Artifacts that Could be Misinterpreted as Ballistic Magnetoresistance

W. F. EGELHOFF, JR.,[1] L. GAN,[1] E. B. SVEDBERG,[2] C. J. POWELL,[1] A. J. SHAPIRO[1], R. D. MCMICHAEL,[1] J. J. MALLETT,[1] T. P. MOFFAT,[1] AND M. D. STILES[1]

1) National Institute of Standards and Technology, Gaithersburg, MD 20899, egelhoff@nist.gov

2) Seagate Technology, Pittsburgh, PA 15222, erik_b_svedberg@notes.seagate.com

Theoretical physics suggests that very large magnetoresistance (MR) values might be found in certain magnetic nanocontacts if a magnetic domain wall could be localized in them with a length scale that would allow conduction electrons to transit the wall ballistically. Recently, several experimental reports of extremely large MR values have been published and claims have been made that these results are due to a ballistic magnetoresistance (BMR) effect.[1,2] Values as large as 1,000,000% have been reported.[2]

If the very large BMR values are real, it would have enormous implications for the hard-disk drive industry. Read heads that are now based on the giant magnetoresistance (GMR) effect might soon be replaced by ones based on a far larger BMR effect. Such heads would likely be able to read far smaller magnetic bits.

We have carried out an extensive search for evidence a ballistic magnetoresistance (BMR) effect in magnetic nanocontacts.[3] We have investigated both thin-film and thin-wire geometries for both mechanically-formed and electrodeposited nanocontacts. We find no systematic differences between mechanically-formed and electrodeposited nanocontacts. The samples we have investigated include mechanical contacts between ferromagnetic wires, electrodeposited nanocontacts between ferromagnetic wires, ferromagnetic nanocontacts electrodeposited on Cu wires, nanocontacts electrodeposited between ferromagnetic films anchored on wafers, ferromagnetic nanocontacts electrodeposited on Cu films anchored on wafers, nanocontacts between two ferromagnetic films connected by a pinhole through an insulating film, and nanocontacts formed by focused ion-beam etching. We did not find any evidence to support the existence of a real BMR effect. However, we did find a number of artifacts due to magnetostrictive, magnetostatic, and magnetomechanical effects that could be misinterpreted as BMR.

Figure 1a presents one geometry in which BMR has been reported and illustrates the magnetostatic force produced by parallel alignment of magnetic wires.[4] Since the Ni wires are anchored at their ends, they will stretch in response to the force. If each Ni wire is 4 mm long, it is a simple calculation, using the modulus of elasticity, to predict that each wire will lengthen 1 nm if the ends are hemispherical and 3 nm if flat. In antiparallel alighnment, each wire will shorten by the same amount. Thus, from parallel to antiparallel the total length change will be from 4 nm to 12 nm. Since BMR nanocontacts are generally thought to have dimensions on the order of 1 nm to 10 nm such length changes could severely distort the nanocontact and give resistance changes that could be mistaken for true BMR.

Figure 1b illustrates the so-called “T” geometry used for some BMR studies.[2] This geometry is subject to the artifacts shown in Fig. 1b, 1c, and 1d. When the magnetic field is applied, magnetostriction will shorten the axial wire in Fig. 1b as illustrated by the black arrow. If the axial wire is Ni and 4 mm long the shortening is calculated to be 136 nm. Another possible artifact is the attraction of the transverse wire by the fringing field of the magnet. The magnitude of this effect will be very much sample-size dependent, and is illustrated by the two arrows pointing to the left in Fig. 1b (the sample size is much exaggerated here for clarity).

Figure 1c illustrates the magnetostatic forces similar to those of Fig 1a but in the “T” geometry. Figure 1d illustrates the bowing-out artifact that will be present for a very straight transverse wire. A transverse wire will lengthen due to the transverse magnetostriction and, if the ends are fixed, it will tend to bow out in some direction. The bowing out can be surprisingly large and in any direction.[3]

We have found that the artifacts in Fig. 1a-d can lead to infinite magnetoresistance. This effect is, of course, not BMR but the breaking and reforming of the nanocontact.

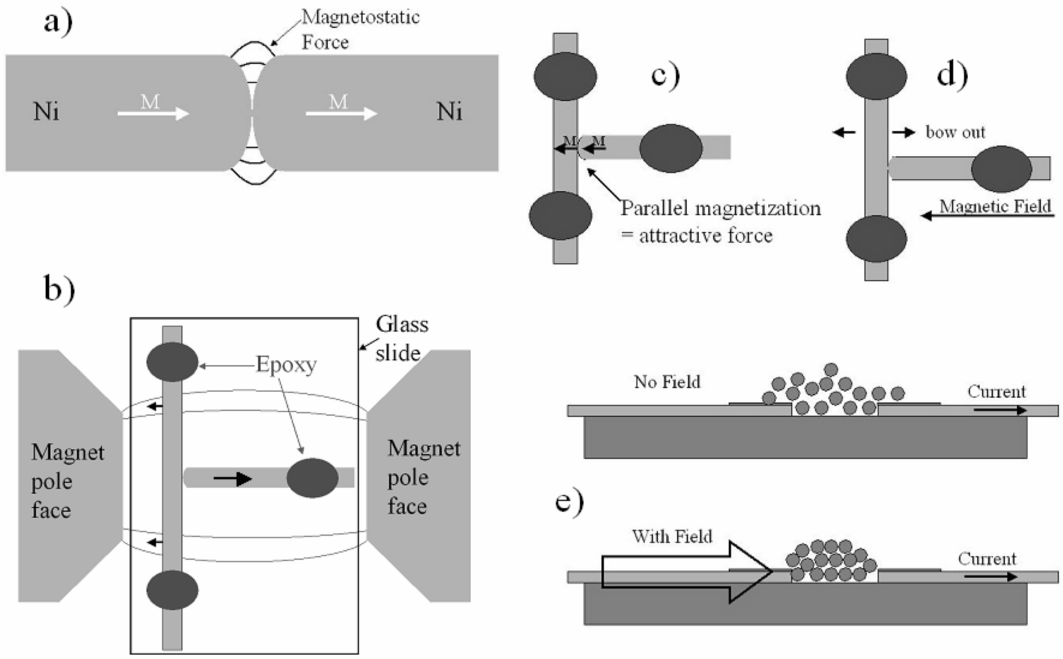

Figure 1 An illustration of the artifacts we have found that can contribute to mistaken interpretations. They are a) magnetostatic attractive force in a linear geometry, b) magnetostriction and the attraction of a fringing field in a "T" geometry, c) the magnetostatic attractive force in the "T" geometry, d) the bowing out due to the increase in length in the transverse wire, and e) the clumping together of a granular assembly of magnetic particles.

Figure 1e illustrates another type of artifact that can occur when a nanocontact is electrodeposited at an unusually high potential.[2] A granular deposit of ferromagnetic particles results. Under the influence of a magnetic field, the particles are magnetized in parallel and tend to clump together forming more intimate contact that lower the electrical resistance. This motion is visible in an optical microscope.[5]

We have designed and fabricated samples in geometries that avoid the above artifacts, but none show any evidence of BMR. While it is impossible for us to prove that artifacts occurred in the work reporting BMR values, our work strongly suggests that possibility. Therefore, we conclude that it is entirely possible that there is no real BMR effect of any significant magnitude in any data published so far. For further details see Ref. 3.

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