

## EXCHANGE BIAS EFFECT IN $\text{RuSr}_2\text{GdCu}_2\text{O}_8/\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ COMPOSITES

M. A. Flórez,<sup>1</sup> M. C. Reyes Ortiz,<sup>1</sup> A.R. Jurelo,<sup>2</sup> D. A. Landínez Téllez,<sup>1</sup> J. Roa-Rojas<sup>1</sup>

1. *Grupo de Física de Nuevos Materiales, Departamento de Física, Universidad Nacional de Colombia and CIF, Bogotá DC*

2. *Laboratório de Materiais Supercondutores, Departamento de Física, UEPG, Ponta Grossa PR, Brazil*

(Recibido 23 de Oct. 2006; Aceptado 2 de Abr. 2007; Publicado 23 de Abr. 2007)

### RESUMEN

Reportamos la síntesis y caracterización del compuesto magnético superconductor  $\text{RuSr}_2\text{GdCu}_2\text{O}_8\text{-La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  con 0% to 50% de  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  en el compuesto. Se realizaron mediciones sistemáticas de magnetización en función del campo magnético aplicado hasta 5 kOe en los regímenes de temperatura por debajo de la temperatura de Curie ( $T_C$ ) del  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  pero arriba de la temperatura de Néel ( $T_N$ ) del  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ ; abajo de  $T_N$  del  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  pero arriba de la temperatura crítica superconductor ( $T_{SC}$ ) del  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ ; y abajo de  $T_{SC}$  del  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ . Nuestros resultados muestran la característica ferromagnética de los compósitos en el régimen de temperatura  $T_N < T < T_C$ . El efecto de exchange bias fue observado para campos débiles ( $H < 1.5$  kOe) en el régimen de temperaturas  $T_{SC} < T < T_N$ . En el régimen superconductor ( $T < T_{SC}$ ) un efecto de exchange bias muy débil se observó en presencia de campos magnéticos ( $H < 0.6$  kOe). Para campos magnéticos fuertes ( $H > 2$  kOe) se recuperó el carácter ferromagnético del sistema.

Palabras clave: Exchange bias, manganita, superconductividad

### ABSTRACT

We report the synthesis and characterization of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8\text{-La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  superconducting-magnetic composites with 0 to 50 wt% of  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  in the composites. Systematic measurements of magnetization as a function of applied magnetic field at up 5 kOe were performed at temperature regimes below the Curie temperature ( $T_C$ ) of  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  but above the Néel temperature ( $T_N$ ) of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ ; below  $T_N$  of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  but above the superconducting critical temperature ( $T_{SC}$ ) of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ ; and below  $T_{SC}$  of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ . Our results reveal the ferromagnetic character of the composites at the temperature regime  $T_N < T < T_C$ . Exchange bias effect was observed for weak applied fields ( $H < 1.5$  kOe) at the temperature regime  $T_{SC} < T < T_N$ . At the superconducting temperature regime ( $T < T_{SC}$ ) weaker exchange bias is observed for low magnetic fields ( $H < 0.6$  kOe). For strong magnetic fields ( $H > 2$  kOe) the ferromagnetic character of the system is recovered.

PACS: 74.72.-h; 74.81.Bd; 74.25.Ha

Keywords: Exchange Bias, Manganite, Superconductivity

### 1. INTRODUCTION

The discovery of the coexistence of the superconducting character and the antiferromagnetic (AFM) ordering in Ru-1212-type  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  compound [1], has provide a opportunity for studying, in the same material, these antagonic phenomenon [2-3]. An important magnetic

characteristic associated with the exchange anisotropy created at the interface between a ferromagnetic (FM) and an antiferromagnetic material occurs when materials FM (with high Curie temperature  $T_C$ ) and AFM (with Néel temperature  $T_N < T_C$ ) are cooled through the  $T_N$  [4-5]. This effect, which is known as exchange bias, produces an asymmetry in the FM hysteresis curve. In this work we present results of exchange bias effect in  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ - $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  composites, prepared in sub-micrometric size grains. The observation of this effect was possible due the AFM character of the  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  materials at low magnetic fields and the typical FM response of the  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  manganites.

## 2. EXPERIMENTAL SETUP

Single phase polycrystalline samples of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  and  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  perovskite materials were prepared by the standard solid state reaction method. Mixture 50 vol%  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  and 50 vol%  $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$  was solid-reacted to form the composite material. Structural and microstructural characterization of compounds and composite were performed by the X- ray diffraction technique and by Scanning Electron Microscopy (SEM). Magnetization measurements of were performed by using a QD 2000 MPMS SQUID.

## 3. RESULTS AND DISCUSSION

X-ray pattern show two separate crystallographic phases in the composite samples without any trace chemical reaction between the respective compounds. SEM images revealed the sub-micrometric character of grains. DC Resistivity measurements showed the superconducting feature of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  with a critical temperature  $T_{SC} = 39.2$  K. Results of magnetization as a function of temperature for the same material exhibited an AFM transition with a  $T_N = 132.7$  K. The magnetic field dependence of the magnetization revealed the characteristic FM behavior of  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ . Figure 1 exhibits the hysteretic behavior of magnetization for  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ - $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  composites at temperature values above  $T_N$  of the AFM  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  but below  $T_C$  of the FM  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  material ( $T_N < T < T_C$ ). At the temperature regime  $T < T_N$ , we observe a weak exchange bias behavior for low applied magnetic fields ( $H < 1.5$  kOe). The characteristic asymmetric curve of this exotic phenomenon is showed in figure 2. We notice that this effect is not observed for magnetic fields higher than 2 kOe. At the superconducting regime ( $T < T_{SC}$ ), we effectively observe a weaker exchange bias effect for low applied fields ( $H < 600$  Oe).

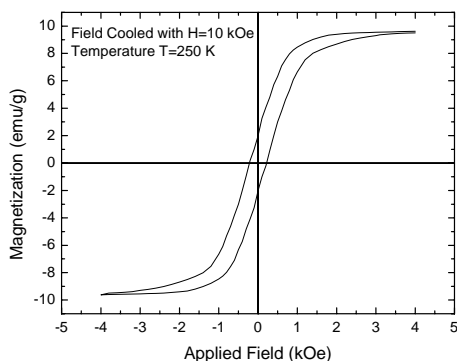


Fig. 1. Hysteretic FM behavior of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ - $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  composites at  $T=250$  K.

When the applied field is increased, we recover the FM curve characteristic of the single  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  material. This behavior may be evidence that the AFM ordering in the  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  only occurs for low magnetic fields. For high applied fields we could be expecting a competition between superconductivity and FM behavior in this interesting material.

#### 4.CONCLUSIONS

We have performed a complete characterization of the magnetic response of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ - $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  composites, constituted by sub micrometric grains. Due the granular interfaces between the AFM  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  and FM  $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  grains, it is observed that the exchange bias effect has place for low applied magnetic fields at the  $T_{\text{SC}} < T < T_{\text{N}}$  temperature regime. An interesting result is that of the absence of exchange bias for strong applied fields. On the other hand, the occurrence of exchange bias for low fields and the respective absence for strong fields, below the superconducting transition, is interpreted as a non conventional magnetic ordering in  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$  perovskite material.

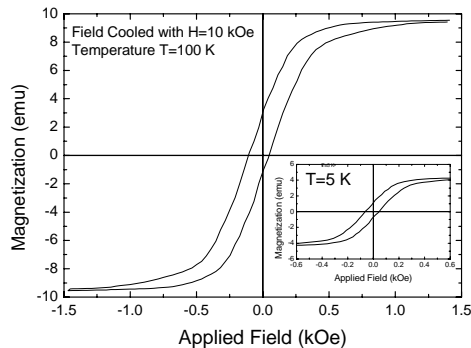


Fig. 2. Exchange bias effect of  $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ - $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$  composites at  $T=100$  K ( $T_{\text{SC}} < T < T_{\text{N}}$ ). The inset show the very weak exchange bias observed at  $T < T_{\text{SC}}$  for low magnetic fields.

#### ACKNOWLEDGEMENTS

This work was partially supported by the COLCIENCIAS Colombian agency on the project No. 1101-06-17622 and Centro de Excelencia en Nuevos Materiales, contract 043-2005.

## 5. REFERENCES

- [1] L. Bauernfeind, W. Widder, H.F. Braun, *Physica C* 254 (1995) 151.
- [2] J.W. Lynn, B. Keimer, C. Ulrich, C. Bernhard, J.L. Tallon, *Phys. Rev. B* 61 (2000) R14964.
- [3] I.I. Mazin, D.J. Singh, *Phys. Rev. Lett.* 82 (1999) 4324.
- [4] W.H. Meiklejohn, C.P. Bean, *Phys. Rev.* 102 (1956) 1413.
- [5] S. Mangin, G. Marchal, B. Barbara, *Phys. Rev. Lett.* 82 (1999) 4336.