tau$) needed for the wall trapped in a potential well to be released. This technique can be applied for the study of the dynamics of a domain wall release from closure domain structure at microwire ends and also for the study of reversed domains nucleation dynamics in regions far from microwire ends. Both above mentioned processes can be influenced by the magnitude of magnetic field before or after application of field pulse ($H, \tau$). That is why we propose to use the so called three level pulse. The three level pulse starts from the first level with parameters ($H_1$, $T_1$), continues at the second level ($H, \tau$) and ends at the third level ($H_2$, $T_2$). The first and the third levels of the field are switched on for a relatively long time ($\tau \ll T_1 \approx T_2 > 1$ ms). Examples of three level pulses generated in the pulse coil are shown in Fig. 2. In the following text the information about the type of field pulse will be given in the form ($H_1$, $H$, $H_2$).

Modification of experimental technique by using three level pulse can provide additional information as for instance about presence of reversed domains in zero external field or about parameters of potential well of the DW trapped in closure domain structure. In this paper we pay attention to the first topic.

Two types of experiments can be carried out to determine critical parameters ($H_c$, $\tau_c$) of the second part of the tree level field pulse. In the first one $\tau$ is kept constant and critical $H$ is determined and in the second one $H$ is kept constant and critical $\tau$ is determined.

The first type of experiment, when $\tau$ is kept constant, was used for mapping critical (nucleation) fields $H_c$ along the sample. In this case magnitudes of magnetic field before and after application of the field pulse ($H, \tau$) were zero ($H_1 = H_2 = 0$). For a given position of the pulse coil $x$ (see Fig. 1) long field pulses ($\tau = 0.5$ ms) were used and minimum critical field at which domain wall was depinned from domain structure or reverse domain was created was determined.

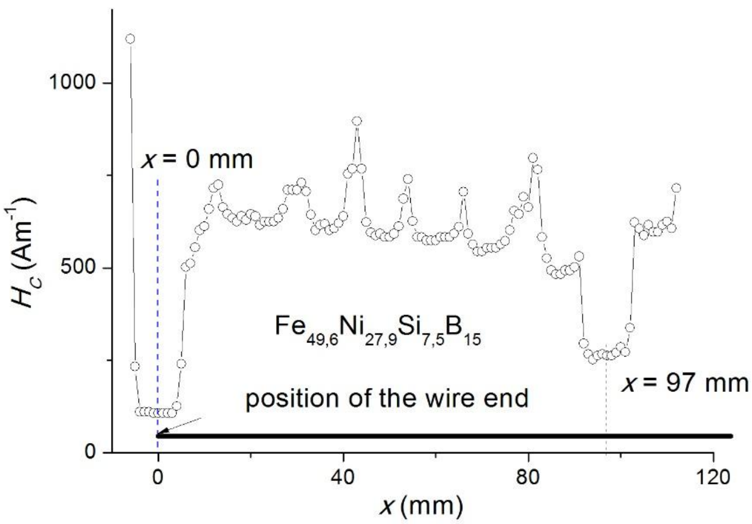


Fig.3: *Distribution of local critical (nucleation) fields along the microwire.*

The distribution of critical (nucleation) fields obtained in this way is shown in Fig. 3. As can be seen in this figure a minimum critical field is obtained for the region close to the wire end. For regions far from wire ends critical fields are higher and they change with position along the microwire.

For the region close to the wire end critical field originates from the mechanism in which free DW is depinned from closure domain structure. In this case presence of reversed domain in zero external field (remanent state) can be expected. It can also be expected that values of $H_1$ and $H_2$ of three level pulse can influence dynamics of depinnig process. For the regions far from the wire ends critical field originates from the process of reversed domain nucleation. In this case we do not know whether a reversed domain is present in zero external field (remanent state). Sensitivity of nucleation dynamics to changes of $H_1$ and $H_2$ values of a three level pulse can provide useful information. It can be expected that if a reversed domain is not present in remanent state nucleation dynamics should not be influenced by the field $H_1$.

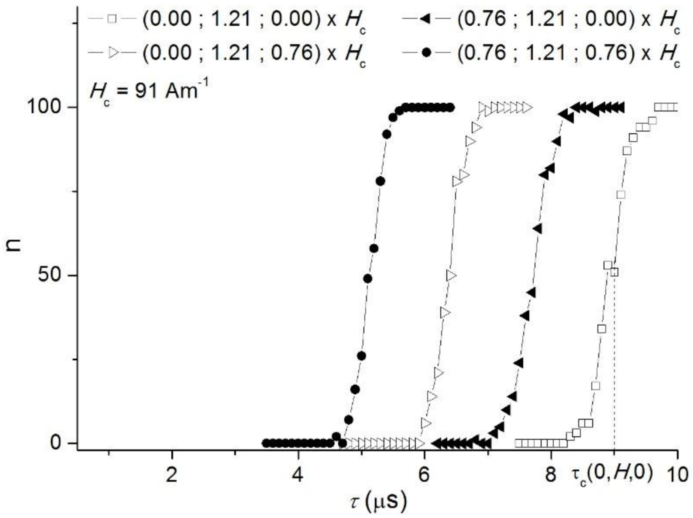


Fig.4: *Number of events n for which a free domain wall is depinned from the wire end (x = 0 mm) for four types of three level field pulses of length τ.*

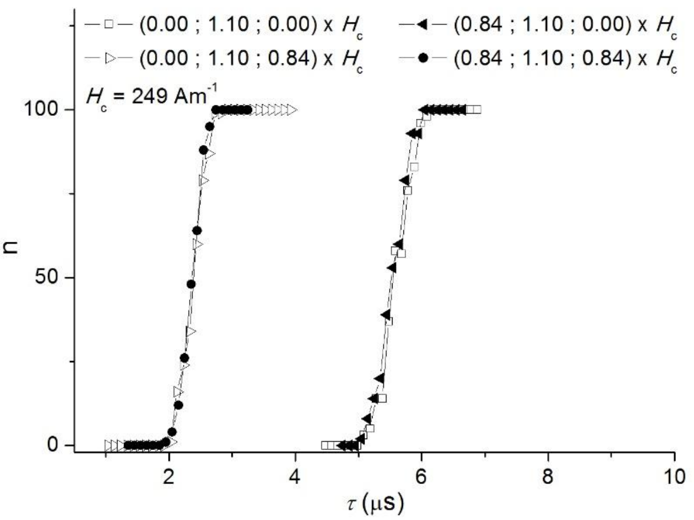


Fig.5: *Number of events n for which a reversed domain was nucleated (x = 0.97 mm) for four types of three level field pulses of length τ.*

In order to compare dynamics of both processes we chose two positions of pulse coil, close to the wire end ($x = 0$) and the position far from the wire end where minimum critical (nucleation field) was observed ($x = 97$ mm, see Fig.3). The second type of experiment, when the field magnitude $H > H_c$ is kept constant, was used. The measurement for a given value of $\tau$ was repeated 100 times and the number of events $n$ when a free DW was depinned/nucleated was determined. Results of these experiments are summarized in Figs.4, 5. Dependences in Fig.4 refer to depinning process and dependences in Fig.5 refer to nucleation process. The shapes of all dependences are very similar. After some time interval in which no free DWs are detected a relatively narrow interval in which the number of events rapidly increases from 0 to 100 follows. As can be expected the length of the first interval is shorter for higher values of $H$ (nucleation mechanism). A very interesting behaviour can be observed when various combinations of $H_1$ and $H_2$ are applied. For depinning process in Fig.4 both $H_1$ and $H_2$ fields influence $n(\tau)$ dependences. On the other hand it is not the case for nucleation process in Fig. 5. In this case $n(\tau)$ dependences are sensitive only to the third part $H_2$ of the three level pulse and they are virtually insensitive to the first level $H_1$. As it has already been mentioned above this result indicates that reversed domains are not present in remanent state and it is probably the case even for regions where nucleation fields are minimum.

**Conclusion**

Three level magnetic field pulses have been used in experiments for the study of critical fields in bistable ferromagnetic microwire. These experiments can provide information about the presence of reversed domains in remanent state. Results obtained in these experiments for glass-coated $Fe_{49.6}Ni_{27.9}B_{15}Si_{7.5}$ microwires indicate that reversed domains are not present in remanent state even in regions where nucleation fields are minimum.

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