Preface

The origins of the International Business Machines Corporation can be traced to Herman Hollerith, who founded the Tabulating Machine Company in 1896 to classify census data using card readers that sensed holes punched in the cards. After merging with two other companies, the Computing Scale Company and the International Time Recording Company, the Computing–Tabulating–Recording Company, or C–T–R, was formed in 1911. In 1924, the name of the company was changed to International Business Machines Corporation, or IBM, as business expanded to overseas markets.

From its inception to its leadership in e-business at the close of the millennium, IBM has played an active role in the myriad steps of the evolution of information technology. Since 1957, much of this work has been chronicled in the *IBM Journal of Research and Development*. During this time, IBM and the information technology industry have been transformed several times, fueled by technological innovations in electronics, such as the replacement of vacuum tubes with discrete transistors in the late 1950s, the integration of transistors onto a single silicon substrate as integrated circuits in the 1960s, and the change from bipolar transistors to field-effect transistors in the 1980s and 1990s. Paralleling the changes in logic circuitry have been equally important changes in volatile and nonvolatile storage systems and in computer architecture. In conjunction with these innovations, exploratory research has yielded products, such as lasers, that have been incorporated into the technology.

There is insufficient space to describe all of the contributions from IBM's research and development community, but the included selections illustrate some of the prominent highlights of work performed in the creation, development, and evolution of computers. This retrospective double issue reprints 27 of the many papers published in the *Journal* during the past 43 years.

The first five papers highlight innovations in computer architecture. In 1957, the Random Access Memory Accounting and Control (RAMAC*) machine revolutionized data storage in computers by storing data on rotating hard disks from which it could be retrieved in less than one second. Today, most data in computers is stored on hard disks. The logical organization of the RAMAC machines and this first commercial application of magnetic disk storage are described, respectively, in the papers by Lesser and Haanstra (1957) and by Noyes and Dickinson (1957). The RAMAC machine was one of the last systems to use vacuum tubes, which were replaced with transistors by 1959, leading to the development of computers with much greater complexity. In 1964, IBM began replacing earlier lines of computers with System/360*. This was the first family of computers built with a single architecture that used interchangeable software and peripheral equipment, designed to be forward- and backward-compatible with other systems, and with facilities suitable for scientific, commercial, and real-time applications. Amdahl et al. (1964) discuss the System/360 design philosophies and the engineering problems encountered in making this system compatible with both large and small models. Today, IBM's largest general-purpose machines, System/390*, are namesakes of the System/360 and still retain many of its innovations. As technology advanced, efforts were made to optimize large-machine performance. In the mid-1970s, Cocke recognized that concepts directed at improving the performance of large computers could be applied to smaller machines. The 801 minicomputer, referred to as the Reduced Instruction Set Computer (RISC), is described in papers by Radin (1982) and by Cocke and Markstein (1990). It was designed using a central processing unit containing a small, uniform set of instructions which were executed with maximum speed and efficiency. Today's IBM PowerPC* microprocessors are based on RISC architecture.

The next nine papers address various aspects of solid-state technology that enabled the full realization of the system architectures by continuously reducing costs and significantly improving system reliability and performance. Solid Logic Technology, or SLT, discussed in the paper by Davis et al. (1964), provided the basis for development of monolithic integrated circuits at IBM. The modular SLT packaging introduced improvements in circuit cost, performance, reliability, and density over previous packaging systems and was subsequently used with much higher circuit densities. Information technology continued to advance as components were miniaturized. Critchlow et al. (1973) described the design and characteristics of field-effect transistors (FETs), devices that would dominate information technology by the end of the twentieth century. Although the use of bipolar transistors was continued for many years for the highest-performance logic, the high device densities enabled by combining FETs into complementary metal–oxide–semiconductor (CMOS) circuits fueled the microprocessor revolution that dominates virtually all digital logic chips today. The physical limits of miniaturization, first considered by Landauer in IBM in 1960, were examined by Keyes (1988), who reviews trends obtained from miniaturized components and compares them with the earlier work.

While the base transistor technology was evolving, various materials and engineering issues had to be solved for progress in the industry to continue. For example, electromigration in aluminum wiring—the current-induced motion of metal atoms in the electrical interconnections between transistors in integrated circuits—caused chip failures as the thickness of aluminum interconnections was reduced. In their studies, Ames et al. (1970) discovered that the introduction of about 4% copper into the aluminum lines greatly reduced the susceptibility of aluminum to electromigration, thereby eliminating this major problem. To decrease the terminal spacings in module substrates, the "controlled collapse chip contact," or C4, chip joining process was developed, as described by Miller (1968). Instead of using copper balls as wiring for connections between the integrated circuit chips and the substrate, a localized volume of solder was substituted. Surface tension brought chips into exact alignment with substrate pads during solder reflow and yielded a higher density and total number of interconnections in comparison with the rest of the industry. The C4 process was first used by IBM in 1968 in System/360; it is now being adopted throughout the industry and has been a source of technological leadership for IBM that has persisted to this day. In 1970, Koenig and Maissel described the application of rf discharge sputtering to the deposition of insulating films. This work set the stage for the industry to use plasma processing to controllably deposit thin insulating films for packaging integrated circuits, as well as for other applications. An aim of device processing is to minimize integrated circuit failures and produce chips with high yield, i.e., a high percentage of correctly functioning manufactured circuits. Using a statistical method to analyze defects in monitors generated during processing, Stapper (1976) describes a procedure to identify yield detractors in the fabrication of large-scale integrated circuits that could be associated with differences in circuit processing. As miniaturization of electronic devices continued, a procedure to obtain minimum feature sizes of less than 300 nm by patterning photoresist using optical lithography was required by the late 1970s. Although ultraviolet laser sources were available, photoresists were insufficiently sensitive to radiation at the required wavelengths. In the early 1980s, Ito (1997) invented "chemically amplified photoresists," which are currently in use worldwide. Irradiation generates catalytic species which induce a cascade of chemical transformations within these photoresists, thereby extending the use of optical lithography to shorter wavelengths and higher resolution. In the last paper in this section, Meyerson (1990) reviews the low-temperature ultrahigh-vacuum chemical vapor deposition of epitaxial silicon and alloyed silicon germanium films and discusses the processing that is required to develop a silicon germanium-based heterojunction bipolar transistor. This alloying of germanium in silicon circuits yields high-frequency transistor performance that was previously attainable only with more expensive compound semiconductor devices. Mixed-signal BiCMOS devices formed by combining the high-frequency silicon germanium analog circuitry with CMOS digital circuits are now having a significant impact on the communications industry.

As integrated circuit complexity increased, computer automation was introduced into the design process to optimize products, shorten design times, and evaluate new products. The finite-element device analysis (FIELDAY) program discussed by Buturla et al. (1981) is a flexible device design tool used extensively in IBM to simulate semiconductor device operation, identify problems affecting device function and reliability, evaluate new device concepts, and optimize device design prior to fabrication. As processor complexity increased, automated chip logic design methodologies such as the Logic Synthesis System (LSS) described by Darringer et al. (1984) were developed. After a designer specifies the required chip behavior, LSS provides the logic implementation with functional blocks optimally connected by signals for individual logic gates, for small logic circuits and then for a complete chip. LSS finally converts the functional implementation of a chip to a technology description with optimized logic circuitry for area, speed, and power. LSS was first used in 1981 for the logic design of the IBM 3090* system. Today, logic synthesis is used industrywide in the design of microprocessors.

IBM has used thin magnetic films for data storage and also for computer memory in one product, the IBM System 360/Model 95, introduced in 1968. Although eddy currents in thick magnetic strips retarded the magnetization switching process, switching in thin deposited films was predicted to be faster. Using the first high-speed sampling oscilloscope, Dietrich et al. (1960) studied magnetization reversal in thin deposited Permalloy films. They experimentally showed that switching, which was inversely proportional to film thickness, could take place in as little as 1 ns. To improve track density and thereby increase data storage on hard disks, Hoagland (1961) describes the design of a servomechanism that precisely positions a recording head along tracks of a storage disk. Between the 1960s and 1990s, significant increases in storage density were made. Speriosu et al. (1990) review advances in magnetic thin films used in recording technology; they discuss the stringent magnetic and mechanical scaling requirements for thin films to accommodate the increased density of magnetic data storage.

The following three papers, each from a different area, illustrate the application of computers in science. In an artificial intelligence study, Samuel (1959) describes machine learning by a computer playing the game of checkers, a very early step toward the match between Chess Grandmaster Gary Kasparov and Deep Blue in 1997. An objective of quantum chemistry had been to obtain accurate solutions to the Schrödinger equation for atoms and molecules in order to address problems of practical importance in chemistry. The paper by Clementi (1965) is an early contribution to *ab initio* quantum-mechanical computations for atoms made possible by the availability of digital computers. This is the most frequently cited paper of any published in the *Journal*. As technology has advanced and computers have been connected in large networks, the security of the network and of stored or transported data from individual machines in the network has increasingly become a priority. Coppersmith's paper on cryptography (1987) discusses aspects of data encryption systems and the Data Encryption Standard (DES), which was invented in 1975 and has remained the United States government standard. Coppersmith's article also considers cryptanalysis, the art of breaking encryption systems.

The last five papers are a selection of major contributions to basic science by researchers in IBM. In 1957, Landauer's first paper in the *IBM Journal of Research and Development* was on the spatial nonuniformity of electric fields and currents viewed on a microscopic basis in the vicinity of localized defects in the crystalline structure of a conductor. His views remained relatively obscure until the 1980s, when it was recognized that the Landauer formula was the simplest and most natural method for calculating conductance in small structures. By considering processing of information in a computer as a physical operation, Landauer (1961) also established that only irreversible operations, those that discard information, dissipate energy. In the early 1970s, Bennett, a colleague of Landauer, pointed out that computation, in principle, did not have to discard information and thus could be carried out with arbitrarily little energy dissipation per step. This invention of reversible computing is considered the most central point in the understanding of the physical limits of computation. The included paper by Bennett (1988) reviews the history of the thermodynamics of information processing. Binnig and Rohrer (1986) present an overview of the status and prospects of scanning tunneling microscopy (STM), which was first described in 1982 and for which they received the 1986 Nobel prize in physics. The STM provides important scientific insights for the characterization of technologically important materials down to atomic dimensions and new diagnostic tools, and has stimulated development of a host of related microscopies. The last paper, by Sorokin (1979), reviews IBM's discoveries of new laser types and discusses many of the scientific achievements using lasers at IBM between 1960 and 1979. Sorokin discovered the second laser on record in 1960; in 1966 he was one of the inventors of the dye laser. Subsequent developments in laser cavity technology allowed dye lasers to become highly monochromatic and tunable, opening the way to high-resolution laser spectroscopy.

In his message in 1957 in the first issue of the *IBM Journal of Research and Development*, Thomas J. Watson, Jr., then president of IBM, wrote "In the *IBM Journal*, our scientists and engineers will describe their latest and most significant new ideas and concepts." Through publications in this *Journal* and elsewhere, "we at IBM can contribute significantly to a freer exchange of ideas and knowledge among all men."

As illustrated by these reprinted papers, the direction established by Watson has been, and continues to be, the aim of the *Journal*. Though these reprints present only a small fraction of the total contributions by IBM engineers and scientists, the impact of each paper has been profound. With this base of solid technological progress, we can anticipate continuing dramatic developments in the coming century.

General references

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