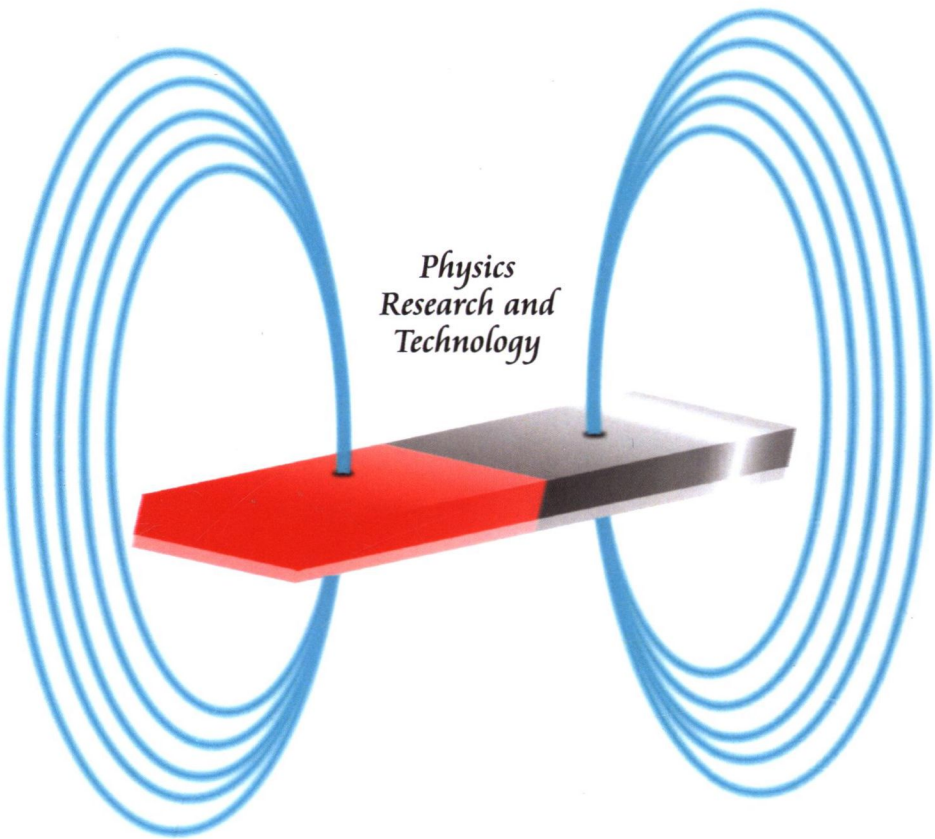
Magnetoresistance

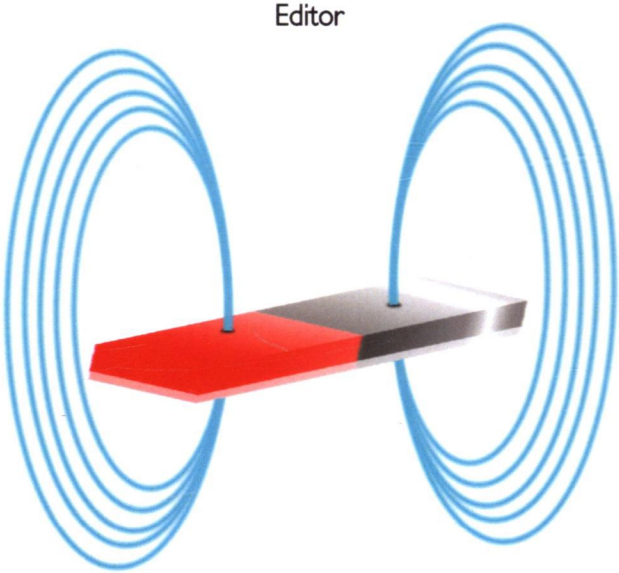
Types, Roles and Research



Russell Gonzalez
Editor

Novinka

Russell Gonzalez
Editor



Magnetoresistance

Types, Roles and Research

Contributors

Hiroshi Matsuda
Stanisław Olszewski
Leonid Lutsev

ISBN 978-1-53610-598-8

nova publishers

www.novapublishers.com

PHYSICS RESEARCH AND TECHNOLOGY

MAGNETORESISTANCE

TYPES, ROLES AND RESEARCH

RUSSELL GONZALEZ
EDITOR

New York

Copyright © 2017 by Nova Science Publishers, Inc.

All rights reserved. No part of this book may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic, tape, mechanical photocopying, recording or otherwise without the written permission of the Publisher.

We have partnered with Copyright Clearance Center to make it easy for you to obtain permissions to reuse content from this publication. Simply navigate to this publication's page on Nova's website and locate the "Get Permission" button below the title description. This button is linked directly to the title's permission page on copyright.com. Alternatively, you can visit copyright.com and search by title, ISBN, or ISSN.

For further questions about using the service on copyright.com, please contact:
Copyright Clearance Center
Phone: +1-(978) 750-8400 Fax: +1-(978) 750-4470 E-mail: info@copyright.com.

NOTICE TO THE READER

The Publisher has taken reasonable care in the preparation of this book, but makes no expressed or implied warranty of any kind and assumes no responsibility for any errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of information contained in this book. The Publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or in part, from the readers' use of, or reliance upon, this material. Any parts of this book based on government reports are so indicated and copyright is claimed for those parts to the extent applicable to compilations of such works.

Independent verification should be sought for any data, advice or recommendations contained in this book. In addition, no responsibility is assumed by the publisher for any injury and/or damage to persons or property arising from any methods, products, instructions, ideas or otherwise contained in this publication.

This publication is designed to provide accurate and authoritative information with regard to the subject matter covered herein. It is sold with the clear understanding that the Publisher is not engaged in rendering legal or any other professional services. If legal or any other expert assistance is required, the services of a competent person should be sought. FROM A DECLARATION OF PARTICIPANTS JOINTLY ADOPTED BY A COMMITTEE OF THE AMERICAN BAR ASSOCIATION AND A COMMITTEE OF PUBLISHERS.

Additional color graphics may be available in the e-book version of this book.

Library of Congress Cataloging-in-Publication Data

Names: Gonzalez, Russell, editor.
Title: Magnetoresistance: types, roles and research / Russell Gonzalez,editor.
Other titles: Physics research and technology.
Description: Hauppauge, New York: Nova Science Publishers, Inc., [2017] |
Series: Physics research and technology | Includes bibliographical references and index.
Identifiers: LCCN 2016052404 (print) | LCCN 2016054308 (ebook) | ISBN 9781536105988 (softcover) | ISBN 1536105988 (hardcover) | ISBN 9781536106220 (ebook) | ISBN 1536106224 (ebook) | ISBN 9781536106220
Subjects: LCSH: Magnetoresistance.
Classification: LCC QC610.7 .M34 2017 (print) | LCC QC610.7 (ebook) | DDC 530.4/12--dc23
LC record available at https://lccn.loc.gov/2016052404

Published by Nova Science Publishers, Inc. † New York

试读结束，需要全本PDF请购买 www.ertongbook.com

PHYSICS RESEARCH AND TECHNOLOGY

MAGNETORESISTANCE

TYPES, ROLES AND RESEARCH

PHYSICS RESEARCH AND TECHNOLOGY

Additional books in this series can be found on Nova's website under the Series tab.

Additional e-books in this series can be found on Nova's website under the e-book tab.

PREFACE

Magnetoresistance is an effect associated with the change of the quanta of the magnetic field due to the energy emission by the atom. In this book, Chapter One discusses magnetoresistive multilayers using various iron oxides and their characteristics. Chapter Two examines magnetoresistance connected with quantum electron transitions in the hydrogen atom. Chapter Three focuses on giant injection magnetoresistance in ferromagnet/semiconductor heterostructures.

As explained in Chapter 1, parallel alignment of spins throughout the crystal lattice results in ferromagnetism with permanent magnetization. On the other hand, equal numbers of spins are aligned in opposite direction, results in antiferromagnetism with no permanent magnetization. A large number of iron oxides are called "ferrites" having ferromagnetic ordering of spins, and have been applied to magnetic recordings and integrated microwave devices. Meanwhile, hematite (α-Fe_2O_3) is well known antiferromagnetic iron oxide with less application as used directly in electronic devices, whereas exhibits the pinning property to fix the spontaneous magnetization of a nearest neighbor ferromagnet by an interlayer exchange coupling in the magnetic multilayers.

In the multilayers composed of ferromagnetic metal/nonmagnetic metal/ferromagnetic metal, magnetization switching between parallel and antiparallel configurations of two ferromagnetic layers leads to drastic change in electric resistance, so called "Giant magnetoresistance (GMR)". In this case, the multilayers are composed of a soft magnetic layer separated by a non-magnetic layer from a hard magnetic layer obtained by pinning due to an interlayer exchange coupling with an antiferromagnet or ferrimagnet (whose spontaneous magnetization remains in spite of cancelling among magnetic

moments), so called "spin valves" exhibit large GMR ratio at low magnetic fields. Spin valve structures have been applied to the reading head of hard disk with high recording density. Using epitaxial magnetite (Fe_3O_4), orthoferrites, and α-Fe_2O_3 as a pinning layer in spin valves, the pinning mechanism is able to be revealed due to their peculiar magnetic ordering in the crystal lattice, so thus might present interesting points for spintronics engineering and applications.

In the magnetic tunnel junctions (the multilayers composed of ferromagnetic metal/nonmagnetic insulator/ferromagnetic metal), "Tunnel magnetoresistance (TMR)" shows large MR ratio by "tunnelling effect" of spin conduction through a very thin insulator, so TMR has been applied to magnetic random access memory (MRAM). The largest TMR has been obtained using "half metal" that is the ferromagnetic conductor having the high spin-polarization as Fe_3O_4, so thus magnetic iron oxides are also expected for spintronics devices.

Many researchers have made a great effort to study spintronics using various magnetic metal oxides for practical applications, however their properties are complicated and poorly understood including exchange interaction, magnetic band structures. In Chapter 1, magnetoresistive multilayers using various iron oxides and their characteristics are discussed. At first, a brief introduction of magnetoresistive multilayers is presented. The second section shows spin valves using epitaxial spinel ferrites, hematite, orthoferrite, and multiferroic bismuth ferrite as a pinning layer, and their interlayer exchange coupling. The 3rd section is dedicated to the magnetic tunnel junctions using a half metallic Fe_3O_4 layer and the spin-dependent tunnel transport.

Problems of the electric resistance and magnetoresistance connected with the electron quantum transfer in the hydrogen atom are discussed in some detail in Chapter 2. The model suitable for examination is based on the properties of the Bohr atom extended by the presence of the quanta of the magnetic induction. These quanta, together with those of the magnetic flux, are mainly considered in the model.

The electric resistance is due to the potential interval connected with the change of the electron occupation of the quantum state in course of the energy emission by the atom. On the other hand, the magnetoresistance is an effect associated with the change of the quanta of the magnetic field due to the same emission. Evidently both resistance effects accompany the change of the electron states population in the atom.

The giant injection magnetoresistance (IMR) in SiO_2(Co)/GaAs heterostructures, where the SiO_2(Co) structure is the granular SiO_2 film with Co nanoparticles, and in TiO_2(Co)/GaAs heterostructures consisting of the amorphous TiO_2 film with Co island sublayers is studied. The IMR-effect has positive values, is expressed, when electrons are injected from the granular film into the GaAs semiconductor, and is of the temperature-peak type character. The temperature location of the effect depends on the Co concentration and can be shifted by the applied electrical field. For the SiO_2(Co)/GaAs heterostructure with 71 at.% Co the IMR value reaches 1000 (10^5 %) at room temperature, which is two-three orders higher than maximum values of GMR in metal magnetic multilayers and TMR in magnetic tunnel junctions. On the contrary, for SiO_2(Co)/Si heterostructures magnetoresistance values are very small (4%) and for SiO_2(Co) films the intrinsic magnetoresistance is equal to opposite values. High values of the IMR-effect in SiO_2(Co)/GaAs heterostructures have been explained by the spin-dependent potential barrier formed in the accumulation electron layer in the semiconductor near the interface. The action of the spin-dependent potential barrier is amplified by the avalanche process in the GaAs and by the electron accumulation in the quantum well in the semiconductor interface region induced by the backscattering process of injected electrons on exchange-splitted levels. The applied magnetic field increases the height and reduces the transparency of the barrier. Efficient magnetic sensors on the basis of ferromagnet/semiconductor heterostructures with holes traps and quantum wells containing spin-dependent potential barrier in the semiconductor at the interface are considered.

试读结束，需要全本PDF请购买 www.ertongbook.com

CONTENTS

Preface		**vii**
Chapter 1	Magnetoresistive Multilayers Using Various Magnetic Iron Oxides *Hiroshi Matsuda*	**1**
Chapter 2	Magnetoresistance Connected with Quantum Electron Transitions in the Hydrogen Atom *Stanisław Olszewski*	**57**
Chapter 3	Giant Injection Magnetoresistance in Ferromagnet/Semiconductor Heterostructures *Leonid Lutsev*	**65**
Index		**123**

In: Magnetoresistance
Editor: Russell Gonzalez, pp. 1-55
ISBN: 978-1-53610-598-8
© 2017 Nova Science Publishers, Inc.

Chapter 1

MAGNETORESISTIVE MULTILAYERS USING VARIOUS MAGNETIC IRON OXIDES

Hiroshi Matsuda*
TOY BOX GALAXY, Kyoto, Japan

Abstract

Parallel alignment of spins throughout the crystal lattice results in ferromagnetism with permanent magnetization. On the other hand, equal numbers of spins are aligned in opposite direction, results in antiferromagnetism with no permanent magnetization. A large number of iron oxides are called "ferrites" having ferromagnetic ordering of spins, and have been applied to magnetic recordings and integrated microwave devices. Meanwhile, hematite (α-Fe2O3) is well known antiferromagnetic iron oxide with less application as used directly in electronic devices, whereas exhibits the pinning property to fix the spontaneous magnetization of a nearest neighbor ferromagnet by an interlayer exchange coupling in the magnetic multilayers.

In the multilayers composed of ferromagnetic metal/nonmagnetic metal/ferromagnetic metal, magnetization switching between parallel and antiparallel configurations of two ferromagnetic layers leads to drastic change in electric resistance, so called "Giant magnetoresistance (GMR)". In this case, the multilayers are composed of a soft magnetic layer separated by a non-magnetic layer from a hard magnetic layer obtained by pinning due to an interlayer exchange coupling with an antiferromagnet or ferrimagnet (whose spontaneous magnetization remains in spite of cancelling among magnetic moments), so called "spin valves" exhibit large GMR ratio at low magnetic fields. Spin valve

* Corresponding author: Email:matsuda.hiroshi01@ms.naist.jp.

structures have been applied to the reading head of hard disk with high recording density. Using epitaxial magnetite (Fe3O4), orthoferrites, and α-Fe2O3 as a pinning layer in spin valves, the pinning mechanism is able to be revealed due to their peculiar magnetic ordering in the crystal lattice, so thus might present interesting points for spintronics engineering and applications.

In the magnetic tunnel junctions (the multilayers composed of ferromagnetic metal/nonmagnetic insulator/ferromagnetic metal), "Tunnel magnetoresistance (TMR)" shows large MR ratio by "tunnelling effect" of spin conduction through a very thin insulator, so TMR has been applied to magnetic random access memory (MRAM). The largest TMR has been obtained using "half metal" that is the ferromagnetic conductor having the high spin-polarization as Fe3O4, so thus magnetic iron oxides are also expected for spintronics devices.

Many researchers have made a great effort to study spintronics using various magnetic metal oxides for practical applications, however their properties are complicated and poorly understood including exchange interaction, magnetic band structures. In this chapter, magnetoresistive multilayers using various iron oxides and their characteristics are discussed. At first, a brief introduction of magnetoresistive multilayers is presented. The second section shows spin valves using epitaxial spinel ferrites, hematite, orthoferrite, and multiferroic bismuth ferrite as a pinning layer, and their interlayer exchange coupling. The 3rd section is dedicated to the magnetic tunnel junctions using a half metallic Fe3O4 layer and the spin-dependent tunnel transport.

1. Background

1.1. Magnetoresistance and Spintronics

"Spintronics" is defined as electronics using spins of an electron. Spin has a parity of up (↑) and down (↓), whose density of state (DOS) imparts the magnetism of materials. Developing the fabrication technology of nanomaterials and microfablication processes, it has been possible to observe a number of quantum mechanical phenomena related between charge and spin of an electron. The phenomenon changing in the electroic resistance of magnetic conductors by applying the magnetic field is known as "Magnetoresistance (MR)", that has been applied to magnetic sensors, reading heads of hard disk drive (HDD), and non-volatile memory devices not only physics of MR have been studied [1]. In these spintronics devices, the change in resistance of thin film MR devices shows the digital information, for example, high resistance state as "0", or low resistance state as "1" as shown in Figure 1.

It is needed to enhance MR (output signal) of reading heads for increament of the magnetic recording density. Giant magnetoresistance (GMR) was discovered in 1988 on Fe/Cr magnetic multilayers that showed high MR values over 10% at

room temperature [1-2], results in the realization of high density magnetic recording. Additionally, for the feasibility of magnetic random accese memory (MRAM) that shows non-volatile, fast reading, and low energy cost, over 100% MR ratio is needed. Thus the properties of spin-dependent transport which shows larger MR ratio than GMR one had been studied. Tunnel magnetoresistance (TMR) is observed in the magnetic tunnel junctions composed of two ferromagnetic layers separated by a very thin tunnel barrier. TMR effects results from the variation of the tunnel conductance when the magnetization configurations of the ferromagnetic electrodes goes from anti-parallel to parallel state with field applying, so the MR ratio is very large over 100% [3]. The property has been intensively studied since 1995, when Miyazaki's group found a large TMR ratio at room temperature for a $Co/Al_2O_3/NiFe$ junction [4].

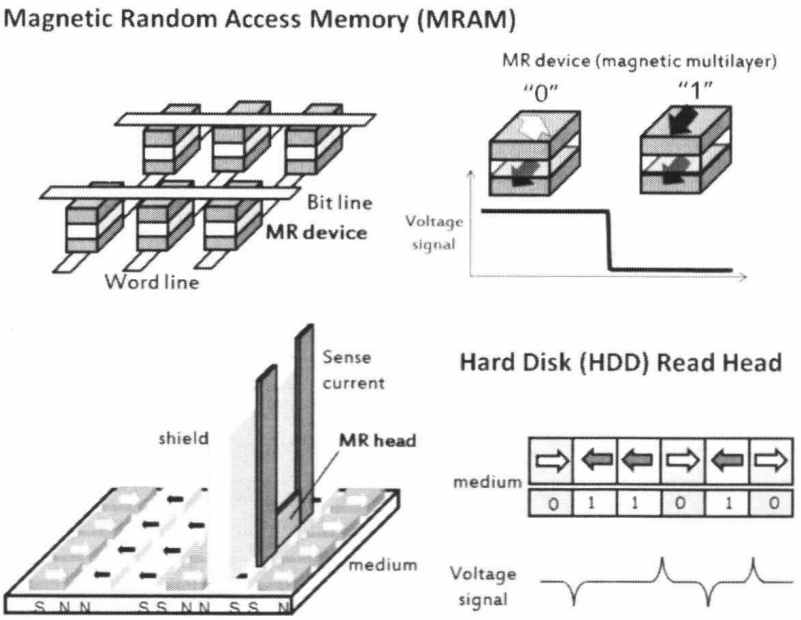


Figure 1. Magnetoresistive devices. (above) magnetic random access memory (MRAM) using tunnel magnetoresistive elements, (below) hard disk reading head using spin valves.

As shown in Figure 1, GMR and TMR are based on the principle that the electric resistance changes by switching between anti-parallel and parallel configurations of magnetizations of the ferromagnetic conductors in the magnetic multilayers composed of ferromagnetic and non magnetic layers with nano-metre thickness. For the enhancement of MR ratio of GMR and/or TMR, an appropriate magnetic material must be selected and used in the magnetoresistive multilayer

[1]. For the ferromagnetic layers, it is needed to use the high spin poralized materials such as iron (Fe), cobalt (Co), their alloys, and metal oxides. For the non magnetic layers, copper (Cu) where a spin of the conduction electrons coming from a neighbor ferromagnetic layers is preserved, and very thin alumina (Al_2O_3) or magnesia (MgO) where a spin-dependent electron can be tunneling, are appropriated [1]. Applying "pinning" layers which pins to the direction of the magnetization of a neighbor ferromagnetic layer in the "spin valves", antiferromagnetic and/or ferrimagnetic materials which have peculiar spin orders in their crystals might be selected [5], so thus various magnetic iron oxides show the interesting MR properties.

1.2. Magnetic Iron Oxides

1.2.1. Magnetite and Related Spinel Ferrites

Magnetite (Lodestone, Fe_3O_4) belongs to a class of ferrites and is known as the oldest magnet since ancient Greece and Egypt. Magnetite had been used for the compass, also appeared in the book "De Magnet" written by William Gilbert in 17th century England [6]. Ferrites have been applied to electronics using an antenna, magnetic core, and magnetic recording media.

Spinel ferrites have the inversed spinel structure (Fd3m, crystal lattice constant a=8.3~8.4Å) at room temperature, and peculiar arrangements of iron and oxygen ions. Iron ions are distinguished between A-site (Fe^{3+}) surrounded by four oxygen atoms and six oxygen coordinated B-site, where both iron ions Fe^{2+} and Fe^{3+} have composition ratio of 1:1, are placed randomly [7]. According to Louis Néel, strong magnetic coupling called "super-exchange interaction" between A- and B-site through oxygen occur in the magnetite crystal, where cancelling the magnetic moments each other show "ferrimagnetism" as shown in Figure 2. As a result a net magnetic moment has $4\mu_B$ (μ_B: Bohr magneton), saturation magnetization of 480 emu/cm^3 [7-8]. Curie temperature (ferromagnetic to non-magnetic transition temperature) is very high (T_C=860K), so Fe_3O_4 has a spontaneous magnetization at room temperature. Since ferrimagnetism is observed in the magnetic structure, magnetite and related spinel iron oxides have both the nature of ferromagnetic and antiferromagnetic properties. Thus, they are expected as GMR pinning layer, which pin the nearest neighbor ferromagnetic layer in spin valve magnetoresistive devices, leading to high MR ratio.

Fe_3O_4 has the electrical conductivity ($4 \times 10^{-3}\Omega$cm at room tempreature). This reason is that free electrons of B-site iron ions are easy to move between Fe^{2+}

试读结束，需要全本PDF请购买 www.ertongbook.com