A CrO_2-based magnetic tunnel junction

2000 J. Phys.: Condens. Matter 12 L173

(http://iopscience.iop.org/0953-8984/12/8/103)

J. Phys.: Condens. Matter **12** (2000) L173–L175. Printed in the UK PII: S0953-8984(00)10893-8

LETTER TO THE EDITOR

A CrO_2-based magnetic tunnel junction

A Barry†, J M D Coey† and M Viret‡

† Department of Physics, Trinity College, Dublin 2, Ireland
‡ Service de Physique de l'Etat Condensée, Orme des Merisiers, CEA-Saclay,
91191 Gif-sur-Yvette, France

Received 11 January 2000

Abstract. A tunnel junction based on the half-metallic oxide CrO_2 uses a native oxide barrier layer and a cobalt top electrode. The $I{:}V$ characteristic is fitted to the Simmons model with $\phi = 0.76$ eV and $t = 2.0$ nm. The magnetoresistance is positive with $\Delta R/R = 1.0\%$ at 77 K.

Half-metallic oxides such as CrO_2 are considered ideal materials for spin electronic devices on account of their spin-split d band and the absence of sp conduction electrons, giving a single sign of spin polarization at the Fermi level [1]. In a recent study of the spin polarization using Andreev reflection in the liquid helium range, CrO_2 was found to exhibit the greatest value of spin polarization (90%) of any of the seven 3d metals examined [2]. The oxide has the rutile structure with a $3d^2$ ($t_{2g}^{2\uparrow}$) configuration and a magnetic moment of 2.0 μ_B/formula unit at 4.2 K. Here we present first results on a spin-polarized junction based on the same CrO_2 films as were used for the Andreev reflection measurements.

The films were deposited on a (110)-oriented TiO_2 substrate by the thermal decomposition of CrO_3, as described previously [3]. The film thickness was ∼800 nm. Full details of their characterization and properties are found in a recent thesis [4].

For the present study, UV lithography was used to pattern the CrO_2 films. The films were wet etched to produce a bar of width 5 μm using an industrial chrome etch composed of ammonium ceric nitrate and nitric acid. Etch rates were in the range 0.008–0.011 $\mu\mathrm{m\ s^{-1}}$, depending on film thickness and quality. The tunnel barrier was a native oxide layer and was grown by exposing the film to air for several weeks. As no attempt was made to reduce the CrO_2 films after deposition, the barrier is probably composed of antiferromagnetic Cr_2O_3, the equilibrium chromium–oxygen phase in ambient conditions. Our experience with the reduction of CrO_2 at elevated temperatures has shown that after the initial reduction, the thickness of the antiferromagnetic layer does not depend on time; it acts as a passivation layer. A Co top electrode, 150 nm in thickness, was deposited by RF sputtering, patterned using UV lithography and etched by ion beam milling. A schematic drawing of the device with dimensions 5×5 $\mu\mathrm{m}^2$ is shown in figure 1. Contacts were made to copper pads by wire bonding using Al wire 50 μm thick.

The $I{:}V$ curve is illustrated in figure 2. It shows a non-linear characteristic consistent with tunnelling across a barrier with a parabolic variation of the conductance ($\mathrm{d}I/\mathrm{d}V$) versus voltage (V). The junction resistance was ∼60 kΩ. A fit to the Simmons model [5] yields barrier thicknesses and barrier heights of 2.0 nm and 0.76 eV at 13 K and 0.79 eV and 2.5 nm at 77 K.

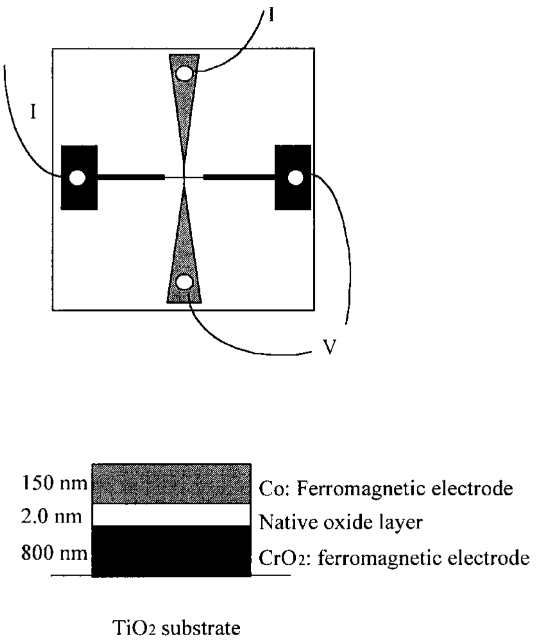

Figure 1. The ferromagnetic tunnel junction: CrO_2/I/Co in the cross-stripe geometry with the current perpendicular to the plane (CPP). Dimensions are in nm.

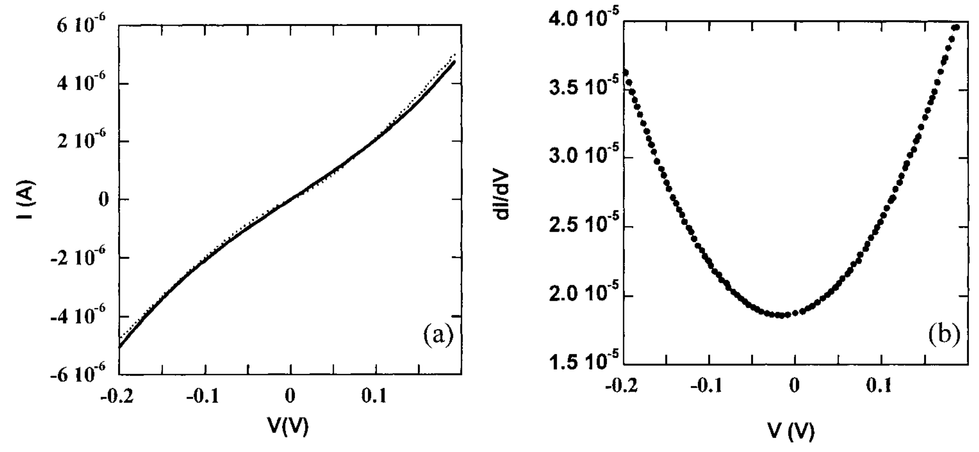

Figure 2. (a) I:V characteristics at $T = 13$ K for a tunnel junction of the type CrO_2/barrier layer/Co fitted to the Simmons model (solid black line) and (b) dI/dV versus V for the same junction.

The R:H curve measured with the field parallel to the 5 μm CrO_2 line is shown in figure 3. The switching field of the CrO_2 electrode is 20 mT and that of the cobalt electrode is 50 mT. For intermediate fields they adopt an antiparallel configuration with a resistance 1% higher than that for the parallel configuration.

The magnitude of the spin-polarized tunnel magnetoresistance observed at 77 K is quite

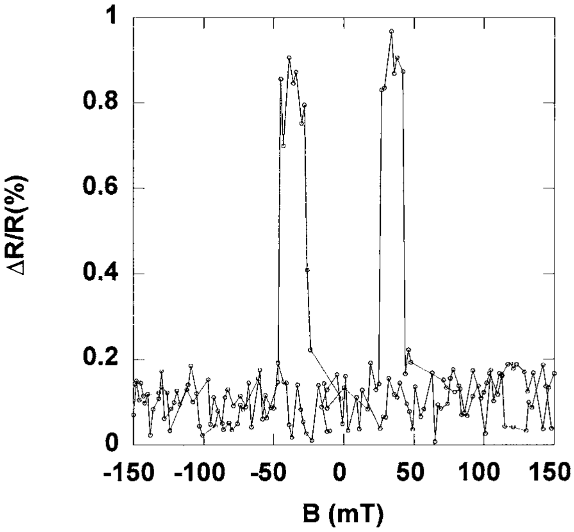

Figure 3. The magnetoresistance curve at 77 K of the 25 μm^2 CrO_2/I/Co tunnel junction.

small. Higher values up to 7% at 77 K and 52% at 4.2 K were found for pressed powder compacts [6, 7] and partly oxidized films [8]. The MR effect is considerably smaller than that expected for complete spin polarization and it is strongly temperature dependent. Part of the problem may be that the barrier oxide Cr_2O_3 is antiferromagnetic, with an antiferromagnetic axis that will bear no relation to the ferromagnetic directions in the adjacent Co or CrO_2 layers. Tunnelling electrons are then subject to a fluctuating exchange field that could induce spin depolarization [9]. Antiferromagnetic magnons can be excited in the barrier. Future work on spin-dependent tunnelling in CrO_2-based structures should investigate non-magnetic barriers such as TiO_2 and ZrO_2.

This work forms part of the Oxide Spin Electronic Network (OXSEN), a TMR network supported by the European Commission.

References

[1] de Groot R A, Mueller F M, Engen P G and Buschow K H J 1983 *Phys. Rev. Lett.* **50** 2024
[2] Soulen R J, Byers J M, Osofosky M S, Nadgorny B, Ambrose T, Cheng S F, Broussard P R, Tanaka C T, Nowak J, Moodera J S, Barry A and Coey J M D 1998 *Science* **282** 85
[3] Ranno L, Barry A and Coey J M D 1997 *J. Appl. Phys.* **81** 5774
[4] Barry A 1999 *PhD Thesis* University of Dublin
[5] Simmons J G and Unterkofler G J 1963 *J. Appl. Phys.* **34** 1828
[6] Coey J M D, Berkowitz A E, Balcells Ll, Putris F and Barry A 1998 *Phys. Rev. Lett.* **80** 3815
[7] Manoharan S S, Elefant D, Reiss G and Goodenough J B 1998 *Appl. Phys. Lett.* **72** 984
[8] Hwang H Y and Cheong S W 1997 *Science* **278** 1607
[9] Guinea F 1998 *Phys. Rev.* B **58** 9212