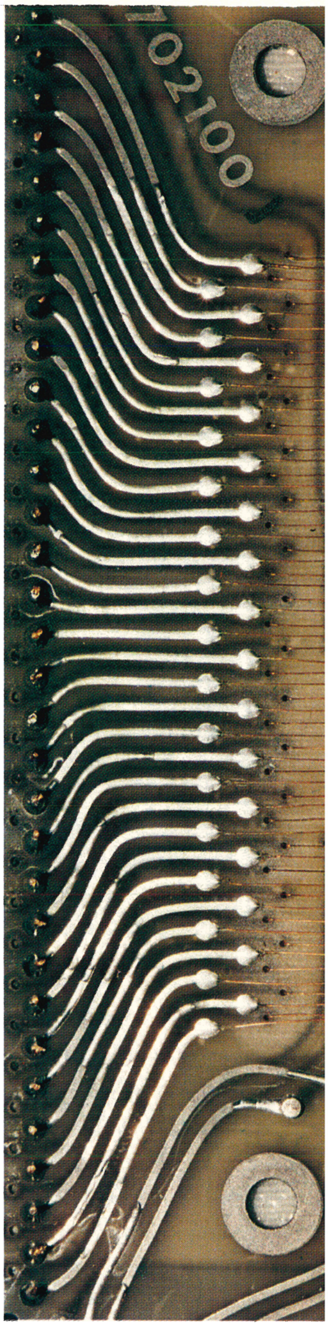


SPECIAL ISSUE:

MAGNETOELECTRONICS

Magnetism abounds with dichotomies: It was known to the ancients and yet is the focus of exciting new research; its manifestations are apparent to every schoolchild yet its origins are rooted deep in quantum mechanics and relativity; its applications underlie huge industries yet its understanding—even in iron—is still incomplete.

Humans have wondered about and used magnetism since the discovery of lodestone more than 4000 years ago. Magnetic materials in motors and generators were essential to the electrical revolution of the 19th century. The first computer memories used ferrite toroids, and data storage still relies on magnetic disks and tapes. Credit and cash cards, antishoplifting tags and kitchen magnets for affixing artwork to refrigerator doors provide daily contact with magnetic materials.

Despite this historical and broad utility, magnetic materials research has lagged behind fields such as semiconductors in the exploration of novel, artificially created atomic- or nano-scale structures. The reason lies in the relevant length scales: Cooperative magnetic behavior derives from electron exchange—and the exchange lengths in most magnetic materials are only a very few atomic spacings. Thus, whereas semiconductors exhibit novel behavior at carrier lengths of tens of nanometers, magnetic material structures must be controlled at the scale of a nanometer or less. It is only in the last few years that advances in atomic-scale growth and characterization methods have produced structures that reveal fascinating new magnetic phenomena. We stand today on the verge of a "magnetoelectronics" revolution, in which these new phenomena will be not only explained but also exploited, in devices combining magnetism with traditional electronic elements.

This year is an anniversary of a sort for the magnetism community in the United States. We will hold the 40th meeting of the Conference on Magnetism and Magnetic Materials, which brings together researchers in both fundamental and applied magnetism, under the joint sponsorship of the American Institute of Physics and the Institute of Electrical and Electronics Engineers. A look at the older proceedings shows that while enormous progress has been made in many areas, a complete understanding of itinerant magnetism in metallic materials has remained elusive. The study of magnetoelectronics, with its focus on the properties of mobile *magnetic* electrons, may provide the key to this long-standing puzzle.

In choosing the articles for this issue we regretfully have had to omit some exciting topics in magnetic materials, such as new permanent magnets and the appearance of chaotic and nonlinear magnetic behavior. We have also not attempted to review the rapidly developing techniques for atomic-scale growth and structural characterization that are essential to produce the materials discussed here. We do, however, hope that the articles presented here will answer the following questions about magnetoelectronics:

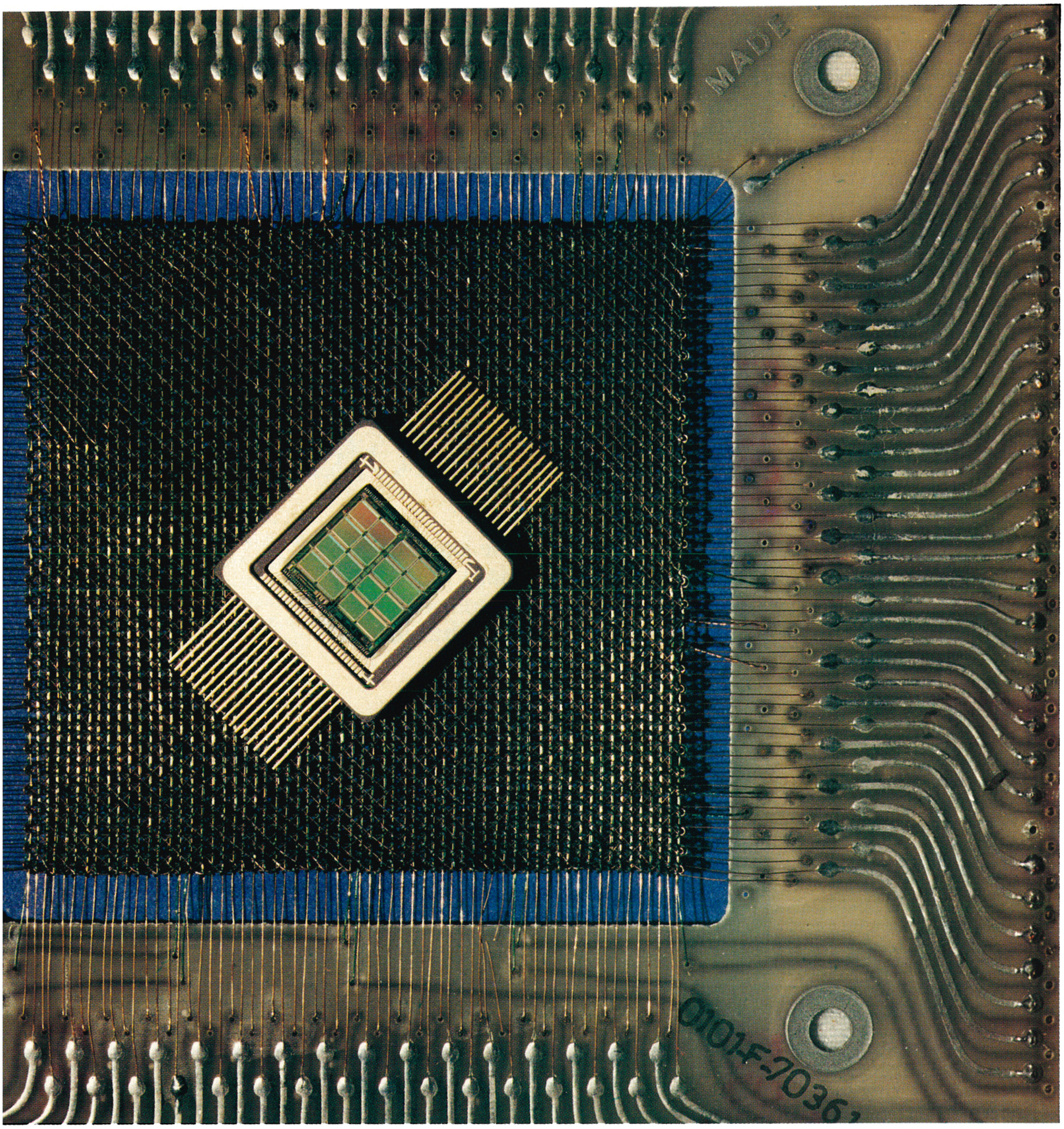
How small is small? In their article (page 43), David Awshalom and David DiVincenzo explore the fascinating world of small magnetic structures down to the nanometer regime and reach the surprising conclusion that some of the most ideal structures are produced by biological systems.

How can we observe and model magnetic behavior at these length scales? J.-G. Zhu and E. Dan Dahlberg (page 34) describe not only calculations that push the limits of modern supercomputing, but also imaging techniques that push the limits of optical and electron resolution. Biological magnets show up here, too; magnetic bacteria produce useful systems for quantifying images.

What can we predict about these systems from first principles? Henri Jansen also describes ways of taxing supercomputing capabilities (page 50). In solids the imbalance of electron spins, which is favored by Hund's rules, must compete with hybridization energies, which favor equal filling of spin states. The delicate energy balance that determines the existence of magnetism requires extremely precise numerical calculation. And the spin–orbit energy, which determines such useful magnetic properties as magnetic anisotropy and magneto-optical activity, is even more difficult to calculate.

What new behaviors occur in these systems? An imbalance of electron spins leads inevitably to the possibility of spin currents; this in turn leads to the idea of electronic devices based not on electrons and holes driven by electric fields, but on spin-up and spin-down electrons biased and controlled by internal magnetic fields. In his article (page 58), Gary Prinz describes some of the surprising and elegant experiments that are beginning to reveal the mysteries of spin currents. The excitement surrounding the discoveries in 1988 of giant magnetoresistance and in 1993 of colossal magnetoresistance may be put into perspective by noting that the absolute change in resistance produced by an applied magnetic field in the CMR oxides is even greater than that produced by cooling a high-temperature superconductor through its superconducting transition temperature.

How will this impact technology? The article by John Simonds (page 26) documents the dramatic reduction of feature sizes for storing



MICHAEL SAVELL, NRL

A MODERN MRAM (MAGNETORESISTIVE RANDOM-ACCESS MEMORY) CHIP from Honeywell, capable of storing 16 kilobits, is seen in this photo resting on an older, one-kilobit ferrite core memory, manufactured circa 1965 by Control Data Corporation.

information bits and predicts what the future might look like. Research in magnetic materials has long been characterized by unusually rapid transitions to technology. Nowhere is that more true than in information storage and processing, where insatiable consumer demand for higher densities, combined with commodity pricing, requires industry to exploit the latest research discoveries very aggressively. Giant magnetoresistance, though discovered only seven years ago, is commercially available today in a sensor packaged on a microchip and will soon be applied in magnetic disk read heads.

It is our hope that the articles presented in this issue, progressing from practical devices to fundamental theory, will offer the reader opportunities to assess the current state of research in magnetoelectronics and to share the sense of excitement enjoyed by those who are actively exploring this field.

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