Proceedings of the 15th Czech and Slovak Conference on Magnetism, Košice, Slovakia, June 17–21 2013

Fine Smoothing of Conductive Substrate for Permalloy Layer Electroplating

M. Butta[a,*], M. Janosek[a], I. Pilarcikova[a], L. Kraus[b]

[a]Faculty of Electrical Engineering, Czech Technical University in Prague, Technicka 2, 16627 Praha, Czech Republic

[b]Czech Accademy of Science, Na Slovance 2, 18221 Prague, Czech Republic

In this paper we study the influence of the roughness of the copper substrate on the magnetic properties of the FeNi film we electroplate onto it. The roughness and the thickness of the copper substrate are reduced by electropolishing in orthophosphoric acid: we show how to select the working point, which gives the highest smoothness, avoiding defects due to gas evolution. Finally we show how a smoother substrate contributes to reducing the coercivity of the magnetic film grown on it.

DOI: 10.12693/APhysPolA.126.150

PACS: 75.75.-c,75.30.-m,75.50.-y,07.55.-w,75.70.-i

1. Introduction

Permalloy films electroplated on conductive substrates are currently investigated due to their feasibility as core for fluxgates. It has been shown that by properly choosing the electroplating parameters the magnetic properties of the Permalloy film can be easily tuned to the desired values.

This has been extensively studied for Permalloy films electroplated on copper wires [1], for which roughness is typically negligible. In our study we consider racetrack cores for parallel fluxgate. The permalloy film is electroplated on PCB copper film. By lithographic method we obtain copper film already shaped to the designed form, such as racetrack or ring shape. This makes such technique suitable because no further mechanical machining of the core is required.

A critical parameter is the roughness of the copper substrate: any defect on the copper layer will be reflected on the Permalloy layer we electroplate on it, therefore we need a very smooth and defect free surface as the base for Permalloy electroplating. Moreover, we want to reduce the thickness of the copper layer as much as possible in order to reduce the eddy currents and make the fluxgate suitable also at high frequency.

2. Smoothing of conductive substrate

The copper film is located on a glass fiber substrate and it's thickness is 18 μm. In order to reduce its thickness and increase its smoothness we electropolish it in a bath of orthophosphoric acid (H_3PO_4) at 85% concentration [2]. The film which is going to be electroplated is used as anode, while as the cathode is used another copper plate, placed above it. The electroplating is performed at room temperature. Higher temperature increases the electropolishing current and therefore decreases the total process time. However, we noticed that the best results, in terms of film roughness, are obtained using very slow electropolishing.

The typical *I*-*V* characteristic of the bath is shown in Fig. 1. The characteristic is non-linear and the results of electropolishing strongly depend on the chosen working point.

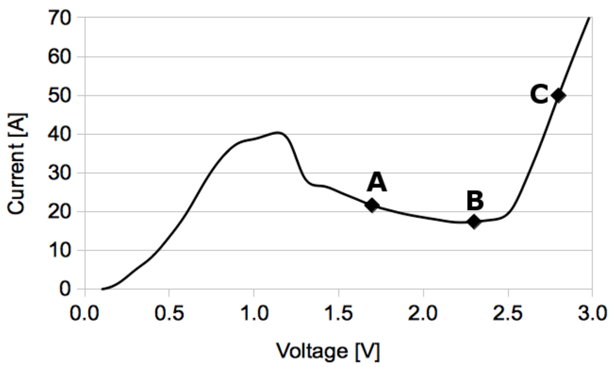

Fig. 1. Typical *I*-*V* characteristic of the electropolishing bath. A, B and C are the three working points.

If gas evolution will occur from the copper film during electropolishing, then the resulting surface will show several defects due to the gas bubbles. Despite the fact that it is suggested to electropolish copper in the middle point of the plateau (that is in point B of Fig. 1), we found out that the best results are obtained for lower voltage, namely in point A.

This is clearly visible in Fig. 2, where we can see the resulting surfaces, electropolished in points A, B and C of the *I*-*V* characteristic. While the substrate electropolished in point A shows no defects, in case of point B some defects appear, and they increase in case of electropolishing in point C.

*corresponding author; e-mail: buttamat@fel.cvut.cz

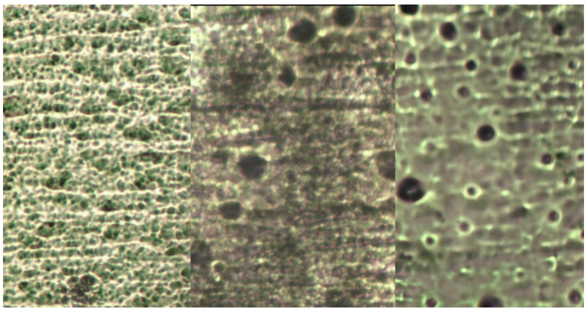

Fig. 2. Surface of copper film after 10 minutes of electropolishing in point A (left), B (center) and C (right) of the *I-V* characteristic.

3. Reduction of thickness and roughness

Once we identified the correct working point for electropolishing, without giving rise to gas evolution, so that we can avoid defects, as shown in Fig. 2, then we have to reduce the overall roughness and reduce the thickness. Both goals are achieved by performing long electropolishing. Reduction of thickness from 18 μm to 9 μm was achieved after 2 hours of electropolishing. The thickness can be further reduced down to 6 μm (lower thickness cannot be achieved without eroding the borders of the film). The thickness has been estimated by four wire measurement of the resistance of the film during electropolishing and then confirmed by the measurement done by Talystep. The same measurement shows that the roughness decreased by one order of magnitude, from 1 μm to 0.1 μm. Figure 3 shows the comparison between the substrate surface before (upper) and after (lower) the electropolishing.

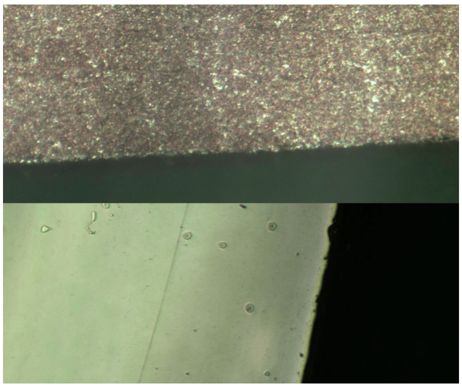

Fig. 3. Copper substrate before electropolishing (upper image) and after electropolishing (lower image).

4. Electroplating of NiFe film

We performed electroplating of permalloy film of a ring core (internal diameter 18 mm, external diameter 28 mm). We used watt type bath – $FeSO_4{\cdot}7H_2O$ (8 g/l), $NiSO_4{\cdot}6H_2O$ (125 g/l), $NiCl_2{\cdot}6H_2O$ (20 g/l), H_3BO_3 (40 g/l), saccharin (6 g/l) in de-mineralized water at 55 °C – with 12 mA/cm2 current density and pulsing current with $f = 0.5$ Hz, duty cycle 50%. The time of electroplating was 70 minutes. The thickness of the resulting film was 8 μm. Figure 4 shows the *B-H* loop of the ring cores electroplated on both electropolished and non-electropolished copper substrates.

The loops have been measure with conventional induction method at 200 Hz.

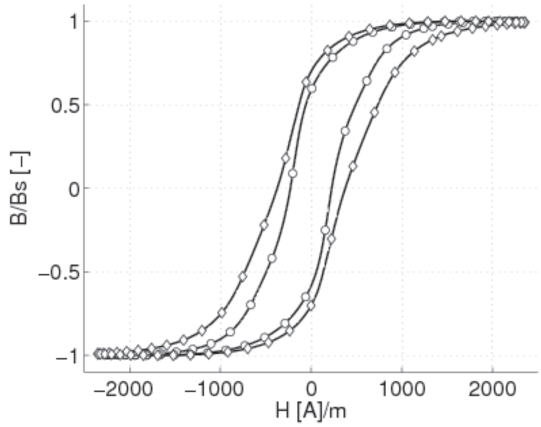

Fig. 4. *B-H* loop of FeNi ring core electroplated on electropolished (circles) and non-electropolished (diamonds) copper substrate.

As we can clearly see in Fig. 4 the ring core electroplated on polished copper shows lower coercivity than the core electroplated on non-polished copper substrate, as is desirable for fluxgate.

5. Conclusions

We have shown that in order to reduce the coercivity of ring core for fluxgate it is effective to electropolish the copper substrate before electroplating permalloy film.

Acknowledgments

This work has been supported by the Grant Agency of the Czech Republic (GACR) under the grant P102/12/2177.

References

[1] X.P. Li, H.L. Seet, J. Fan, J.B. Yi, *J. Magn. Magn. Mater.* **304**, 111 (2006).

[2] A.M. Awad, N.A. Abdel Ghany, T.M. Dahy, *Applied Surface Science* **256**, 4370 (2010).