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Magnetostriction and magnetoresistance in nanocontacts

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Abstract

Ni nanocontacts have been grown by electrodeposition using a self-terminating technique in a single electrolyte bath based on nickel sulfate, nickel chloride and boric acid. Resistance measurements performed on different samples presented two kinds of obviously different magnetoresistance effects. The analysis of the data sets showed that magnetostriction might play a key role in magnetoresistance of the electrodeposited Ni nanocontacts.
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1. Introduction

The study of magnetoresistance (MR) is one of the most exciting topics, due to its great importance for technical applications as hard-disk read heads and magnetic storage media like magnetoresistance random access memory. Renewed interest in submicron scale ferromagnetic nanocontacts has been stimulated greatly by the discovery of ballistic magnetoresistance (BMR) in 1999 [1]. The obtained BMR in mechanically formed nanocontacts reaches few hundred percents [1–4], which is attributed to the scattering of conducting electrons by a constricted domain wall (DW) within the nanocontacts. Recently, Chung et al. [3] have shown that the MR oscillates as a function of the nanocontacts' resistance. Many electrodeposited nanocontacts were also used to investigate BMR [5–11], some of which demonstrate even larger MR than the mechanically formed ones [9,10]. There is no correlation between MR and resistance of the electrodeposited nanocontacts [8], and there are some major issues in the electrodeposited nanocontacts, such as poor reproducibility and low stability [12]. So far, there is no widely accepted explanation for these phenomena [13]. In this paper, we report our own data sets and propose a mechanism to explain them.

2. Experiment

Samples with geometry schematically shown in Fig. 1 were used: Two 99.9% pure Ni wires having diameter in 200 μm, which were mounted on a piece of glass substrate with epoxy. The wire I and wire II were posited perpendicular to each other. The distance between wire I and the tip of wire II was about 20 μm [8,9]. The details to make samples are given elsewhere [7–10].

The nanocontacts were grown by electrodeposition from a single electrolyte containing Ni^{2+} ions. The composition of the electrolyte is as follows: 2.5 g $NiSO_4 \cdot 6H_2O$ and 1.4 g $NiCl_2 \cdot 6H_2O$ and 0.3 g H_3BO_3 added at 10 ml H_2O. The pH of this solution is about 3–4. The self-terminating electrochemical method of Boussaad and Tao was used in the electrodeposition process [14]. The deposition of nanocontacts was carried out at room temperature. We applied a constant potential of 1.05 V to deposit Ni from wire I to the top of wire II. A lower pH of the electrolyte and/or a higher potential between the wires will cause the generation of hydrogen, which may affect the rat of deposition and prevent the formation of Ni tip. A MR measuring system was also employed to investigate nanocontacts. The

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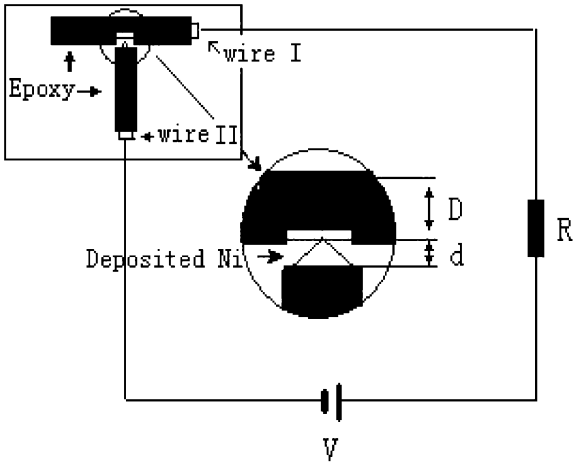

Fig. 1. Schematic drawing of the experimental setup. The length of the electrodeposited Ni: $d \approx 20\,\mu m$. The diameter of Ni wire: $D = 200\,\mu m$.

resistance of nanocontact was continuously monitored in a constant current mode with a voltage measurement technique, while magnetic field between ± 5.0 kOe was applied parallel to the wire II axis.

3. Results and discussion

Fig. 2 shows consecutive magnetoresistance curves in a sample whose initial zero-field contact resistance was $1.75\,\Omega$ after electrodepostion. It is seen from the first loop that, with increase in the field in the positive direction, the resistance increases with field until it reaches a saturation value ($10.1\,\Omega$) which represents ~477% MR (Fig. 2(a)). The MR curves are similar to the previous reports [7–10].

During the period of experimentation, we made hundreds of samples. In addition to Fig. 2, Fig. 3 is another typical MR loop we often obtained. When the external magnetic field increases from 0 to ± 5.0 KOe, the resistance of nanocontact increases. When the nanocontact's resistance arrives at a maximum value, it jumps to about the initial value. However, when the magnetic field decreases, the resistance of nanocontact decreases continuously. There is no jump during this period.

Since the pioneering MR measurements of the mechanically formed nanocontacts by García et al. [1], The MR has been attributed to the scattering of spin-polarized electrons on DW formed in the constriction. Lepadatu and Xu [15] gave the empirical relations between the percentage changes in resistance and the cross-sectional area at the constriction:

$$\frac{\Delta\rho}{\rho} = \frac{K}{S^{\alpha}},$$

where S is the cross-sectional area at the constriction. For Ni, the constant K and α take the values of 1.12×10^{-6} and 0.3, respectively. The resistance of the nanocontact after electrodeposition is $1.75\,\Omega$ (see Fig. 2). Using $d = \sqrt{1000/R\,(\Omega)}$ (in nm) [16], we can get the diameter of this sample is 23.9 nm. Thus the predicted MR due to DW scattering is $\approx 4.5\%$, which is not in agreement with the experimental result (MR = 477%). Therefore, the DW scattering theory can not be used to explain the electrodeposited nanocontact's MR. What can be the explanation of the huge MR in these contacts?

Nickel has negative magnetostriction and the saturation magnetostriction constant $\lambda_s = -34 \times 10^{-6}$ [17]. As shown in Fig. 1, the length of the electrodeposited Ni between wires is about $20\,\mu m$ [8] (even reaches few tens of microns [9]). Therefore, a magnetic field parallel to the wire II axis will induce magnetostriction, which causes pulling nanocontact away from the central part of wire I. For a length of the electrodeposited Ni of $20\,\mu m$, the contraction due to magnetostriction is $\lambda_s d = -6.8\,\text{Å}$. Because the epoxy covers the wire I except for the central part [8,9], there is a small free part in wire I (see Fig. 1). A magnetic field perpendicular to wire I will cause the free part to shrink by less than 6.8 nm. Combination of the shrinking of wire I and shortening of the electrodeposited Ni will cause a displacement of between 0.68 and 7.5 nm. This displacement would have a profound effect on the structure and diameter of the nanocontact.

If the displacement is very small, it may deform the nanocontact. While the nanocontact is slowly stretched, its cross-section is necking down. Since the conductivity decreases in proportion to the cross-sectional area, the resistance of nanocontact increases with increasing the magnetic field, as the typical MR curves shown in Fig. 2. When decreasing the magnetic field, the resistance of nanocontact cannot drop to the initial value; it may be due to that the nanocontact is distorted, which causes the poor reproducibility of the electrodeposited nanocontacts (see Fig. 2(b)). The resistance drops to minimum while the magnetic field is not at zero (see inset at Fig. 2(a)), which may be caused by the hysteresis of Ni wires.

Different length changes near the nanocontact result in different MR effects. If the length change is very large, it may break the nanocontact. Since we used a constant current to measure the resistance of the nanocontact, breaking the nanocontact will cause a very high electric field between the gap formed by displacement, strong electric field make the atoms in the contact move [18], and then a discrete jump is obtained, as shown in Fig. 3. Decreasing the magnetic field leads the wire I and wire II to an intimate situation, thus there is no discrete jump during this period. Therefore, we conclude that the huge MR may partly due to the magnetostriction of the electrodeposited Ni and the bulk Ni wire I. Moreover, the MR could range between few hundred percents [5,8,16] and 100 000% [10].

Recent work by Yang et al. [6] has demonstrated little MR effect, in which they eliminated magnetostriction, and they also provide an independent confirmation that magnetostriction may play a key role in the previous reported huge BMR.

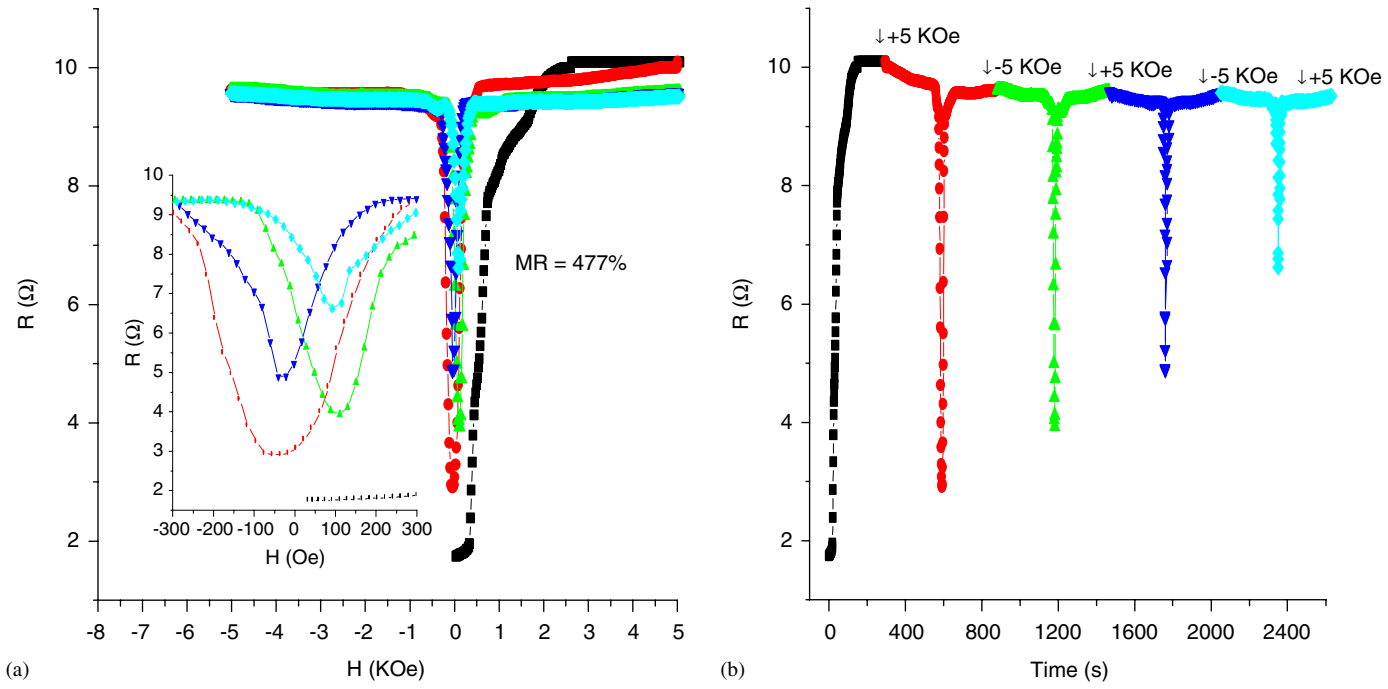

Fig. 2. (a) Several typical MR curves recorded from the same Ni nanocontact. $R_0 = 1.75\,\Omega$, $R_H = 10.1\,\Omega$, MR = 477%. The inset shows the details of the MR curves at field value ranging between –300 Oe and +300 Oe. It demonstrates that the resistance of nanocontact drops to minimum while the magnetic field is not zero. (b) The same MR curves are arranged by time order to demonstrate the unproducible nature of electrodeposited Ni nanocontact clearly.

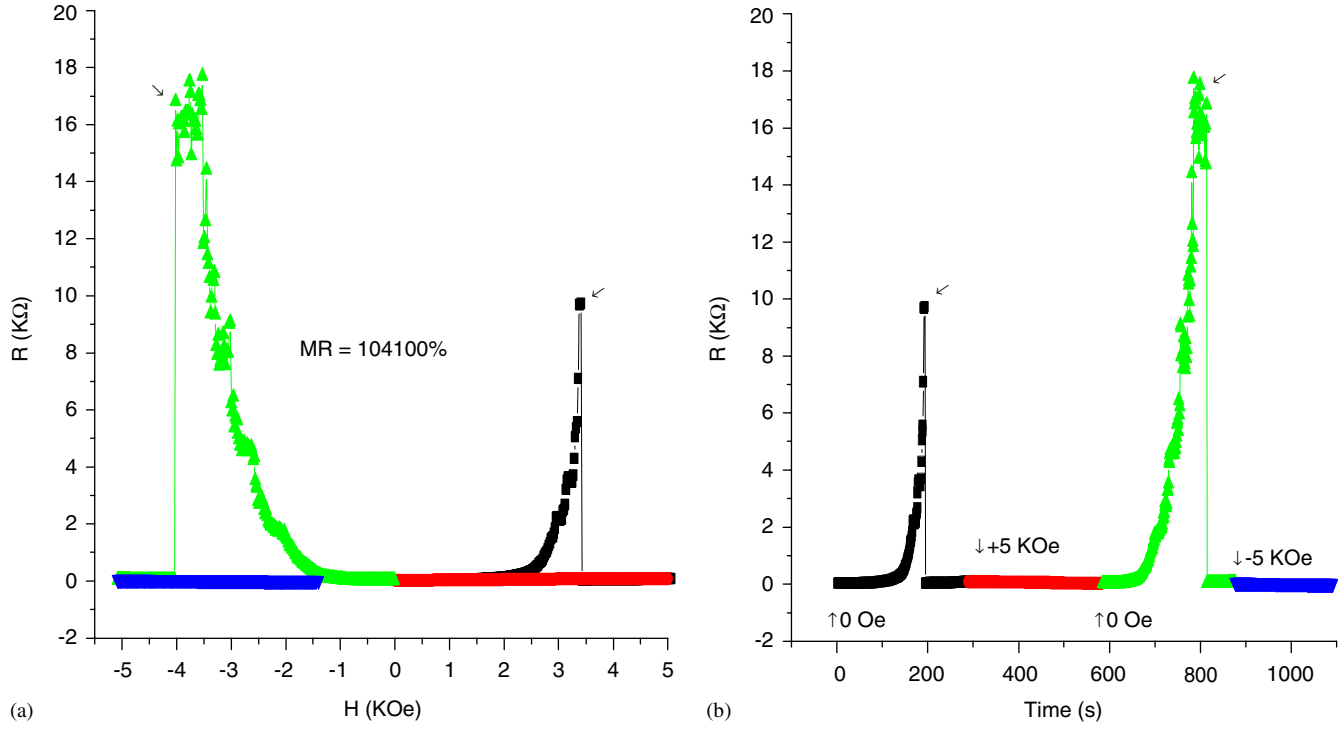

Fig. 3. (a) Another typical MR curve recorded from a Ni nanocontact, $R_{min} = 16.3\,\Omega$, $R_{max} = 17\,000\,\Omega$, MR = 104 100%. $R_{max} > 12\,900\,\Omega$, which indicates the contact has broken. (b) The same MR curve is arranged by time order to show clearly. The arrows in (a) and (b) indicate a significant decrease in the resistance of nanocontact, corresponding to the movement of atoms in the nanocontact (see the text for details).

4. Conclusion

To summarize, nanocontacts between two bulk Ni wires were fabricated by electrodeposition, the magnetoresistance effects of nanocontacts after the fabrication were studied. Contrary to previous reports, in some samples, there are discrete jumps during the measuring process. We attribute them to the magnetic-field-induced

electrodeposited Ni shortening and bulk Ni wire shrinking. Using the mechanism proposed in this report, we can explain the previously reported huge BMR, poor reproducibility and low stability of the electrochemically made nanocontacts.

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References

[1] N. García, M. Muñoz, Y.-W. Zhao, Phys. Rev. Lett. 82 (1999) 2923.
[2] J.J. Versluijs, M.A. Bari, J.M.D. Coey, Phys. Rev. Lett. 87 (2001) 026601.
[3] S.H. Chung, M. Muñoz, N. García, W.F. Egelhoff Jr., R.D. Gomez, Phys. Rev. Lett. 89 (2002) 287203.
[4] S.H. Chung, M. Muñoz, N. García, W. Egelhoff, R.D. Gomez, J. Appl. Phys. 93 (2003) 7939.
[5] N. García, I.G. Saveliev, Y.-W. Zhao, A. Zlatkine. J. Magn. Magn. Mater. 214 (2000) 7.
[6] C.-S. Yang, et al., J. Magn. Magn. Mater. 286 (2005) 186.
[7] N. García, H. Rohrer, I.G. Saveliev, Y.-W. Zhao, Phys. Rev. Lett. 85 (2000) 3053.
[8] N. García, G.G. Qiang, I.G. Saveliev, Appl. Phys. Lett. 80 (2002) 1785.
[9] H.D. Chopra, S.Z. Hua, Phys. Rev. B 66 (2002) 020403(R).
[10] S.Z. Hua, H.D. Chopra, Phys. Rev. B 67 (2003) 060401(R).
[11] Erik B. Svedberg, Jonathan J. Mallett, et al., Appl. Phys. Lett. 84 (2004) 236.
[12] S. Khizroev, et al., Appl. Phys. Lett. 86 (2005) 042502 (and references therein).
[13] Ge Yi, Phys. Rev. B 69 (2004) 132405.
[14] S. Boussaad, N.J. Tao, Appl. Phys. Lett. 80 (2002) 2398.
[15] S. Lepadatu, Y.B. Xu, Phys. Rev. Lett. 92 (2004) 127201.
[16] N. García, M. Muñoz, G.G. Qian, H. Rohrer, I.G. Saveliev, Y.-W. Zhao, Appl. Phys. Lett. 79 (2001) 4550.
[17] E.W. Lee, Rep. Prog. Phys. 18 (1955) 184.
[18] M. Viret, et al., Phys. Rev. B 66 (2002) 220401(R).