1. Tunneling magnetoresistance from a symmetry filtering effect

William H Butler

This paper is about:
Exploiting the ‘spin’ as well as the charge of electrons shows potential for the realization of novel non-volatile memories and high sensitivity magnetic sensors. In this review, William Butler of the Center for Materials for Information Technology and Department of Physics, University of Alabama, USA gives a detailed explanation of the physical mechanisms of tunneling magnetoresistance (TMR) devices with emphasis on the preferential transmission of wavefunctions with certain symmetries. Other topics covered include giant magnetoresistance (GMR) and spin-torque; applications, including read sensors for hard disks and magnetic random access memory and logic circuits.

What the authors say: Latest views from materials scientists and engineers

The prediction and discovery of symmetry based spin filter tunneling magnetoresistance has had a significant impact on magnetic storage. I am told that all hard drives sold today take advantage of this discovery to read the stored data. It has also ignited interest in a new type of solid-sate memory called spin-torque switched magnetic random access memory. The larger lesson, in my opinion, of this particular discovery is the importance of obtaining a fundamental understanding of materials and their properties. It is also important to recognize that sometimes we are lucky and nature is kind. We did not expect that this materials set would be amenable to sputter processing when we proposed it.

2. Spin current, spin accumulation and spin Hall effect

Saburo Takahashi and Sadamichi Maekawa

What the authors say: Latest views from materials scientists and engineers

Modern information technology is based on semiconductor and ferromagnetic materials. Information processing and computation are performed using electron charge by semiconductor transistors and integrated circuits, and the information is stored on magnetic high-density hard disks by electron spins. Recently, the so-called spin electronics or spintronics has rapidly emerged as a new branch of physics and nanotechnology, aiming at simultaneously exploiting both charge and spin of electrons in the same device. Our primary goal is to develop new functionality that emerges from nano-structured devices combined with ferromagnets, metals, and semiconductors and to present new directions in the development of spin electronics in both basic physics and technology which will become the foundation of future electronics.
3. **Rational design of new materials for spintronics: Co$_2$FeZ (Z=Al, Ga, Si, Ge)**

Benjamin Balke, Sabine Wurmehl, Gerhard H Fecher, Claudia Felser and Jürgen Kübler

**This paper is about:**

Materials known as ‘Heusler compounds’—ternary intermetallics (half-metals) such as Co$_2$FeSi, with a 2:1:1 stoichiometry and composed of two transition metals (Co, Fe) and a main group element such as Si—are important for the development of ‘spintronic’ devices because they show high spin polarization and Curie temperatures above room temperature.

Here, Benjamin Balke, Sabine Wurmehl, Gerhard H Fecher, Claudia Felser of the Institut für Anorganische Chemie und Analytische Chemie, Johannes Gutenberg-Universität Mainz, Germany and Jürgen Kübler of the Institut für Festkörperphysik, Technische Universität Darmstadt, Germany, describe the latest developments in research on Heusler materials. The review includes, a theoretical assessment of electron spin polarization at the Fermi level of materials; crystal structure; theory and experimental results of research on Co$_2$FeZ (Z=Al, Ga, Si, or Ge); role of correlation in the Heusler compounds Co$_2$MnSi and Co$_2$FeSi; and experiments on Co$_2$Mn$_{1-x}$Fe$_x$Si, Co$_2$FeAl$_{1-x}$Si$_x$, and Co$_2$FeGa and Co$_2$FeGe. The review includes 14 figures and 96 references.

**What the authors say: Latest views from materials scientists and engineers**

Spintronics is an emerging field where both the electric charge and the spin of conduction electrons are used, and has been developing rapidly after the discovery of giant magnetoresistance effect in metallic magnetic multilayers. The performance of spintronics depends on spin polarization of the current. Therefore, highly spin polarized current source is strongly desired in spintronics. The use of half-metallic ferromagnets (HMFs) with 100% spin polarization is a typical approach for this purpose. In particular, Co-based full-Heusler alloys with a chemical form of Co$_2$YZ and L2$_1$ structure potentially become half-metallic even at room temperature. A spin filtering device using a ferromagnetic barrier such as insulating Co-ferrites is also a promising candidate. The successful incorporation of these materials in tunneling magnetoresistance (TMR), current perpendicular to plane (CPP)-GMR and spin injection into semiconductors will provide a new generation in spintronics with high performance and new functions.

4. **Highly spin-polarized materials and devices for spintronics**

Koichiro Inomata, Naomichi Ikeda, Nobuki Tezuka, Ryogo Goto, Satoshi Sugimoto, Marek Wojcik and Eva Jedryka

**This paper is about:**

A high degree of spin polarization is important for the realization of ‘spintronic’ devices, whose operation is governed by electron-spin. Needless to say, there is tremendous interest in research on the search for materials exhibiting high spin polarization and with Curie temperatures above 300 K. Materials known as ‘Heusler compounds’ have received attention because Heusler and colleagues showed Cu2MnAl to be ferromagnetic even though none of its constituents is ferromagnetic by itself.

Here, Koichiro Inomata and colleagues from NIMS, Satoshi Sugimoto of Tohoku University and Marek Wojcik and coworkers of the Polish Academy of Sciences describe the latest experimental results on research on half-metallic Co-based full-Heusler alloys and spin filtering devices with ferromagnetic barriers. The authors focus on the deposition and crystalline structure and magnetic properties of Co-based full-Heusler alloys: Co$_2$Cr$_{1-x}$Fe$_x$Al and Co$_2$FeSi$_{1-x}$Al$_x$. These compounds showed giant tunnel magnetoresistance of up to 220% at 300 K and 390% at 5 K for the magnetic tunnel junctions using Co$_2$FeSi$_{0.5}$Al$_{0.5}$ Heusler alloy electrodes. The review includes 34 figures and 43 references.

**What the authors say: Latest views from materials scientists and engineers**

Spintronics is an emerging technology, for which the materials and the properties of the interfaces of different materials have to be taken into account. The importance of the field was recently documented by awarding the Nobel prize to Peter Grünberg and Albert Fert. Half metallic Heusler compounds, showing a high spin polarization of the conduction electrons of up to 100% in tunnel junctions become more and more important. High Curie temperatures were found in Co$_2$-Heusler compounds with values up to 1120 K in Co$_2$FeSi. Ferrimagnetic Mn$_2$-Heusler compounds are candidates for spin torque application, because of their low magnetic moments, their low Gilbert damping constant despite their high Curie temperatures. The greatest challenge of the future is to find suitable spacer layers for different applications such as CPP-GMR and spin transfer devices, for example.
5. Optics of high-performance electron microscopes
H H Rose

This paper is about:

Electron microscopes are ubiquitous. With a spatial resolution of about one thousand times greater than their optical counterparts, electron microscopes are indispensable for imaging in materials science. The foundations of modern electron microscopy were laid in the 1920s by the imagination of Louis de Broglie and Hans Busch’s observation that magnetic fields affected the trajectories of electrons—like a convex glass lens bends light rays. These early ideas and experiments led Ernst Ruska to design and build electron microscopes which later became de-facto standards of modern-day instruments.

In this article, Harald Rose of the Darmstadt University of Technology, Germany describes the development and future of electron microscopes based on the concepts of light optics. The contents are centered on the underlying theoretical analysis for modeling the components of electron microscopes, such as the design of aberration correctors, imaging energy filters, monochromators and quadrupole systems with very small focal length. Each of the sections contains a detailed theoretical analysis of subject matter. For example, charged particle trajectories are described using the well known Lagrange variational principle and the use of ‘theorem of alternating images’ for modeling the location of images produced by particle trajectories in a transmission electron microscope. The author envisions that future electron-optical instruments will reach a degree of perfection comparable to that attained in light optics. With 32 figures and 39 references this paper offers a comprehensive theoretical analysis for the design of ultra-high performance electron microscopes.

What the authors say: Latest views from materials scientists and engineers

During the last decade the electron microscope has evolved into a high-performance analytical instrument providing sub-micron spatial resolution as well as chemical and electronic information on an atomic scale. These remarkable advancements have primarily been due to the development of several novel electron-optical components such as the monochromator, highly dispersive aberration-free imaging energy filters, and correctors compensating for the unavoidable chromatic and spherical aberrations of the standard rotationally symmetric electron lenses.

The realization of these components was only possible due to advances in the theory of electron optics and use of fast computers for the final design. Moreover, computer aided procedures have been developed enabling a fast and precise alignment of the many elements of the novel compound systems. The successful incorporation of the components in highly stable standard instruments will provide a new generation of analytical electron microscopes with an energy resolution of several tens of milli-electron volts and sub-micron spatial resolution.

6. Present status and future prospects of spherical aberration corrected TEM/STEM for study of nanomaterials
Nobuo Tanaka

This paper is about:

In the field of optics a perfect lens gathers incident rays of light and focuses them to a single point—referred to as the ideal focal point (IFP)—on the optical axis of the lens. However, a real convex-lens focuses light incident at its edges at a point close to itself (at a distance nearer than the IFP) and, conversely, light incident near its center at a point further away from the IFP. This deviation from the ideal focal point is known as ‘spherical aberration’. Similar problems exist in electron microscopes and in particular, spherical aberration can drastically reduce the ultimate resolution of transmission electron microscopes (TEM).

Here, Nobuo Tanaka of EcoTopia Science Institute, Nagoya University, Japan describes recent developments in spherical aberration (Cs) corrected TEM and scanning TEM (STEM) instruments. Following a review of the advantages of TEM over conventional X-ray diffraction for real-space analysis of materials containing defects and fluctuations in their crystalline structure, the author describes the development of spherical aberration correctors that have improved the point-to-point resolution of TEM from 0.2 to 0.1 nm. The topics covered include methods for improving point-to-point resolution and producing sharp interface images without Fresnel fringes; use of Z-slice imaging by Cs-corrected TEM for analysis of single-wall carbon nanotubes and Pt-Rh chain molecules; and the features and advantages of Cs-corrected STEM and 3D observation of atomic objects. With 19 figures and 33 references this review provides a wealth of experimental knowledge on the analysis of a wide selection of nanomaterials by Cs-TEM/STEM.

What the authors say: Latest views from materials scientists and engineers

Clarifying the relationship between the structure and physical properties of nanomaterials—such as carbon nanotubes, quantum dots—is one of the most important areas of research in the 21st century. Compared with X-ray diffraction analysis, electron microscopy has a unique advantage in being able to extract non-averaged structural and elemental information from a wide range of materials. In particular, the recent development of aberration correctors and monochromators has opened up a new field of research with a resolution less than 0.1 nm. As a research tool, electron microscopy has reached ‘picometer resolution’ and correction of third-order spherical aberration has already been implemented in commercial TEM/STEM instruments.

One of the next targets in the development of electron microscopes is to study ways of correcting chromatic and higher-order spherical aberrations in order to produce an ultimate resolution approaching 0.01 nm—equivalent to 10 picometers.
7. Nanofabrication by advanced electron microscopy using intense and focused beam
Kazuo Furuya

This paper is about:

Two distinctly different approaches are widely used for fabricating nanostructures and nanodevices. Specifically, ‘top-down’ strategies, where nanostructures are produced by lithography and etching of macroscopic structures and, ‘bottom-up’ methods, which exploit ‘self-assembly’ of components such as hydrogen bonding of molecules. However, there is potentially a third approach that combines the advantages of both the ‘bottom-up’ and ‘top-down’ methods.

Here, Kazuo Furuya of the High Voltage Electron Microscopy Station, National Institute for Materials Science, Tsukuba, Japan describes the versatility of high speed electron-beam-induced deposition (EBID) for maskless fabrication of nanostructures—such as magnetic nanodots—where gas molecules are decomposed with a beam of highly focused electrons in specimen chambers of high resolution electron microscopes. The article contains details about the use of EBID for the growth of freestanding nanotrees on insulator substrates by TEM; exploitation of scanning TEM (STEM) for controlling the position and size of nanostructures such as iron ‘nanomagnets’ deposited by electron beam decomposition of iron-containing precursor gas, Fe(CO)5; and the effect of the electron microscope vacuum on the size and growth process of tungsten nanodots in an ultrahigh-vacuum field-emission TEM. The smallest nanostructure produced was about 1.5 nm in diameter, which is the smallest size ever reported using this method. The author concludes by describing the development of an ultrahigh-vacuum spherical aberration corrected STEM at NIMS. The 36 figures and 94 references are an invaluable description of the development and challenges for the application of ultra-high resolution electron microscopes for fabrication and in-situ evaluation of 2D and 3D nanostructures on a wide range of substrates.

What the authors say: Latest views from materials scientists and engineers

Aberration corrected (Cs) scanning transmission electron microscopes (STEM) produce highly focused electron probes with high probe currents, which enables high speed electron microscopy. These STEM systems can also be used for electron beam induced deposition (EBID) of nanostructures. During EBID the interaction of gas molecules with incident electrons near the material surface leads to the ‘in-situ’ formation of novel metallic nanostructures; the electron beam controls both the nucleation and growth processes. A serious drawback with high energy, focused electron beam deposition is contamination of specimens during observation and analysis. Ultrahigh-vacuum TEM (UHV-TEM) is a potential solution to this problem.
8. Electrochromic materials using mechanically interlocked molecules
Taichi Ikeda and James Fraser Stoddart

This paper is about:

Novel organic materials are increasingly being used for the development of light, flexible and inexpensive electronic devices such as electronic paper displays (E-PADs). Organic materials are particularly promising because they are electrochromic materials—namely, they change color when an electric voltage is applied to them.

Here, Taichi Ikeda of the Functional Modules Group, Organic Nanomaterials Center, NIMS, and James Fraser Stoddart of the California NanoSystems Institute and Department of Chemistry and Biochemistry, University of California, Los Angeles, USA, describe the properties and applications of electrochromic materials composed of mechanically interlocked molecules—a unique type of electrochromic materials initially proposed by the authors. Mechanically interlocked compounds consisting of a pair of mutually interlocked ring components are referred to as catenanes—from the Latin, ‘catena’, meaning ‘chain’. After an in-depth introduction, the authors describe color tuning; thermodynamics; electrochemistry; molecular design; electromechanical behavior of RGB14+ and RGB24+; and electrochromism in polymer and gel matrices. This review contains six figures and 38 references.

What the authors say: Latest views from materials scientists and engineers

The principle behind conventional electrochromic materials has been based on color changes of the chromosphere by either oxidation or reduction. In our review, we outline the design and synthesis of electrochromic materials based on switchable three-station donor-acceptor [2]catenanes. The color change is controlled at the molecular level by employing a uniquely crafted design. The tetracationic cyclophane, cyclobis(paraquat-p-phenylene), which serves as the π-electron deficient ring, circumrotates between three different π-electron rich recognition sites located within a macrocyclic polyether, generating the three different primary colors (Red, Green and Blue, RGB) produced by charge-transfer interactions between the cyclophane and recognition sites, which are 1,5-dioxynaphthalene (R), tetrathiafulvalene (G) and benzidine (B) units. Practical issues relating to the realization of an RGB [2]catenane are discussed at length in the review: (1) color tuning, (2) thermodynamic considerations, (3) electrochemistry on model compounds, (4) molecular design, (5) the electrochemical behavior of three-station [2]catenanes, and (6) electrochromism in polymer gel matrices.

9. Chemistry and application of flexible porous coordination polymers
Sareeya Bureekaew, Satoru Shimomura and Susumu Kitagawa

This paper is about:

Chemists are studying the properties of porous coordination polymers (PCPs)—three dimensional structures consisting of coordination bonds of metal ions and organic ligands—for wide ranging applications including catalysis, storage of gases, ion exchange and separation, and polymerization. The structural regularity, high porosity, large surface area, and design flexibility of PCPs are features that give these materials important advantages over zeolites.

Here, Sareeya Bureekaew, Satoru Shimomura and Susumu Kitagawa of the Department of Synthetic Chemistry and Biological Chemistry, Graduate School of Engineering, Kyoto University, Japan describe the chemistry and applications—such as gas storage—of flexible crystalline PCPs. The review covers areas that include, methods used for synthesis; classification; the unique properties of flexible PCPs; structural transformation of flexible PCPs by guest molecules; and adsorption properties and applications for storage and trapping gases. With 12 detailed figures and 74 references, this review is an excellent introduction to the present status and potential of this exciting field of research.

What the authors say: Latest views from materials scientists and engineers

In the past decade, an upsurge of attention has been paid to porous coordination polymers (PCPs) or metal organic frameworks (MOFs) as novel porous materials for various applications such as gas storage, separation, heterogeneous catalysis, magnetism, and conductivity, due to their well-defined structures and rational design. Previously, we tried to synthesize PCPs with open structured accompanied with high surface area. However, recently, to develop competency of PCPs, not only the above requirements but also flexibility, unable to find in conventional porous materials such as zeolites and activated carbons, has been concerned. Because of this dynamic property, flexible PCPs can respond to external stimuli differently. Using this unique properties, PCPs could open up new frontiers for chemists.
10. Metallo-supramolecular modules as a paradigm for materials science
Dirk G Kurth

This paper is about:

Supramolecular scientists exploit noncovalent interaction of molecules—by for example hydrogen bonding, van der Waals forces and electrostatic binding—for construction of nanostructures and related devices. A major challenge for the evolution of ‘supramolecular based self-assembly’ is the development of general approaches to collect and arrange nanometer sized components in the form the surface-confined structures.

Here, Dirk Kurth of National Institute for Materials Science, Tsukuba, Japan and Max Planck Institute of Colloids and Interfaces, Potsdam, Germany describes the potential of nano-building blocks composed of metallo-supramolecular modules for fabrication of active components in functional nanomaterials. Embedding metal ions in appropriate ligand fields offers a wide range of physical and structural properties that for active components in functional materials. The areas covered include metallo-supramolecular polymers (thin films, mesophases, langmuir monolayer and LB multilayers, nanostructures) and polyoxometalates (ultra thin films, surfactant-encapsulated POM cluster, and LB films). The review contains 159 references and 32 figures.

What the authors say: Latest views from materials scientists and engineers

In recent years chemical materials science has matured into a quickly evolving field of its own. Much progress has been made in combining molecular components into supramolecular architectures, which in turn have been introduced into varying device designs. The methods of molecular recognition and self-assembly have been explored in many ways to combine functional supramolecular modules giving rise to many potentially useful materials with novel functions. Now the move is onto responsive systems capable of adapting structure and function to external stimuli. Mendable materials exhibit the ability to undergo self-repair. While such systems are based on equilibrium thermodynamics the development of active systems and materials is going to be the next major breakthrough in this area. So, while we regularly witness exciting developments it has already become clear that the full potential of chemical materials science is just beginning to unfold.

11. Challenges and breakthroughs in recent research on self-assembly
Katsuhiko Ariga, Jonathan P Hill, Michael V Lee, Ajayan Vinu, Richard Charvet and Somobrata Acharya

This paper is about:

The ‘lock-and-key’ self-assembly of supramolecular structures facilitated by supramolecular chemistry—interaction of molecules via noncovalent bonding—is a critical feature of the ‘bottom-up’ approach for synthesis of molecular nanodevices.

Here, Katsuhiko Ariga and colleagues from the World Premier International, Research Center for Materials Nanoarchitectonics, NIMS, describe recent trends in supramolecular self assembly. Three areas are covered: (1) Self-assembly in bulk media. Here the topics described are small molecule assembly; porous crystals by metal coordination and hydrogen bonding; lipid assembly; gels and liquid crystals; structure-transcribed material; macroscopic assembly. (2) Types of components required for self-assembly in bulk media. The emphasis is on small molecule assembly; porous crystals by metal coordination and hydrogen bonding; lipid assembly; gels and liquid crystals; structure-transcribed material; macroscopic assembly; porphyrin; fullerene and graphene; other small molecules; polymers; biomolecules; and inorganic substances. (3) The final section is on self-assembly at interfaces which describes langmuir-blotchet films; layer-by-layer assembly; self-assembled monolayers; molecular arrays and material arrays on surfaces. This article contains 127 figures and 1030 references.

What the authors say: Latest views from materials scientists and engineers

Although naturally-occurring systems already possess excellent nanosystems, we have tried to create nanostructures through totally different concepts. The latter methodologies rely much on fabrication techniques that provide micro and nanostructures from bulk materials and are generally called “top-down” approach. As some parts of readers may know, this strategy is going to encounter certain fundamental limitation in structural precision, material variety, and so on. We now re-realize excellent processes conducted by nature (bio-system) where all the sophisticated functional structures are constructed through “self-assembly” in bottom-up fashion. It is high time to seriously introduce bio-like “self-assembly” into nanotechnology and other technologies for advanced materials. Fortunately, huge research data on self-assembly have already been accumulated as scientific knowledge in some kinds of chemistries such as supramolecular chemistry and biomimetic chemistry. Applying these accomplishments, what we wrote in this review, into practical material technology lead to new challenges and breakthrough in nanotechnology.