

Sensor properties of a robust giant magnetoresistance material system at elevated temperatures

Citation for published version (APA):

Lenssen, K. M. H., Kuiper, A. E. T., Broek, van den, J. J., Rijt, van der, R. A. F., & Loon, van, A. M. (2000). Sensor properties of a robust giant magnetoresistance material system at elevated temperatures. *Journal of Applied Physics*, 87(9), 6665-6667. <https://doi.org/10.1063/1.372804>

DOI:

[10.1063/1.372804](https://doi.org/10.1063/1.372804)

Document status and date:

Published: 01/01/2000

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Sensor properties of a robust giant magnetoresistance material system at elevated temperatures

K.-M. H. Lenssen,^{a)} A. E. T. Kuiper, J. J. van den Broek, and R. A. F. van der Rijt
Philips Research Laboratories, Prof. Holstlaan 4, NL-5656 AA Eindhoven, The Netherlands

A. van Loon

Eindhoven University of Technology, Applied Physics Department, P.O. Box 513, NL-5600 MB Eindhoven, The Netherlands

The temperature dependence of the giant magnetoresistance (GMR) ratio, resistance and exchange-biasing field for a spin valve comprising an Ir₁₉Mn₈₁-biased artificial antiferromagnet (AAF) has been studied up to 325 °C. Up to 200–250 °C the temperature effects are reversible, at higher temperatures gradual irreversible changes are observed, probably due to atomic diffusion. The magnetoresistance effect is even at 200 °C still higher than for anisotropic magnetoresistance sensors at room temperature. The resistance of the multilayer shows a maximum around 250 °C. We found that this is due to the peculiar behavior of Ir–Mn, which has a negative temperature coefficient of the resistance. This provides a possibility to tune the temperature coefficient for the complete multilayer by varying the thickness of the Ir–Mn layer. The relative decrease of the exchange-biasing field as a function of temperature is much smaller for spin valves with AAF than for conventional spin valves (without AAF). Furthermore, it was demonstrated that the GMR ratio can be increased to 12% at room temperature by using a dual spin valve with two AAFs. © 2000 American Institute of Physics. [S0021-8979(00)49008-0]

I. INTRODUCTION

Automotive and industrial sensor applications pose very stringent requirements on giant magnetoresistance (GMR) materials. The output signal should meet the specifications over a wide field range (up to several tens of kiloamperes per meter) and temperature range (up to ~175 °C). More than is the case for recording applications, the GMR properties at elevated temperatures are very important.

Therefore, we have studied the sensor properties of our GMR material system not only after heating, but also at high temperatures up to 325 °C. This multilayer is based on a Co–Fe/Ru/Co–Fe artificial antiferromagnet (AAF) that is exchange biased with Ir–Mn.^{1,2} This material typically shows a GMR effect of ~7% at room temperature. Recently we have even obtained a GMR ratio of 12% in a dual spin valve (see Fig. 1); this is one of the highest values reported so far for a spin valve comprising an AAF (compare, for example, Ref. 3).

In this article we will discuss the investigations of the characteristics of single spin valves with exchange-biased AAF at elevated temperatures.

II. EXPERIMENTAL SETUP

All samples were grown at room temperature by dc magnetron sputtering (base pressure ~10⁻⁸ mbar). As substrates 4 × 12 mm² Si(100) crystals were used, as well as similar substrates with 0.5-μm-thick thermal oxide. During deposition, a field of ~20 kA/m was applied along the long axis of the substrates.

The magnetoresistance of the spin valves was measured in a four-terminal configuration (current and field both along the long axis), in which the temperature of the film (in a nitrogen atmosphere) could be varied between room temperature and 325 °C. In this study the time period that the film was exposed to elevated temperatures during a magnetoresistance measurement was circa 1.5 h (including a delay of 0.5 h before the start of the measurement for temperature stabilization).

The four-point measurements of the sheet resistance R_{sheet} as a function of temperature were carried out in a dedicated setup, in which the film was heated in vacuum (<10⁻⁶ mbar). From these experiments the temperature coefficient of the resistance {defined as $[\Delta R/\Delta T]/R(25\text{ °C})$ } can be determined.

The studied films consist of: 3.5 nm Ta/2 nm Ni₈₀Fe₂₀/10 nm Ir₁₉Mn₈₁/4.5 nm Co₉₀Fe₁₀/0.8 nm Ru/4 nm Co₉₀Fe₁₀/

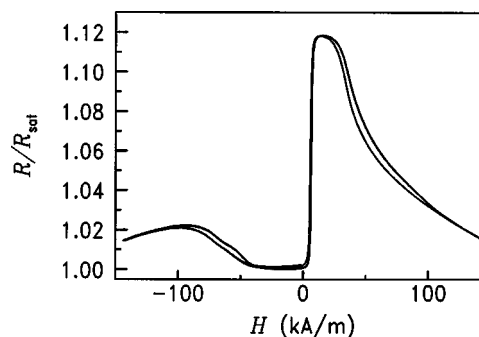


FIG. 1. Magnetoresistance curve of a dual spin valve with AAFs, consisting of 3.5 nm Ta/2 nm Ni₈₀Fe₂₀/6 nm Ir₁₉Mn₈₁/4 nm Co₉₀Fe₁₀/0.8 nm Ru/4 nm Co₉₀Fe₁₀/2.5 nm Cu/1.6 nm Co₉₀Fe₁₀/2.5 nm Cu/4 nm Co₉₀Fe₁₀/0.8 nm Ru/4 nm Co₉₀Fe₁₀/6 nm Ir₁₉Mn₈₁/3.5 nm Ta.

^{a)}Electronic mail: lenssen@natlab.research.philips.com

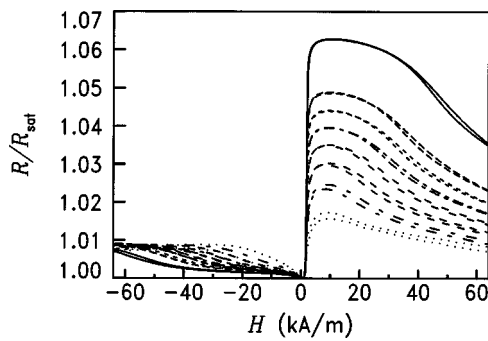


FIG. 2. Magnetoresistance curves of a multilayer consisting of 3.5 nm Ta/2 nm $\text{Ni}_{80}\text{Fe}_{20}$ /10 nm $\text{Ir}_{19}\text{Mn}_{81}$ /4.5 nm $\text{Co}_{90}\text{Fe}_{10}$ /0.8 nm Ru/4 nm $\text{Co}_{90}\text{Fe}_{10}$ /3 nm Cu/0.8 nm $\text{Co}_{90}\text{Fe}_{10}$ /5 nm $\text{Ni}_{80}\text{Fe}_{20}$ /4 nm Ta at, respectively, 25, 100, 125, 150, 175, 200, 225, and 250 °C (from top down).

t_{Cu} Cu/0.8 nm $\text{Co}_{90}\text{Fe}_{10}$ /5 nm $\text{Ni}_{80}\text{Fe}_{20}$ /4 nm Ta, with $t_{\text{Cu}} = 1.5, 2.0, 2.5, 3.0, 3.5,$ and 5.0 nm. For comparison, some conventional exchange-biased spin valves containing the same materials have also been measured. Their composition was 3.5 nm Ta/2 nm $\text{Ni}_{80}\text{Fe}_{20}$ /10 nm $\text{Ir}_{19}\text{Mn}_{81}$ /4 nm $\text{Co}_{90}\text{Fe}_{10}$ / t_{Cu} Cu/0.8 nm $\text{Co}_{90}\text{Fe}_{10}$ /5 nm $\text{Ni}_{80}\text{Fe}_{20}$ /4 nm Ta, in which the thickness of the Cu spacer was 2.5 or 3.5 nm. Already as deposited the films showed exchange biasing.

III. TEMPERATURE DEPENDENCE

A. GMR ratio

The magnetoresistance curves at different temperatures up to 250 °C are shown in Fig. 2 for the multilayer containing 3.0 nm Cu. It can be seen that the typical shape of the curves remains similar for all temperatures, which is promising for application in sensors. The GMR ratio $\Delta R/R_{\text{sat}}$ (with R_{sat} the saturation resistance, which is assumed to be equal to the lowest measured resistance) only decreases by about half of its value when heated up to 200 °C. Note that the remaining effect of $\sim 3\%$ is still larger than the anisotropic magnetoresistance (AMR) effect at room temperature. So this opens possibilities for a magnetic sensor that could work up to 200 °C or higher.

The temperature dependence of the GMR ratio is shown in Fig. 3. Over a large temperature range the GMR ratio decreases approximately linearly. Just below 290 °C (i.e., the blocking temperature of our Ir–Mn films)⁴ it drops to a low

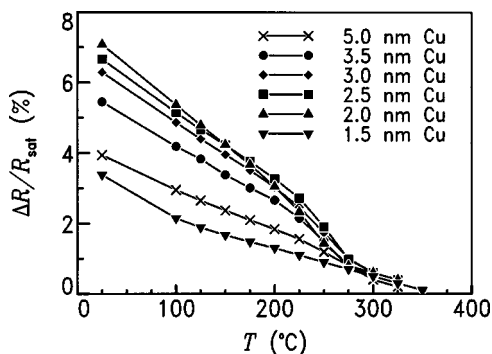


FIG. 3. The GMR ratio as a function of temperature for several thicknesses of the Cu layer.

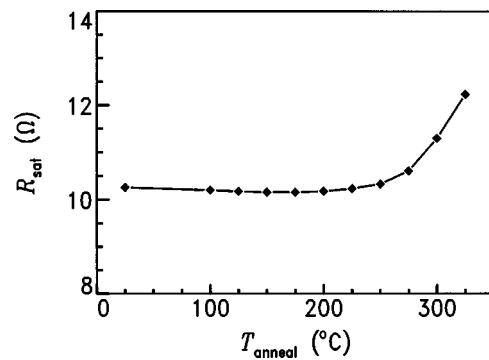


FIG. 4. The saturation resistance of the multilayer with 3 nm Cu at room temperature after annealing at several temperatures.

value. Despite the absence of exchange biasing above this temperature, there is still a small GMR effect left up to ≈ 350 °C. This is attributed to the different coercivities of the AAF and the free layer. At these high temperatures the magnetoresistance curves become symmetric around zero field (like in so-called hard-soft multilayers). The dependence of the GMR ratio on the Cu-layer thickness is, as expected, similar to what has been found earlier for conventional spin valves.⁵

B. Resistivity

In order to check whether any irreversible changes were caused by the elevated temperatures, after each of the measurements of Fig. 2 another magnetoresistance measurement was done at room temperature. The resistance is a good measure for a possibly induced change in the material. The experimental results for R_{sat} of the film with 3.0 nm Cu are presented in Fig. 4. The increase in resistance at the highest temperatures is probably due to interface diffusion. In this temperature regime time is an important parameter. Earlier experiments with rapid thermal processing¹ for 1 min indicated that diffusion starts around 300 °C; the present investigations show that on a longer time scale (~ 1.5 h) diffusion effects can be observed at lower temperatures.

Figure 4 shows that no significant change occurs up to 200–250 °C. This indicates that the effects that we observe in this temperature interval are reversible.

The resistance of an identical multilayer as a function of the temperature is presented in Fig. 5. The resistance increases monotonically up to ~ 250 °C, but then starts to decrease. It has been verified that this is not due to the substrate, but is a real characteristic of our multilayer. In order to investigate this remarkable dependence further, the temperature coefficients of constituting materials (with and without buffer layer) have been measured. The 10-nm-thick films of $\text{Ni}_{80}\text{Fe}_{20}$ and $\text{Co}_{90}\text{Fe}_{10}$ showed an approximately linear temperature dependence (at least up to 300 °C) with a positive slope of, respectively, 0.14%/°C and 0.08%/°C. For 10 nm $\text{Ir}_{19}\text{Mn}_{81}$, however, a peculiar temperature dependence was discovered (see Fig. 6): the curve decreases monotonically and becomes even steeper above ~ 250 °C. Up to 250 °C the slope is around $-0.027\%/^{\circ}\text{C}$, above this temperature it even almost doubles. It is this increase in the negative

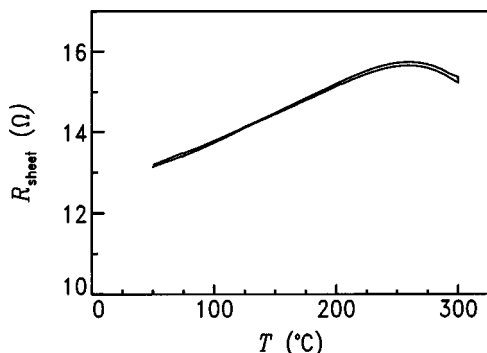


FIG. 5. Temperature dependence of the sheet resistance of the multilayer with 3 nm Cu.

slope that causes the maximum in the $R(T)$ curve of the total multilayer. Repeatedly sweeping the temperature up and down showed that this effect is reversible and fast, and therefore cannot be due to diffusion or a structural phase transformation.

From Fig. 5 it can be deduced that the temperature coefficient of the resistance of our GMR material is almost constant up to ~ 200 °C and has a value of about $\sim 0.1\%/^{\circ}\text{C}$. For sensor applications it is interesting to note that this is almost three times smaller than that of a typical AMR sensor ($0.3\%/^{\circ}\text{C}$).

The discovery of the negative temperature coefficient of $\text{Ir}_{19}\text{Mn}_{81}$ provides the possibility to tune the temperature coefficient of our multilayer by adapting the thickness of the Ir–Mn layer. This is, however, limited in practice, since a thicker Ir–Mn layer causes more electrical shunting and thus reduces the GMR ratio. Moreover, the thickness of Ir–Mn influences the blocking temperature and exchange-biasing field.⁶

C. Exchange biasing

In Fig. 7 the exchange-biasing field is plotted as a function of the temperature for exchange-biased spin valves with and without AAF. For the multilayers with AAF this was defined as the width between the two points where the magnetoresistance is half of its maximal value. Because of the relatively large hysteresis for the spin valves without AAF the exchange-biasing field has been determined from the

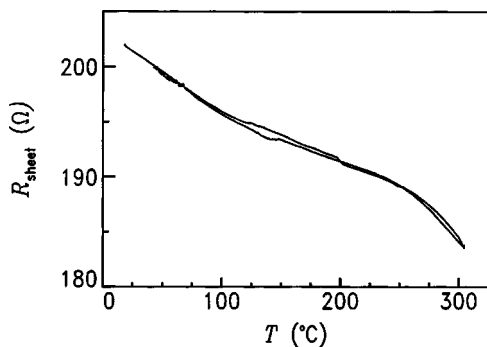


FIG. 6. Temperature dependence of the sheet resistance of a 10.0 nm $\text{Ir}_{19}\text{Mn}_{81}$ film.

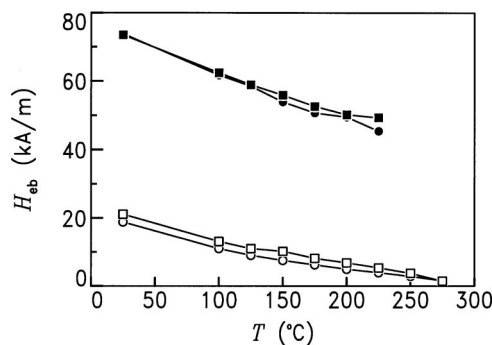


FIG. 7. Temperature dependence of the exchange-biasing field for spin valves with (solid markers) and without (open markers) AAF (squares: 2.5 nm Cu, circles: 3.5 nm Cu).

curve for increasing magnetic field. For the conventional spin valves (with a single 4 nm $\text{Co}_{90}\text{Fe}_{10}$ layer instead of the AAF) the exchange biasing decreases linearly with temperature. The temperature value that is obtained if these curves are extrapolated to zero field is in good agreement with the blocking temperature that was determined from magnetization measurements.⁴

It is remarkable that the relative decrease of the exchange-biasing field is much smaller for the films with an exchange-biased AAF. This is obviously a big advantage for sensor applications, in particular in automotive and industrial environments.

IV. CONCLUSIONS

We have studied the temperature dependence of GMR ratio, resistance, and exchange-biasing field for a spin valve comprising an $\text{Ir}_{19}\text{Mn}_{81}$ -biased AAF. Up to 200–250 °C the temperature effects are reversible, at higher temperatures atomic diffusion starts to occur. At 200 °C the magnetoresistance effect is still higher than for AMR sensors at room temperature.

The resistance of the multilayer shows a maximum around 250 °C. We found that this is due to the peculiar behavior of Ir–Mn, which has a negative temperature coefficient of the resistance. This provides a possibility to tune the temperature coefficient for the complete multilayer by varying the thickness of the Ir–Mn layer.

The relative decrease of the exchange-biasing field as a function of temperature is much smaller for spin valves with AAF than for conventional spin valves.

All measurements indicate that an operating range up to 200 °C seems feasible and that higher operation temperatures up to ≈ 270 °C could be possible for limited times.

¹K.-M. H. Lenssen, A. E. T. Kuiper, and F. Roozeboom, *J. Appl. Phys.* **85**, 5531 (1999).

²Y. Huai, J. Zhang, G. W. Anderson, P. Rana, S. Funada, C.-Y. Hung, M. Zhao, and S. Tran, *J. Appl. Phys.* **85**, 5528 (1999).

³M. Saito, N. Hasegawa, F. Koike, H. Seki, and T. Kuriyama, *J. Appl. Phys.* **85**, 4928 (1999).

⁴J. van Driel, R. Coehoorn, K.-M. H. Lenssen, A. E. T. Kuiper, and F. R. de Boer, *J. Appl. Phys.* **85**, 5522 (1999).

⁵Th. G. S. M. Rijks, R. Coehoorn, J. T. F. Daemen, and W. J. M. de Jonge, *J. Appl. Phys.* **76**, 1092 (1994).

⁶K.-M. H. Lenssen, J. J. T. M. Donkers, A. E. T. Kuiper, and J. van Driel, *Mater. Res. Soc. Symp. Proc.* **562**, 33 (1999).