"Electrical characterization of nanocontacts fabricated by nanoindentation and electrodeposition"

Carrey, J ; Bouzehouane, K. ; George, JM. ; Ceneray, C ; Blon, T. ; Bibes, M ; Vaures, A ; Fusil, S. ; Kenane, Salah ; Vila, Laurent ; Piraux, Luc

ABSTRACT

We report on the electrical characterization of various types of nanocontacts fabricated by nanoindentation and electrodeposition. Arrays of holes with depths ranging from 0 to 20 nm were produced by nanoindenting at different strengths an Al2O3-50 Angstrom/NiFe-150 Angstrom/Si bilayer. NiFe was then electrodeposited, which led to the growth of particles in the holes. The resistance of the particles was measured with a conducting tip atomic force microscope. Depending on the strength used during the nanoindentation, the resistance ranges from less than 5x10³ Ω to more than 10¹² Ω. The low-resistance constrictions can be used to study ballistic transport in materials. High-resistance contacts presumably correspond to tunnel nanojunctions. (C) 2002 American Institute of Physics.

CITE THIS VERSION


Le dépôt institutionnel DIAL est destiné au dépôt et à la diffusion de documents scientifiques émanant des membres de l'UCLouvain. Toute utilisation de ce document à des fins lucratives ou commerciales est strictement interdite. L'utilisateur s'engage à respecter les droits d'auteur liés à ce document, principalement le droit à l'intégrité de l'œuvre et le droit à la paternité. La politique complète de copyright est disponible sur la page Copyright policy.

DIAL is an institutional repository for the deposit and dissemination of scientific documents from UCLouvain members. Usage of this document for profit or commercial purposes is strictly prohibited. User agrees to respect copyright about this document, mainly text integrity and source mention. Full content of copyright policy is available at Copyright policy.

Available at: http://hdl.handle.net/2078.1/41821 [Downloaded 2020/09/02 at 16:17:25]
Electrical characterization of nanocontacts fabricated by nanoindentation and electrodeposition

J. Carrey, a) K. Bouzehouane, J. M. George, C. Ceneray, T. Blon, M. Bibes, and A. Vaurès
Unité mixte de Physique CNRS/THALES, Domaine de Corbeville, 91404 Orsay Cedex, France
and Université Paris-Sud, 91405 Orsay Cedex, France

S. Fusill
Université d’Evry, Laboratoire Multicouches Nanométriques, Bâtiment des Sciences, Rue du Père Jarlan, 91025 Evry Cedex, France

S. Kenane, L. Vila, and L. Piraux
Laboratoire PCPM, Université Louvain-La-Neuve, Place croix du sud, 1348 Louvain-La-Neuve, Belgium

(Received 13 December 2001; accepted for publication 28 May 2002)

We report on the electrical characterization of various types of nanocontacts fabricated by nanoindentation and electrodeposition. Arrays of holes with depths ranging from 0 to 20 nm were produced by nanoindenting at different strengths an Al₂O₃-50 Å/NiFe-150 Å//Si bilayer. NiFe was then electrodeposited, which led to the growth of particles in the holes. The resistance of the particles was measured with a conducting tip atomic force microscope. Depending on the strength used during the nanoindentation, the resistance ranges from less than 5×10³ Ω to more than 10¹² Ω. The low-resistance constrictions can be used to study ballistic transport in materials. High-resistance contacts presumably correspond to tunnel nanojunctions. © 2002 American Institute of Physics. [DOI: 10.1063/1.1495524]

Experiments on nanocontacts are of great interest in many fields of physics. They allow study of ballistic transport, conductance quantization, inelastic scattering, and electron injection into the quantized levels of small clusters. Between ferromagnetic conductors, a nanocontact can pin a very thin domain wall, which gives rise to interesting effects of ballistic magnetoresistance.

Such contacts have been obtained by the break junction method, by electrodeposition or using tips, which can give unstable contacts or hardly reproducible results, and can not be used for applications. Small contacts on isolated clusters have also been fabricated by a lithographic process as we can choose the location of the nanocontact.

In this letter, we show that a good alternative method is the combination of nanoindentation and electrodeposition. The nanoindentation is performed with a diamond-tipped atomic force microscope (AFM), which allows us to make a hole in the alumina barrier and then to fill it using electrodeposition. The electrodeposition occurs preferentially in the hole and, if the depth of the hole is of the order of the alumina barrier thickness, a direct nanocontact is created. If the depth of the hole is lower, a very small tunnel junction is created. Various types of nanocontacts can thus be fabricated this way. This technique is compatible with a lithographic process as we can choose the location of the nanocontact.

The samples we study were grown in an Alcatel 610 sputtering equipment and have the following structure: Al₂O₃/Ni₈₀Fe₂₀-150 Å//Si. The Al₂O₃ layer was elaborated by the successive fabrication of two Al₂O₃ layers. Each one is elaborated by the oxydation of a 15 Å thick Al layer in an Ar/O₂ plasma. The partial pressure of both gases is 2 mTorr. Oxidation times were previously optimized during the study of tunnel junctions. From transmission electron microscopy experiments, the aluminum oxide barrier was found amorphous and its thickness is larger than the deposited Al by 50%, in agreement with the expected value for crystalline alumina (Al₂O₃). Thus, the successive elaboration of two barriers leads to an alumina layer about 45 Å thick. In a previous paper, we have shown that, for such a thickness, the density of “natural” defects decorated by electrodeposition is low, so that the defects created by nanoindentation will be predominant.

Nanoindenting is performed with a diamond-tipped cantilever mounted on a D3100 Nanoscope III (Digital Instruments, Santa Barbara, CA). The stainless steel cantilever used has a spring constant of 221 N/m. The typical forces applied are centered around 20 μN according to Hooke’s law. The nominal tip radius of curvature is less than 20 nm and the tip apex angle is 60°. The indented area can be imaged non destructively with the same tip by operating the AFM in a tapping mode. It can be useful to check the indent shape afterward or to image the indents in the area of interest. The relation between the holes depths and the cantilever deflection is presented in Fig. 1. Using the diamond tip to measure the hole depths leads to underestimating the depths

a)Electronic mail: julian.carrey@thalesgroup.com
as the tip does not reach the bottom of the hole. Sharper silicon tips (Olympus) have also been used and show that the hole depth is, in fact, about 2 nm deeper than when measured with the diamond tip.

Automated indentation can be operated and $10 \times 10$ indents matrices have been fabricated this way. Each column is composed of indents corresponding to the same value of the cantilever deflection. Each line consists of indents corresponding to stepped increased values of the cantilever deflection. The depths of the indent measured in the same column have a dispersion of 25%. Results on three different matrices are presented in this letter: matrix 1 was made with high cantilever deflection values, from 75 to 250 nm; matrix 2 was made with lower ones, from 20 to 90 nm; matrix 3 was intermediate, with deflection values from 40 to 130 nm.

After nanoindenting, electrodeposition was performed by using a bath of Ni sulfate and Fe sulfate with concentrations of 0.5 and 0.02 M, respectively. A concentration of 0.4 M of boric acid was added as a chemical buffer to limit the pH rise at the surface. The electrolyte temperature was maintained at 25 °C. No chemical additives were used because they could be incorporated into the deposit. The deposition was controlled by EG&G model 263 potentiostat/galvanostat. Permalloy was deposited at $-1$ V relative to Ag/AgCl electrode. A pure Ni plate was used as counter electrode. The sample was electrodeposited during 120 s.

Two matrices after electrodeposition, imaged by scanning electron microscopy (SEM), are presented in Fig. 2. The sample was also observed with a conducting tip AFM. The one we used has been fabricated by Houzé et al., and has a resistance measurement range from 100 to $10^{12}$ Ω with bias voltage ranging from 0.1 to 10 V. It allows us to measure the resistance of the contact between the particle and the bottom layer. The resistance of the contact as a function the tip deflection used for the nanoindentation process is presented in Fig. 3.

According to SEM observation, there are some anomalies in the alignment of the particles which are due to the nonlinearity of the AFM piezoelectric $XY$ displacement during the nanoindentation. Such problems can be solved with appropriate softwares.

For most indents of matrix 1, the hole depth is greater than the alumina layer so that a direct contact is taken on the permalloy layer beneath alumina. In this case, the growth of the particles during electrodeposition is only limited by the charge transfer in the solution, and not by the resistance of the contact. This explains the very uniform distribution in the size of particles in matrix 1 (Fig. 2). The measure of the particle resistance in this case is limited by the resistance of the AFM conducting tip (Fig. 3). Therefore, we can only say that this resistance is smaller than $5 \times 10^3$ Ω.

Particles in matrix 2 are fabricated with lower cantilever

![Fig. 1. Relation between the cantilever deflection and the hole depth (measured with the diamond tip used during nanoindentation).](image1)

![Fig. 2. SEM image of electrodeposited particles in matrix 1(a) and matrix 2(b). Each column corresponds to the same value of the cantilever deflection during nanoindentation. The cantilever deflection decreases when going from the left- to the right-hand side.](image2)

![Fig. 3. (a) Resistance of the particles vs the deflection used during nanoindentation. (b) Resistance of three lines of particles in matrix 3. Points with the same symbol belong to the same line of the matrix so that nanoindentation was performed one after the other. For (a) and (b), the bias of the conducting tip AFM was 0.5 V and the tip resistance $5 \times 10^4$ Ω. The vertical line is an estimation of the deflection needed to pierce the alumina layer.](image3)
deflections during nanoindentation, so that the holes do not pierce the whole Al2O3 layer. In such cases, the resistance of the Al2O3 layer remaining beneath the hole limits the current during electrodeposition and thus limits the particle growth. This is the reason why, in matrix 2, we observe smaller particles, which correspond to higher-resistance contacts. This resistance can reach values above 10^12 Ω for the smallest particles (Fig. 3). The three columns on the right-hand side of matrix 2 correspond to the lowest cantilever deflections. One can note that most holes in these columns are not filled at all, as the Al2O3 barrier beneath the holes is too thick to allow electrodeposition.

Particles in matrix 3 are fabricated with cantilever deflections around what is needed to pierce the Al2O3 layer. In a few lines of this matrix, the transition between two regimes is clearly observed: When the Al2O3 has not been pierced, the resistance of the nanocontact strongly depends on the cantilever deflection (increasing as the deflection decreases), which reflects that the indentation let different barrier thicknesses beneath the hole. When the Al2O3 layer is pierced, the resistance is predominantly limited by the tip resistance and is more or less constant [see Fig. 3 (b)]. From Fig. 3 (a), the cantilever deflexion at which the piercing occurs can be estimated to 100 nm. It corresponds to holes about 9 nm thick, though the alumina layer is about 4.5 nm thick. The dispersion in the hole depth is not sufficient to explain this. It is more probable that the NiFe layer under the alumina buckles during the nanoindentation process.

We observe a large dispersion in the graph in Fig. 3. Two reasons can be put forward to explain this: First, the hole depth can vary of ±25% using the same conditions which, in the case of tunnel barriers, can lead to a large variation of resistance. Then we see, in Fig. 3, that even in the case of very low depth holes, low resistance contacts can be found. It is possible that, in some cases, the process of nanoindentation damages the tunnel barrier beneath the hole.

The general variation of the contact resistance with the deflection of cantilever shows that our technique can be used to produce various types of nanocontacts. Some are direct contacts between the metallic layers and can be used to study ballistic transport. Some are tunnel nanojunctions and this technique is a unique one to fabricate them. In particular, they could be useful to elaborate small contacts near a particle embedded in an insulating material.

The authors thank F. Houzé and O. Schneegans from the Laboratoire de Génie électrique de Paris for providing apparatus and stimulating discussions. This work was partly supported by the Belgian Interuniversity Attraction Pole Program (PAI-IUAP PS/1/1).