50 Years

of Components, Packaging and Manufacturing Technology

IEEE

CPMT 1950-2000

Celebrating 50 Years of Technology

50 YEARS of COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY

The IEEE CPMT Society and its Technologies 1950-2000

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Acknowledgements

Many people gave unstintingly of their time and expertise to help with this project. My special thanks go to Jack Balde, Ron Gedney, Charles Eldon, Mauro Walker, and Paul Wesling for their insights; Dimitry Grabbe, who provided access to his first-class components collection; and Gus Shapiro, who shared early material on the beginnings of the Components Group with me, as well as insights into the people involved in its nascence. In addition, I had the enthusiastic support of Dennis Olsen and the CPMT Society committee, who smoothed my way and introduced me to many of the giants in the field.

ROBERT COLBURN
IEEE HISTORY CENTER

"There is one component of electronic systems which appears not to have had sufficient attention and which only recently has been recognized as an important element in the entire electronics industry. That element is the components engineer himself."

So wrote Robert G. Sprague in his paper given at the 1950 Symposium on Improved Quality Electronic Components. He also noted that "studies made in the last few years under Armed Forces contracts and by civilian industry all show that many millions of dollars worth of end equipment and thousands of man-hours of field servicing could have been saved with just a little more attention to components in the design stage."[1] World War II had generated an intense demand for electronic components, and had subjected those components to extreme operating stresses in the field, in the air, and at sea. Airborne radar sets, artillery proximity fuses, portable radios – to give only a few examples – all needed to withstand temperature shock, vibration, friction, fatigue, and moisture, and be able to function with a high degree of dependability. New and increasingly complex equipment was being developed, and new applications were providing challenges to the component manufacturing industry.

Controlled processes and accurate testing methods were critical, as the cost of components is inversely proportional to the yield. In 1950, electronic components were anything but reliable. According to J. G. Reid, the program Chair of that year's Electronics Components Symposium (ECS), "The meteoric rise in extent of application of electronic devices...within the past decade has completely outstripped the ability of the electrical engineering profession...to avoid operational and maintenance problems for the user which are out of reasonable proportions." Or, as Ron Gedney, then of IBM, described it even more succinctly: "We were writing the book on reliability in those days. There were no standard tests, and we had to devise them." [2]

Approximately 60% of component failures were because of poor manufacturing methods, or the use of unsuitable materials.[3] Differing shrinkage coefficients of materials caused major component damage. Heat, moisture, or fungus attack (the paper laminate boards were prone to this) comprised 80% of the environmental factors which contributed to component failure, with the remaining 20% of the failures caused by shock or vibration. Dissipating the heat generated by the components became a more difficult problem, as increasing miniaturization required that they be mounted closer to each other on the boards.

In the 1950s, the passive components which engineers had to buy, use, and understand, were:

1. resistors: *carbon composition, carbon film, metal film (nichrome or tin oxide), and wire wound;*

2. capacitors: *aluminum electrolytic, paper, mylar, ceramic, mica, tantalum (liquid electrolyte), and power supplies used large oil-filled paper capacitors sealed in large cans (e.g. 3" diameter by 6" high);*

1 Sprague, Robert G. "The Components Engineer – His Place and Importance." Proceedings of Symposium on Improved Quality Electronic Components, 1950, Washington, DC

2 Gedney, Ron, Oral History, June 1999

3 Henney, K. (ed.) 1956 Reliability Factors for Ground Electronic Equipment, New York, McGraw-Hill

To address the problems of reliability, the Institute of Radio Engineers (IRE), the American Institute of Electrical Engineers (AIEE), and the Electronics Industry Association (EIA) jointly sponsored a "Symposium on Improved Quality Electronic Components" held in Washington, DC in May of 1950. Within the IRE, it was the Professional Group on Instrumentation and Measurement that sponsored the symposium. The IM group had several subcommittees, one of which was the Electronic Components Subcommittee. The people working on the conference grew into the IRE Ad Hoc Group on Components. Eventually, they would become the nucleus of a new IRE professional group, the Professional Group on Component Parts, and that professional group would evolve into the IEEE Society on Components, Packaging, and Manufacturing Technology.

In 1948, another revolution began within the electronics industry with the invention of the transistor. Miniaturization, power reduction, and manufacturing cost and reliability improvements of those solid-state components caused one of the most decisive technological leaps in history. The hearing aid broke down the barriers of silence and reunited many hearing-impaired people with their families and friends. It is heartening to reflect that the first use of this new invention improved the quality of life for people whose disability would otherwise have isolated them from the world around them. The transistor radio put a world of news and entertainment in one's pocket. These were two of the most well known applications of the new technology. In 1957, the technology accelerated again when the invention of the integrated circuit spawned the discovery and testing of new materials, and the development of manufacturing techniques of daunting precision. This invention also required that interconnection standards were developed, and reliability levels maintained and improved. After the technical barriers and manufacturing obstacles were overcome, reduction in the cost of manufacturing components allowed the consumer to embrace the new technology. The insatiable consumer demand caused spectacular growth of the market, although the early component advances were a result of the funding support provided by the United States military.

Dummer's Prediction - ECS 1952

In May 1952, the Professional Group on Components Parts presented ideas at its conference that directed the course of the industry. The ECS was the scene of Geoffrey Dummer's world-changing prediction, presented in the closing paragraphs of his paper on the reliability of radar components: "...it seems now possible to envisage electronic equipment in a solid block with no connecting wires. The block may consist of layers of insulating, conducting, rectifying, and amplifying materials, the electrical functions being connected directly by cutting out areas of the various layers." This became a verbal blueprint for the device that

3. inductors: *axial leaded and wire wound;*

4. connectors *of many types;*

5. quartz crystals: *almost all timing circuits used crystals — these were hermetic metal cans, flat with leads from the bottom;*

6. pulse transformers*, which had wound ferrite cores;*

7. memory elements*, which were exclusively ferrite cores with three or four wires through the center; and*

8. switches, fans, wire harnesses, and frames: *all of which were large, many unreliable, and they were difficult to automate for manufacturing assembly.*

would one day be known as the integrated circuit.[5] Dummer actually built and exhibited a metal model of a "semiconductor integrated circuit" at the 1957 Royal Radar Establishment International Components Symposium. However, the actual invention came from a man in the United States who did not hear about Dummer or his predictions until several years later.

A New Profession - Component Parts Engineering, 1953

On 25 February, 1953, a petition to form the IRE Professional Group on Component Parts was circulated to the IRE's Board of Directors. They approved the formation on 17 August, 1953. At the close of its first year, the Group had 375 paid members. (As of the end of 1999, the CP Group's successor, the IEEE CPMT Society, numbered more than 3,800 members and affiliates.) The following year, in the Transactions of the IRE Group on Component Parts, the Chair of the Group, Floyd A. Paul, described the component parts engineer as someone who "can provide data concerning the reliability of parts in the specific environments and who is able to select the proper vendors and products for specific applications, because he knows not only the component performance, but also knows enough about the materials used in the components to explain why components perform in a certain manner under given conditions." Components engineers were also required to use their knowledge of materials to ensure the proper usage of components in the fabrication of electronic equipment for various applications.

Leon Podolsky, a tireless worker who had been an active member of the Group on Component Parts from its inception, had also, since 1952, been the chief US delegate on electronic components to the International Electrotechnical Commission. Podolsky advanced the interests of the US electronics industry internationally, and convinced US industry that international standards were imperative. At Podolsky's urging, the predecessor body of the IEEE Life Member Fund provided money to encourage greater member participation in international standards activities. In March of 1954, the Professional Group on Component Parts published its first Transactions under the editorship of Gus Shapiro of the National Bureau of Standards, who was also the Washington, DC Chapter Chair.

Today, 90% of all the semiconductor packages in the world are epoxy molder. Five decades ago epoxy was not reliable enough for US military applications. Ceramic base materials were developed during World War II for applications such as proximity fuses. Initially ceramics, which are tremendously stable after firing, had advantages over the early organic materials, which despite being easier to manufacture, were prone to brittleness, shrinkage, sensitivity to moisture, and temperature limitations. As advances were made in the chemistry of the organic materials, various combinations of glass and resins became the board materials of choice, and ceramics would later become the choice material for chip carriers.[6]

> *"The customer's influence on electronics eventually is going to bring you around to dependable gear, dependable for the purpose for which it is designed. My only comment in passing is 'eventually, why not now?'"*
>
> — F. R. LACK, WESTERN ELECTRIC CO, 1950[4]

A technique for sensitizing plastic so that copper could be directly electroplated in the hole instead of using an eyelet was a major development in circuit board manufacturing. In 1954, the United States military approved the plated through-hole method of attaching components to the circuit board. This method was used in the Gemini space program, and various Bell Laboratories and Western Electric designs as well. It offered greater strength in the connections and a more economical means of production. However, even a process as simple as punching holes in circuit boards had its difficulties, as the edge of the hole might have rough filaments that could protrude and spoil the connection. For which reason, many manufacturers developed a process to drill and mill certain types of laminate. New and very precise machines had to be designed to increase the reliability of the connections, which expanded the manufacturing industry even further.

The trend towards miniaturization required a grid system, a new method of dimensioning to guide the design of equipment, components, and machinery for automated manufacture. Two design systems were evolved, designated A and B, which were based on multiples of 0.025 inch.[7]

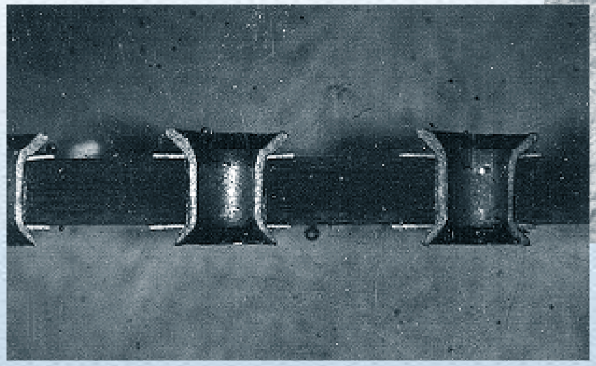
As production techniques became more specialized, the IRE required a specific organization to address its needs. The petition for the formation of the IRE Professional Group on Production Techniques circulated on 24 March, 1954, and was approved by the IRE's Executive Committee the next month. In 1961, the GPT changed its name to "IRE Professional Group on Product Engineering and Production." This was start of the "M" in what became the IEEE CPMT Society.

April of 1954 saw Texas Instruments succeed in growing the first grown-junction silicon transistor, and later that year TI began producing junction transistors for portable radios. This first attempt at portable, solid-state, and mass-market electronics heralded tremendous possibilities, and created a new packaging challenge. Popular culture boomed in October of 1954, when the Regency TR1 transistor (germanium) radio hit the sales shelves. Suddenly, people could take music and news with them anywhere. Three months after the TR1 debuted, the newly named Sony Corporation of Japan introduced its own entry, the TR-52, to the market. The final challenge drove the cost of the components down to where the popular market could embrace them.

Meanwhile, the membership of the Group on Component Parts grew steadily, reaching 1,700 members by 1958.

Laser-drilled hole

Plated flange eyelets



PHOTOS COURTESY OF DIMITRY GRABBE

4 Lack, F. R., "Why Not Dependability in Electronics?" Proceedings of Symposium on Improved Quality Electronic Components, 1950, Washington, DC

5 Wolff, M. 1976. "The Genesis of the Integrated Circuit." IEEE Spectrum (August), pp. 45-53

6 Schlabach, T. D. and Rider, D. D., 1963 Printed and Integrated Circuitry: Materials and Processes, New York, McGraw-Hill

7 Ibid

C P M T ~50~ Y E A R S

Such an elegantly simple idea - the Integrated Circuit

Cost concerns sparked the next great component leap. Prior to 1958, there was still a lot of variation in the processes used to manufacture transistors. Major companies such as Texas Instruments, the world's largest producer of silicon transistors at that time, was using half a dozen processes. A place on the cutting edge was expensive, and Jack Kilby, who joined Texas Instruments in May of 1958, knew the overhead. Costs of a research-rich, productive environment drove up the costs of whatever finished products would utilize the components. "Therefore," Kilby thought "it would be very desirable to make an all-semiconductors circuit to make everything from a single material.[8] Further thought led me to the conclusion that semiconductors were all that were really required – that resistors and capacitors in particular could be made from the same material as the active devices."[9]

At this point, some of the most daunting production problems shifted from materials to layout. Packaging experience showed that the best place for resistors and capacitors was on the board, although they took up a lot of room in a circuit design. Originally, IC packages were round, and wasted a lot of precious real estate on the boards making manipulation difficult for circuit board engineers. The increasingly large number of interconnections represented an inefficient use of space, which ironically, became more pronounced as components became smaller. As miniaturization continued to reduce the size of the discrete components and circuits, the interconnections required a greater proportion of the packaging volume. The increasing density of IC devices required denser interconnection wiring than could be provided by a single or double circuit printed wiring board. A partial solution to the space problem was multilayer circuitry. Multiple etched circuit boards were built up, and soldering through oversized clearance holes made connections to individual layers. By 1963-64 multilayer boards had evolved to a commercially practical level.

During the mid-1960s, mounting chips on ceramic produced even higher density, as big ceramic multi-chip modules were used for mainframe computer design. Having so many active devices in a small space generated a lot of heat, and the means for heat dissipation down through the substrate was inadequate. By the early 1970s, most packages required finned heat sinks (the use of liquid cooling – always possible – proved to be problematic because it depended on the building services of the customer.)

Heat dissipation remained a problem because the rate of physical size reduction tended to exceed the rate of reduction in circuit power use. As circuits became smaller, the size of the thermal conducting paths and heat sinks was restricted even further, and new approaches to dissipating heat would need to be found. [10]

An example of heat dissipation

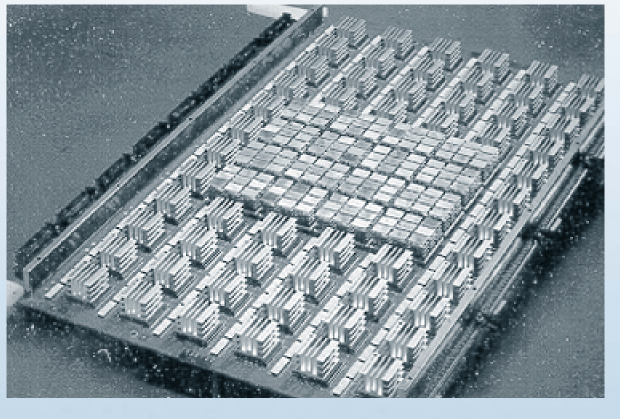


PHOTO COURTESY OF DIMITRY GRABBE

8 Kilby, Jack S., Oral History

9 Kilby, Jack S., "Invention of the Integrated Circuit" I EEE Transactions on Electron Devices, Vol 23, #7, July, 1976, pp 648-654

10 Schlabach, T. D. and Rider, D. D., 1963 Printed and Integrated Circuitry: Materials and Processes, New York, McGraw-Hill

The axial leaded components from the 1950s took up far too much space for 1960s technologies. In the early 1960s, Sprague Electric Co. approached IBM with an idea for an R-pac that was made from hybrid technology (paste on ceramic). The leads came from the bottom of the package and the whole package was dipped in a Durez coating for reliability. By 1965, because of large demand, R-pacs became an industry, particularly by IBM. Simultaneously, chip capacitors were needed for mounting on hybrid circuits. Early suppliers of ceramic chip capacitors were AVX, Erie Technological Products and Sprague Electric Co.

Floyd Wenger, the 1960-61 Chair of the Component Parts Group, described the 1950s as "a decade of fabulous growth. Component parts, the building blocks of electronics, have sparked this great expansion. New applications have been discovered for old components, and a deluge of new materials and components has been tailored to meet expanding requirements and applications." Noting that components engineers had gained recognition and stature and would be the leaders in approaches to new circuitry, Wenger predicted that "the new popularity of the component engineering field will result in a phenomenal growth during the '60s."[11]

1960 - Professional Group on Product Engineering and Production

During this period, the IRE published many articles on the new wonder components. However, very few of those articles dealt directly with the problems confronting the production engineers responsible for producing the components reliably, inexpensively, and in bulk. They petitioned for the formation of the IRE Professional Group on Product Engineering and Production. They described themselves as the engineers who "convert the one-dimensional 'lines of thought,' and the two-dimensional 'block diagram, pages of equations and circuit diagrams' into the three-dimensional equipment" for sale. People began to think in terms of broad commercial applications, where the marketplace would push the technology beyond specialized uses. As a result, the foundations were laid for several, enormous markets for components. Satellite communications, both telephone and television, became technically possible and economically attractive. The IRE Professional Group on Product Engineering and Production was formed, and merged in 1963 with the Professional Group on Component Parts, forming the Professional Group on Components, Packaging, and Production.

In the mid-1960s, IBM developed the first semiconductor main memory (with 16 bits to a chip; four chips on a half inch square ceramic substrate). For the System 370, IBM manufactured a MOS memory cell at eight times the density (128 bits/chip), that began shipping in 1971. The System 360 (1964-1971) used ferrite core memories with small ceramic hybrid circuits providing the core drive and sense functions. By then, IBM was in

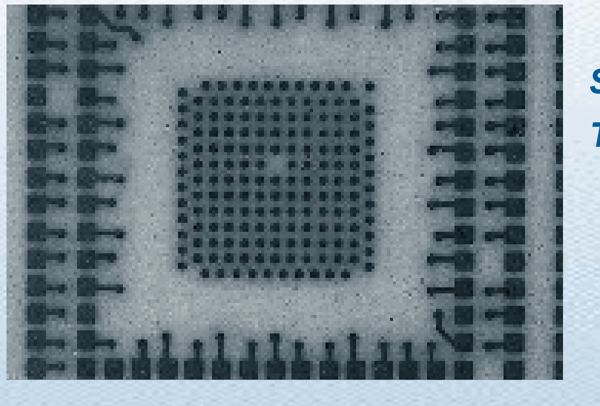


PHOTO COURTESY OF DIMITRY GRABBE

Solid Logic Technology

11 Wenger, Floyd E., "A Message from the Chairman", IRE Transactions on Component Parts, Vol CP-7, #3, Sept., 1960, pg 69

mass production with C-4 technology, so the typical memory module (1/2 inch square) had four memory chips, or 512 bits per module. Later, IBM switched from all hybrid technology to integrated (at that time called "monolithic") circuitry. The System 370 used integrated circuit chips with up to 16 circuits per chip mounted on two to four chips on a 1/2-inch substrate.

At this time, the large boards ("mother boards") were processed primarily in 10 x 15 inch panels. An entirely new family of highly reliable, dense connectors had to be developed and released for these computer systems. The sheer number of connections in a single block forced the design of a computer-aided manufacturing system to mate the connectors.

"That was when we realized we were in trouble; we could not buy enough components" - 1961

By this time, increasing demand for components greatly outstripped the suppliers' abilities to produce them, and traditional customers formed their own manufacturing fulfillment divisions. International Business Machines formed its own components division (in 1961) to build circuitry for the new generation of integrated circuit-based computers (in this case, the System 360). In the course of developing the System 360, the switch was made from paper epoxy to glass epoxy circuit boards. Ron Gedney remembers that "the day the System 360 was announced, we sold the entire five-year forecast. That was when we realized we were in trouble; we could not buy enough components to build the systems in anywhere near the quantities that our customers were asking...I had planned in 1964 I was going to need about 10 million R-packs. We needed 50 million."

Mainframe computer technology required at least four levels of packaging. The first level contained chips, and in the case of hybrid circuits, passive components. A small printed circuit board (often called a card or daughter board) with a connector, became the "field replaceable unit," which was an island of circuitry (usually functional) that could be replaced by a field engineer if a fault was detected by system diagnostics. The third level of packaging was a board or back-plane on which the daughter cards were mounted. The back-plane would interconnect dozens of daughter cards to form a large part of a system. In those days however, a large computer had a number of back-planes within a single box (fourth level of packaging) and needed multiple boxes. (Filling a 10,000 square foot room was not uncommon). Mounting the back-planes within a frame, interconnecting the back-planes, bringing in power systems and cooling the whole box were all challenges for the packaging engineer.

These challenges were not trivial. New solutions in the precise use of materials were required to bring 1000 amperes to a single board, and distribute power to the daughter cards equally while managing ground bounce and other noise sources with decoupling capacitors at the board level. In addition, it was not unusual for a single board to dissipate several thousand watts of power, presenting a formidable cooling challenge.

All of this activity at the chip package level made for increasing density on the circuit board level. Early multilayer boards were inferior, with their FR4 epoxy reinforced with glass window curtain material. The expansion coefficient, which was much higher than that of copper, caused these materials to expand and contract more than the copper leads, causing the leads to crack and peel off. Proper packaging materials had to be developed, such as pure molding compounds and epoxies, which were free of corrosives such as chlorine and ammonia.

Subsequently, there were problems procuring the materials from the chemical manufacturers. In the late 1960s and early 1970s, the amounts of these specialized chemicals used by fairly large component manufacturers (e.g. a few hundred gallons in a year) were too small to be worth a production run by a large chemical company. "Every year I had to go out and beg a major chemical manufacturer to do another small pilot run on my back seal." [12]

Eventually, as the volumes of components increased, the chemical manufacturers became more interested in the new market, and supplying specialized chemicals to the components industry became big business. Often, the component manufacturers developed their own ingenious solutions. The K-17 screening ink used for imaging circuit boards was common road asphalt dissolved in naptha. In 1954, a material tested and used for circuit boards was fiberglass window curtains (because they would not burn). Dozens of processes were used at various times to produce printed wiring boards. Of those, the most common became the etched foil process, in which metal was selectively removed by photoetching to leave the desired configuration.

IBM's concerns about reliability eventually led to a partnership between Ron Gedney and George Harman of the US National Institute of Standards and Technology, who pioneered the VLSI workshops. These were the first annual conferences which dealt almost entirely with reliability issues in multilayer ceramic packaging. This workshop is still sponsored by the CPMT Society, although the locations rotate from the US to Japan and Europe. The VLSI format combined reliability issues with package and systems design, which proved to be a powerful mix of topics.

In the early 1960s, the hybrid circuit was developed. This consisted mainly of screened paste passive components and interconnections on ceramic substrates. The hybrid circuit often contained semiconductors mounted on the surface of the

***The CPMT David Feldman OUTSTANDING CONTRIBUTION AWARD** was established in 1962 as the Outstanding Contributions Award, to recognize an outstanding contribution to the fields encompassed by the CPMT Society through invention, technical development or executive or managerial direction.*

1962.........Paul S. Darnell
1965.........A. W. Rogers
1967.........F. E. Wenger
1968.........P. K. McElroy
1969.........R. Holm
1972.........Gus Shapiro
1973.........Louis Kahn
1975.........Rudolf Thun
1976.........David A. McLean
1977.........David Feldman
1978.........Ralph E. Armington
1983.........John H. Powers Jr.
1986.........Paul B. Wesling
1988.........Nicholas T. Panousis
1989.........George H. Donaldson
1990.........Morton Antler
1991.........David W. Palmer
1992.........George G. Harman
1993.........Leo G. Feinstein
1994.........Les Fox
1995.........Iwona Turlik
1996.........Karel Kurzweil
1998.........Dr. Koji Nehei
1999.........Ron Gedney
2000.........John H. Lau

***The CPMT ELECTRONICS MANUFACTURING TECHNOLOGY AWARD** was established in 1968 to recognize major contributions to Electronic Manufacturing Technology in fields encompassed by the CPMT Society.*

1988.........John H. Powers
1989.........Mauro J. Walker
1990.........Diana J. Bendz
1992.........Steven D. Prough
1993.........William M. Beckenbaugh
1994.........John Lau
1995.........Not awarded
1996.........Michael Cassidy
1997.........not awarded
1998.........Dr. Paul Totta
1999.........Dimitry Grabbe
2000.........Rama Shukla

12 Gedney, Ron, Oral History, June 1999

ceramic. The early hybrids were made with Du Pont platinum-gold pastes which were very expensive, but highly reliable. By the 1970s, Du Pont developed a ruthenium based resistor paste. During the 1960s many companies, including IBM, worked with Du Pont to lower the paste cost, replacing platinum gold with silver palladium. These pastes were "fired" on ceramic substrates at 850-950 degrees Celsius, and were extremely reliable. The glass in the pastes tended to form a coating over the top of the lines, which made them virtually impervious to moisture. Resistor pastes were also reliable, but "sand-blasting" or, by the late 1960s, laser trimming, disturbed the glassy phase, making resistors more susceptible to the external environment.

In 1962, Texas Instruments was awarded a large contract to design and build 22 special circuits for the Minuteman II missile, which reduced the weight of its guidance systems, and increased the missile's range. Fairchild Corporation received substantial contracts from NASA and other clients. The United States Air Force sponsored a program at Motorola which combined the best characteristics of thin-film technology with the integrated circuit (Systems Command). The processes used to fabricate thin films lend themselves to automated manufacture, and multiple elements of the same type can be deposited simultaneously.[13] By 1963, the techniques of thin film deposition were in the advanced stages of development.

Bell System launched the Telstar satellite in 1962, which was the first to transmit live television signals and telephone conversations across the Atlantic. The vast opportunities presented by wireless communications and satellite television by subscription generated yet another mass market for components. (By 1997, the customer bases for wireless communications had become so broad that there would be estimated 185 million wireless telephone subscribers worldwide.) In November of 1963, the first integrated circuits went into space aboard the IMP satellite.

By 1963 and 1964, complimentary to the improvements in multilayer boards, the process of ion plating of plastics and metals led to more reliable component connections. Three main types of solder – gold, tin and tin-lead alloys, and nickel-rhodium – were commonly used for mounting the components to a board. Tin was used most often, as it was more cost-effective, and could be deposited from acid solutions at room temperature. Harder nickel-rhodium alloys were developed for contacts that might deteriorate. Despite these advances, solder was not considered suitable for connecting components that might experience conditions of extreme environmental stress. For programs such as the Polaris missile and the Apollo guidance computers, the United States military required all of its boards to be welded rather than soldered, to strengthen the connections and protect against shock. Flaws in the soldering could create solid

1961 saw the release of the Darnell Report on Reliability. *Paul S. Darnell, a veteran of Western Electric and its later manifestation, Bell Laboratories, also served as the Chair of the IRE Professional Group on Component Parts in 1958-1959. As Director of military apparatus development, he was responsible for directing the development of electronic components for military applications, and overseeing a group within Bell Labs concerned with the reliability of the components used in military systems. Darnell's findings triggered a revision of the M-200 US Department of Defense standardization manual of US military standards for semiconductor devices, and improvements to the failure reporting process. In 1962, the IRE Component Parts Group recognized Darnell's contributions by making him the first recipient of its Outstanding Contributions award.*

13 Kilby, Jack S., "Invention of the Integrated Circuit" IEEE Transactions on Electron Devices, Vol 23, #7, July, 1976, pp 648-654

state interference which could actually flip the waveform and cause diode-like behavior. There were also problems with the welding approach because the manufacturers would select whatever material was convenient for them to make the component leads, and some of these materials were not necessarily weldable.

In 1963, the Institute of Radio Engineers (IRE) and the American Institute of Electrical Engineers (AIEE) merged. The combined society became the Institute of Electrical and Electronics Engineers (IEEE), and is to this day, the largest professional society in the world.

As the 1960s progressed, more demanding and unusual applications of components were engineered which encouraged new developments and ingenuity on the part of designers and manufacturers. Built in 1967-68, the Cray 7600 supercomputer was at the high end of large-scale applications, using 2000 different board types. It was a masterpiece of packaging made possible by innovation. The Cray 7600 used transistors for very high speed switching, thus designing boards with the shortest possible connections became very important to maintain the speed of the machine, as well as to prevent standing wave problems. Cubes were used to provide the shortest possible connections. However, heat dissipation remained a challenge. The heat generated by the Cray was excessive enough to be transferred to underground water pipes and used to heat the homes of an adjacent community.

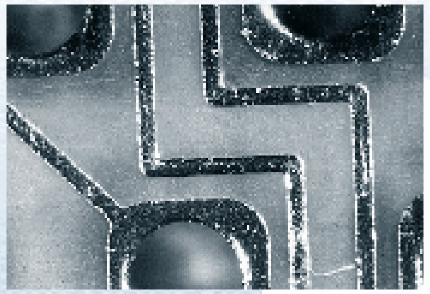
In addition, high-speed switching required curved traces on the circuit boards, because sharp corners became sources of unwanted electrical signal reflections. Substantial redesigns were required for the mass production of circuit boards on machines that previously could produce only straight lines and sharp corners.

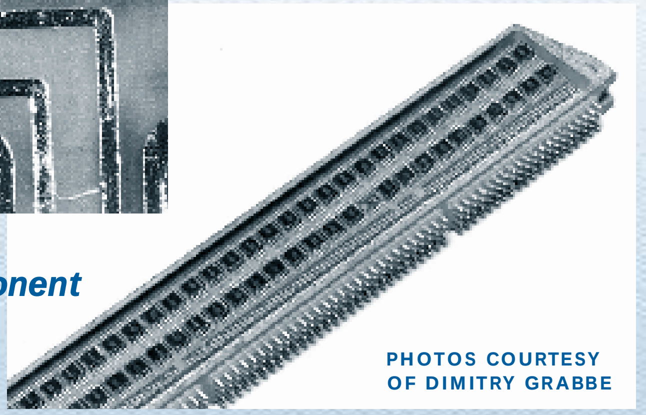
At this time, Bell Labs pioneered several packaging advances. The introduction of beam leads, tiny metal strips that extend metallization and ran beyond the edge of the chip, made it possible to fix the chip to a substrate and simultaneously provide electrical connections. The miniaturization of beam-lead interconnects enabled the development of compact and robust electronics for the Minuteman missile and other military and space programs.

Other manufactures did not have the luxury of producing their own components, and it was difficult to obtain IC chips of the same technology while using multiple vendors. Computer designers ordered parts from a variety of manufacturers, not all of whom provided them in beam leads, so it became the designers responsibility to solder them on. Successful beam lead technology required a cooperative effort by every semiconductor manufacturer in the world, which was impossible to achieve.

IBM introduced flip-chip interconnection technology in 1964 to replace the beam leaded devices and the need for wire bonding of components. This led

Sharp corners are sources of unwanted signal reflections





Apollo command vehicle memory component

PHOTOS COURTESY OF DIMITRY GRABBE

1967, Perkin-Elmer's microprocessor projector

Eventually, every major industry develops its own supplier, and in the case of microprocessors, there was a necessity for high-technology photoetching projectors. Paradoxically, as the price of components fell, the machinery required to produce them became more expensive.

By the mid-1960s, the patterns reproduced on the microprocessors encompassed approximately ten wavelengths of ultraviolet light. At that level of detail, a particle of dust caught between the mask and the wafer, or the opacity caused by a mask not clamped tightly enough to the wafer, could distort exposure. The amount of exposures required per chip gave ample opportunity for defects to appear at every step, rendering a high percentage of chips unusable.

In June of 1967, the US Air Force awarded Perkin-Elmer a contract to build the machine that would become the Micralign, a projector used to expose microcircuits. The projector used mirrors instead of lenses, and could resolve details of 2 microns, or 80 millionths of an inch. This breakthrough solved the problems of wavelength range and alignment. Abe Offner, the optical designer at Perkin-Elmer, realized that the mask could be scanned, rather than being exposed all at once, which gave excellent resolution across the entire wafer. A curved lamp was developed, which enabled projection through the slit without distortion. Launched in 1973 and commercially viable by 1974, the Micralign improved chip yields. This allowed the necessary microprocessors to be manufactured less expensively, and ultimately, made the personal computer possible.[16]

In June of 1969, the IEEE realized the importance of packaging in successful applications of components, and formed the Technical Group on Parts, Materials, and Packaging.

The interests of this group were the "scientific, engineering, and production aspects of Component Parts and Materials...[including] application of parts and materials in equipment and the techniques of assembly generally referred to in the profession as 'packaging'."[17] Meanwhile, the Group on Component Parts petitioned to merge with the Electronics Transformer Committee.

16 Burbank, Danield P., "The Near Impossibility of Making a Microchip" Invention and Technology, Vol 15, #2, Fall 1999, pp 44-52

17 Bylaws of the IEEE Professional Group on Precision Manufacturing of Parts

to Lou Miller's invention of the Controlled Collapse Chip Connection, the C4, and Kyoto Ceramics in Japan followed quickly. The C4 became a computer industry standard. Originally developed for use with ceramic carriers, the C4 used solder balls as a chip to carrier interconnect. Arrays of these balls or bumps were arranged around the surface of the chip, either in an area or a peripheral configuration. The chip was placed face down on a carrier prepared with corresponding metallized pads, which had been flashed with gold to prevent corrosion. When heat was applied, the solder reflowed to the pads.[14]

General Electric began tape-automated bonding, and Bryant Rogers at Fairchild oversaw the invention of the Dual-In-Line Package (DIP), which had fourteen leads. Simultaneously, Postma and Olsen at Philips Eindoven developed a method using very thin polyimid and additive metallization of copper, so transparent that they could line it up with the chip and place a piece of plastic in between, which melted when heat was applied. Once melted, it had reducing properties that removed the oxides, allowing bonding without using flux, which would have had to be removed subsequently. The process was easily instrumented because the transparency eased alignment. It was a good method, but the process developed as large amounts of money were invested in equipment for automating the placement of DIPs.[15]

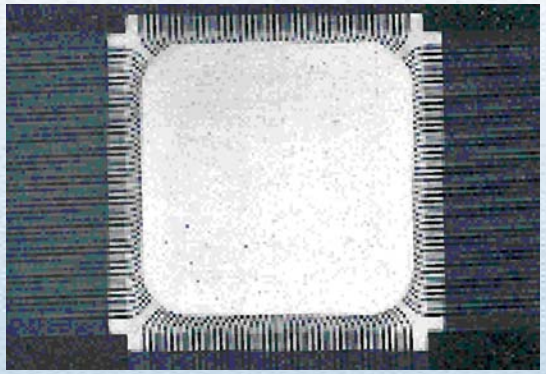
In 1965, as their fields of interest began a metamorphosis, the IEEE professional groups on Product Engineering and Production and Components Packaging, merged to form the IEEE Professional Group on Parts, Materials, and Packaging.

While great strides were made in the production of microprocessors, new applications were discovered for the microprocessors themselves. In 1967, two particular applications – the Polaroid SX70 camera and the Hewlett-Packard and Texas Instruments entries into the hand-held calculator market – produced new markets for miniature components.

The founding of Intel Corporation in 1968 by Robert Noyce, Gordon Moore, and Andrew Grove proved prescient. Intel not only pioneered several manufacturing advances, it changed the concept of the capabilities of a microprocessor.

Meanwhile, Westinghouse, GT&E Labs, and RCA Sylvania, each using differing production methods, (of which GT&E Labs' was considered to be the simplest), produced the CMOS (Complimentary Metal-Oxide-Semiconductor) integrated circuit. CMOS technology improved chip density ten to twenty times over bipolar circuits. CMOS integrated circuits used less power, and allowed more productive use for the space that was reserved for heat dissipation.

PHOTO COURTESY OF DIMITRY GRABBE



Leaded chip carrier

14 IBM product description

15 Grabbe, Dimitry "Electronic Packaging Seminar" 1998

In November of 1971, Intel took a dramatic step forward with the introduction of the first commercial microprocessor that could be programmed to execute instructions. The 4004 contained 2,300 transistors, and could perform 60,000 calculations per second. That same year, the Minnesota Mining and Manufacturing Company in St. Paul developed the ceramic chip carrier, a square, multilayered ceramic package whose base contained a pattern of gold bumps. The chip was bonded to a gold base pad inside a cavity within the ceramic. This small, hermetically sealed package was a tremendous manufacturing advance, as it could be easily attached or removed from boards and hybrids.[18] These integrated circuits had to be interconnected in order to build a functioning circuit board. Later, two major technologies were soldered to ceramic hybrid circuits: the plastic DIP, and the leaded ceramic carrier. Chips needed an interchangeable and reusable package (for commercial equipment, the molded plastic dual in line package became dominant; for military equipment, the 3M style ceramic chip carrier became dominant). Billy Hardis of 3M performed much of the production of leadless ceramic packages. RCA Moorestown used this technology for Aegis radar and other naval systems. John Bauer became the first packaging engineer to make IEEE Fellow as a result of his innovative work on leadless chip carrier technology and surface mounting packaging techniques.

As the integrated circuit became more pervasive, the personal computer revolution began. Here, a whole level of packaging was removed. Chips were mounted on chip carriers and combined with many passive components on a large planar board. This board was interconnected to I/O devices (e.g. disks, monitors, keyboard) to make up the whole system.

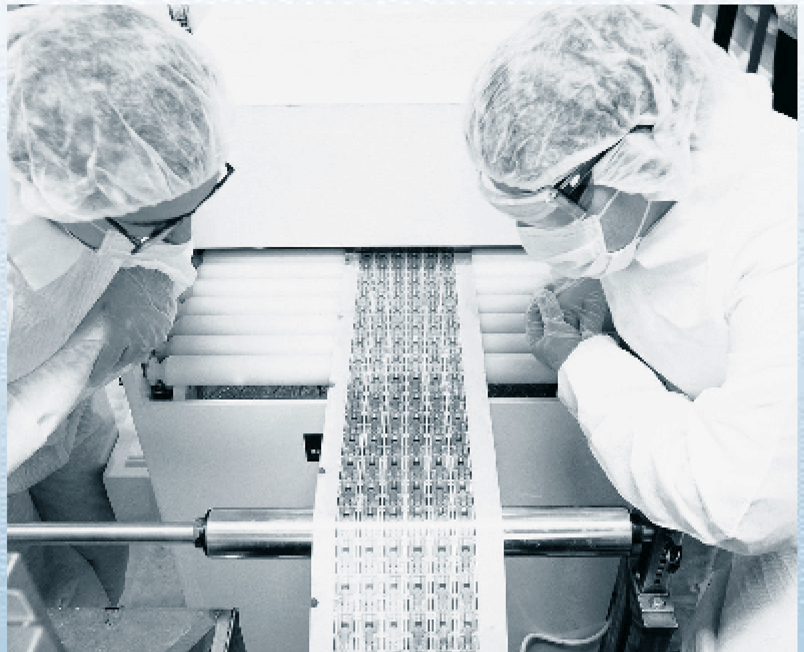
Developments in the packaging of individual wireless communications required new packaging techniques. Prior to 1970, two-way radios and pagers were manufactured using transistors. But Motorola's Pageboy II was manufactured using thick film hybrid modules and wire-bonded integrated circuits attached directly to the hybrid circuit. By 1972, this method evolved into a high-density, packaged IC using ceramic chip carriers. Sharp's introduction of calculators with liquid crystal displays where the LCD, the chips, and all of the other components were mounted on the same piece of glass was a packaging technique well in advance of its time.

The increasing complexity of manufacturing was reflected in activity within the IEEE as well.

By 1972, IEEE manufacturing engineers felt that the IEEE Professional Group on Parts, Hybrids and Packaging, which was born of the 1965 merger of Product Engineering and Production and Components Packaging, left them without an organizational structure which could meet their growing professional needs. In March, the manufacturing engineers

Manufacturing flexible components at 3M

PHOTO COURTESY OF 3M



18 Dummer, G., Electronic Inventions and Discoveries, 1997, London, Institute of Physics

CPMT ~50~ YEARS

within the Group (IEEE was then in the process of consolidating its Groups into Societies) formed the IEEE Manufacturing Technology Society to address their specific areas of manufacturing. However, the Manufacturing Technology Society's existence was somewhat unsteady and ambiguous. By 1975, PHP and MT groups discussed a reunion, which actually occurred in 1977.

In 1974, Amdahl Corporation introduced a mainframe computer that used thousands of integrated circuits in identical 84-lead surface-mount packages. Forty-nine were mounted to a board with developments that advanced packaging technology. Built from 3-watt ECL gate arrays, this design used novel methods to keep the chip temperature below 85 degrees C. Using a metal cooling tower with three fins, and fans in a push-pull configuration to create airflow of 1200 linear feet per minute, this system was cooled without the use of chilled water. The twelve-layer PC boards allowed controlled-impedance signal transmission as well as distribution of multiple supply voltages. Inter-board signals traveled through miniature coaxial cables, while high-precision laser bonding was used to reflow solder the surface-mount packages, and rework wires to the boards.

Chip Carrier Task Force - 1974

Meanwhile, technology progressed from the dual in-line package, which required an array of through holes in the printed circuit board, to a surface mount package, which became known as the chip carrier. At that stage, there were more than 3,500 different varieties of chip carrier, most of them within 1/8th to 1/10th of an inch of another in size.[19] The leads and the sizes were spaced differently; no two were interchangeable. Twenty-seven different companies cooperated on a uniformity task force. They decided that no two sizes should be separated by any less than the square root of 2. The task force not only settled on what the sizes would be, it also established standards for the carriers with edge clips.

By 1978, the work was done, and the task force took the standards to JEDEC (Joint Electronic Device Engineering Committee). The proposed acceptable sizes were published in the Electronic Components and Technology Conference (ECTC) in 1975. The standards process usually took 3-4 years, but by publishing in ECTC, the committee brought about a *de facto* industry acceptance three years early. Fewer sizes allowed smaller companies to build chip carriers at competitive prices. This illustrated the power of the public forum of the ECTC to elicit change.

By 1982, Japanese components were equivalent in performance and reliability to those made by American manufacturers. The talks by Japanese and US manufacturers (IBM, ITT, NEC, NTT etc.) moved the CPMT and ECTC into system packaging — a major change in the focus of the ECTC. The new emphasis on related technologies led to the inclusion of the word "manufacturing"

***The CPMT OUTSTANDING SUSTAINED TECHNICAL CONTRIBUTIONS AWARD** was established in 1992 to recognize outstanding sustained and continuing contributions to the technology in fields encompassed by the CPMT Society.*

1992.........Peter M. Hall
1993.........Rao R. Tummala
1994.........Takaaki Ohsaki
1995.........C.P. Wong
1996.........Leonard Schaper
1998.........Prof. Kanji Otsuka
1999.........Toshi Watari
2000.........Ephraim Suhir

***The CPMT OUTSTANDING YOUNG ENGINEER AWARD** was established in 1996 to recognize outstanding contributions to the fields encompassed by the CPMT Society through invention, technical development, publications, or new product implementation.*

1996.........Michael S. Lebby
1998.........Thomas Swirbel
1999.........Corey Koehler
2000.........Matt Schwiebert

19 Jack Balde, Oral History

in the formation of International Electronics Manufacturing Technology (IEMT) workshops in the US and Japan. These workshops provided a forum for manufacturing technology, computer aided manufacture, soldering and parts handling processes, and inventory and parts control.

Important changes also occurred with the molded plastic packages used on printed circuit boards. Dimitry Grabbe of AMP invented the compliant "J" leads package of premolded or postmolded plastic. The flexibility of the leads of these packages made it possible to put IC chips in a plastic package (CTE3) and connect them to a printed circuit board (CTE16). Texas Instruments adopted this packaging idea first, and subsequently all the major Japanese IC manufacturers followed suit. For the first time, connections were made to printed circuit boards without having to drill holes for pinned leads. The soldering technology changed from wave soldering, to infrared or convection soldering. The industry considered surface mount technology, since resistors and capacitors were also soldered.

The ECTC was concerned with "big iron" and consumer items such as laptops and cell phones. The technologies were small-scale versions of the powerful combination of IC chips and hybrids originally developed for mainframes.

By 1976, the microchip wristwatch emerged on the scene. This was another mass-production item that contributed to circuit board development, which tried and evaluated techniques of circuit encapsulation. For this market, there was a focus on low-cost epoxy encapsulated packaging.

Through the late 1970s, a major topic of interest to the Group on Components, Packaging, and Production was the automated equipment and cabling used to load circuit boards. Microwave type assemblies and molded plastic parts also began to take over from the ceramic.[20]

As the integrated circuit revolution continued, the next generation of systems required better technology. In 1981, IBM announced the 9370 systems, which used 150 circuit logic chips, dissipating 8-10 watts each, 100 of which were mounted on large multi-layer interconnect, ceramic (described by A.J. Blodgett and D.R. Barbour. "Thermal-Conduction Module: A High-Performance Multilayer Ceramic Package," IBM J. Res. Deve.op., 26: pp 30-36, January 1982. Also, see B.T. Clark. "Design of the IBM Thermal Conduction Module," IEEE CHMT Transactions, CHMT-4: 1981). These "multi-chip modules" replaced the "daughter card," and were mounted directly on large (24" by 28") boards with 32 layers of circuitry. With 1000 amperes of current, these boards used large copper bus bars and heavy copper inner planes for power distribution. A finished board could weigh more than 100 pounds. Although IBM's technology was not duplicated exactly, almost all of the large Japanese

Simple multi-chip modules

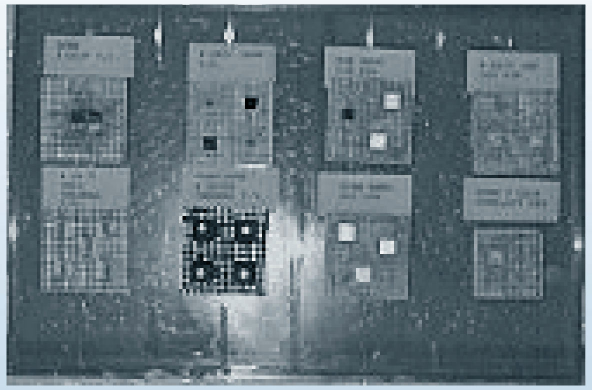


PHOTO COURTESY OF RON GEDNEY

20 Charles Eldon, conversation with

computer manufacturers adopted a variation of the large ceramic "chip carrier" and large board interconnecting system.

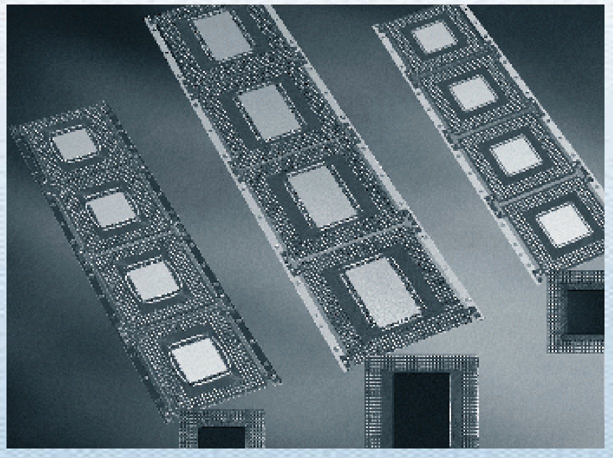
The move to the leaded plastic chip carrier had a major effect on the development of materials that reduced the environmental degradation of components. The IC packages were tested for their ability to protect the IC chips from corrosion. Many of the chips were coated with a material called globtop. An IEEE task force was formed, chaired by Jack Balde, to investigate the use of silicon gel as a surface encapsulant. The task force presented their reports at the ECTC, indicating that the reliability was more than ten times better than molded plastic (more than thirty times better than globtop). The relative reliability of various materials, including the areas of corrosion protection by surface coatings of parylene and silicon carbide, is the subject of ongoing research.

Some companies changed the alloy of the leads, which made the leads very rigid, and caused the plastic package with its compliant J leads to produce mixed reliability and performance. The joints between the leaded packages and the PC boards often failed. The IEEE task force on reliability of compliant lead packages used the ECTC as a forum once again to encourage manufacturers to recognize the appropriate leads.

Beginning in 1992 and thereafter, the Japanese made mainframes in competition with IBM. They also began manufacturing fax machines, a market they dominate today even though Rockwell makes the chips inside those machines.

Despite these technical successes, the United States components industry began leaning towards offshore manufacturing. Special tariffs allowed duties to be paid only on the cost of the work done overseas, providing the components were later incorporated in a product assembled in the United States. US manufacturers took advantage of lower labor costs to shift their components manufacturing operations abroad. In the process, they began the technology transfer, providing a manufacturing edge to thousands of start-up companies around the globe, which caused the United States to face stiff competition from its own technical offspring.

In June 1978, Intel introduced the 8086 chip used in the IBM-PC, and its' popularity made the 8086 an industry standard. In 1984, they reached a milestone by unveiling the 80486 microprocessor, which contained more than a million transistors in a single chip. The advent of Surface Mount Technology (SMT) started a major revolution in packaging in the 1980s. Rather than using a package with pins that went into a printed through hole in the printed wiring board, packages were produced with peripheral leads that mounted flat on the board ("flat pacs"). In the most popular



Flexible circuit packaging

PHOTO COURTESY OF 3M

embodiment, components were placed so that the leads contacted a solder paste that was deposited on the surface of the board. The whole board was then heated to a high temperature, which reflowed the solder paste, making a reliable interconnection. Components could be mounted on both sides of the circuit board, increasing packaging density.

Packaging materials also changed to keep up with the components. The rise in gold prices during the late 1970s put enormous pressure on an industry whose manufacturing process depended on gold for its connections. New alloys were developed for connecting components to boards.

1983 - Japan's Emphasis on Reliability

In the 1960s and 1970s Japan produced many electronic consumer goods that had bad reputations for poor quality and reliability. In the late 1970s, Japanese manufacturers realized that something had to be done if they were to be globally competitive. Back in 1947, a US statistician named W. Edwards Deming arrived in Japan with new theories on statistical quality control, which US manufacturers had paid little attention to. Japanese manufacturers were very receptive, and put Deming's methods into practice. By late 1983, a Hewlett-Packard executive named Paul Ely, using data submitted to him by quality control manager Malcolm Smith, reported that Japanese components were three orders of magnitude more reliable than equivalent parts made in the United States. They surpassed the US in manufacturing quality, and their electronics were paragons of reliability. Their automobiles, with a favorable exchange rate, found great acceptance with American consumers.

As the components became smaller and more reliable, they were designed into more complex systems, requiring more interconnections, which decreased system reliability. System reliability is dependent upon the level at which the units are protected against the environment, and the methods used to connect the functional assemblies.[21] Japanese manufacturers such as NEC, Toshiba, Hitachi, and Fujitsu entered the memory chip manufacturing business when the price of memory began to drop. The US firms, fearing eroding profit margins, chose to get out of the memory business.

The Japanese considered quality control to be a part of the production process, while Americans concentrated on post-production testing and checking. The Japanese also put a high emphasis on production equipment maintenance, and made automation a key factor in their manufacturing. From the standpoint of the components industry (and unquestionably from the consumer's point of view), the cross-fertilization was beneficial, despite the fact that many United States companies found it difficult to compete with rising quality and reduced sales prices.

Product Engineering and Production Group

1954 - 1957: Chairman: Ralph R. Batcher
1958: Chairman: Edwin R. Gamson
1959 - 1960: Chairman: Lewis M. Ewing
1961: Chairman: Warren D. Novak
1962: Chairman: John W. Trinkaus
1963 - 1964: Chairman: Charles (Bud) Eldon
1965: Chairman: L. Kahn

Professional Technical Group on Component Parts

1953 - 1955: Chairman: Floyd A. Paul
1956: Chairman: Alfred W. Rogers
1957 - 1958: Chairman: Rudolf M. Soria
1959: Chairman: Paul S. Darnell
1960: Chairman: J. J. Drvostep
1961 - 1962: Chairman: F. E. Wenger
1963 - 1965: Chairman: L. Kahn
1966: Chairman: Paul K. McElroy
1967 - 1968: Chairman: A. P. Kromer
1969: Chairman: Chauncy W. Watt

21 Schlabach, T. D. and Rider, D. D., 1963 Printed and Integrated Circuitry: Materials and Processes, New York, McGraw-Hill

The Japanese improved upon US technology, and developed manufacturing processes that were more cost-effective and reliable. The US companies often borrowed back this expertise, particularly in replicating Japanese fabrication plant design.

Early 1980 was a time of reassessment for the CPMT (then CHMT) Society. In October, the Administrative Committee commissioned a study of the Society's conferences, publications, organization, and administration. The Society increased its membership, the number of Society-sponsored conferences and workshops, and the amount of published technical material.

Although the Electronic Components Conference became a primary forum for the presentation of new developments in components, packaging, and reliability, no similar event for manufacturing existed in 1977 when the MT and PHP Groups merged to form the Components, Hybrids, and Manufacturing Technology Society (CHMT). In 1984, with no meeting targeted at the design and assembly process, the Japan CHMT Chapter organized a symposium that focused on the technology required for improvements in the production process. The successful symposium drew a number of excellent papers, and the Society decided to further develop its coverage of this portion of the Society's charter. Dennis Olsen and Paul Wesling planned a new symposium in San Francisco in 1986, dubbed the "2nd International Electronics Manufacturing Technology (IEMT) Symposium", with Terry Chappell handling publicity and registration. It assembled technologists from around the world, and was repeated in Anaheim, CA in 1987 and in Orlando, FL in 1988. In 1988 there were two IEMTs, one of which was held in Paris. In 1989, the Japan IEMT was conducted in Nara, and the North American IEMT, in San Francisco. Since then, it has been held semi-annually in North America and alternated between Europe and Japan. In 1996, the Japan IEMT Committee combined their semi-annual IEMT Symposium with the International Microelectronics and Packaging Society's semi-annual Japan International Microelectronics Conference to form the IEMT/IMC Symposium. The North American IEMT was co-sponsored by the EIA for several years. Its current co-sponsor is SEMI and the Symposium held in Austin, TX is coincident with SEMICON/Southwest.

While the production of systems, assemblies, and components was covered through the ECTC and IEMT conferences, the specialized field of semiconductor production was addressed only peripherally. In 1986, Court Skinner of the IEEE Electron Devices Society (EDS) and Paul Wesling from CHMT developed a plan for a new journal to address this critical area. The *Transactions on Semiconductor Manufacturing* was launched in 1988. It was sponsored by the Solid-State Circuits Council, the Reliability Society, EDS and CHMT.

1970: President: Vincent J. Kublin
1971 - 1972: President: S. M. Stuhlbarg
1973 - 1974: President: David Feldman
1975 - 1977: President: Ralph E. Armington

Components, Hybrids, and Manufacturing Technology Society

1978: President: D. P. Burks
1979: President: Albert R. Angevine
1980 - 1981: President: John H. Powers
1982: President: W. Arthur Porter
1983: President: H. J. Gisler, Jr.
1984 - 1985: President: George H. Donaldson
1986 - 1987: President: P. H. Eisenberg
1988 - 1989: President: Leonard G. Feinstein
1990 - 1991: President: Ronald W. Gedney
1992 - 1993: President: C. P. Wong

Components, Packaging, and Manufacturing Technology Society

1994 - 1995: President: Dennis R. Olsen
1996 - 1997: President: Ralph W. Wyndrum, Jr.
1998 - 1999: President: John W. Stafford
2000: President: Rao R. Tummala

A concurrent effort was made to bring technologists together in an annual meeting, and the International Semiconductor Manufacturing Sciences Symposium (ISMSS) became the technical program for SEMICON/West, a large trade show for equipment manufacturers held near the Silicon Valley, with SEMI as its co-sponsor. Court Skinner and Paul Wesling provided the IEEE leadership.

SEMI agreed to add a similar IEEE/SEMI technical track to the SEMICON/Northeast show following its popularity in the Burlingame, CA location. The Advanced Semiconductor Manufacturing Conference (ASMC) launched in 1990, and provided two annual venues for the presentation of new techniques in IC production.

Electrical engineers are in the minority within CPMT; the majority of members are engineers from mechanical, chemical, vacuum, materials, physics and mathematics disciplines. Most people enter the CPMT field after graduating and working (or teaching) in allied fields, and the Society has not been successful in forming student chapters because of the lack of undergraduate curricula in passive device design, electronics packaging, and production technology.[22]

However, the Society was productive in establishing a number of Chapters located in key Sections around the world. The oldest of these Chapters are in Tokyo, Los Angeles, Boston, and the Santa Clara Valley (Silicon Valley). The importance of our disciplines to the success of electronics devices and products has increased the number of Chapters in recent years, under the guidance of Chapter Development Chair Ralph Russell and our CPMT Executive Director Marsha Tickman. As we enter the 21st Century, there are more than 30 local Chapters (some organized as joint chapters with other IEEE Societies). In 1999 the Santa Clara Valley Chapter won the newly established "Chapter of the Year" award over several other strong chapters such as those in Hong Kong, Tokyo, Sweden, and Singapore.

Reporting on the Technology

As noted earlier, the Society's journals started with an issue of the *IRE Transactions on Component Parts in March*, 1954, and this series was published until March, 1965. Similarly, the *IRE Transactions on Production Techniques* began in September 1956, becoming the *IRE Transactions on Product Engineering and Production* in 1961. These two journals merged in 1965 to form the *IEEE Transactions on Parts, Materials and Packaging*, which was renamed to the *IEEE Transactions on Parts, Hybrids and Packaging* in June 1971.

The IEEE Group on Manufacturing Technology began its Transactions in June 1972, and the merger between the MT and PHP groups in 1977 resulted in the *IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, which was published between 1978 and 1993. In the early 1980's, the Transactions published between 500 and 650 pages of technical papers each year. However, as components, reliability, and packaging problems and developments began to dominate the electronics industry, the number of pages quickly expanded to more than 1000, with Paul Wesling in the newly created position of vice-president of publications. The response was to abandon the quarterly publication schedule and go to six issues each year.

When the Society name was revised in 1994, the Transactions were split into two journals – the *IEEE Transactions on CPMT, Part A*, containing all non-packaging papers; and the *IEEE Transactions on CPMT, Part B: Advanced Packaging*, to support the growing number of packaging-related manuscripts. As the page count rose to more than 1500 (combined), a third split was approved, creating the *IEEE Transactions on CPMT, Part C: Manufacturing*. These three journals were renamed in 1999 to become the current three Society journals: the *IEEE Transactions on Components and Packaging Technologies*; the *IEEE Transactions on Advanced Packaging*; and the *IEEE Transactions on Electronics Packaging Manufacturing*, which combined, exceed 1800 pages.

In 1988, the CPMT Society formed a joint publication with the Electron Devices Society to address the need for a forum for the specialized manuscripts on process modeling, development and implementation for the production of semiconductor devices. The *IEEE Transactions on Semiconductor Manufacturing* has grown to over 600 pages in four issues per year.

In preparation for the 50th anniversary celebration, all past issues of the IEEE CPMT Society's Transactions – over 25,000 pages – have been published on a set of CD-ROMs and made available at minimal cost to our current Society members. Replacing over three meters (10 feet) of shelved "paper" copies with a few CD-ROMs illustrates the quickening pace of technology.

The late 1980s recognized packaging technology as a profession in its own right. In 1989, three major books were published on Packaging Technology, the most noteworthy being Tummala et al's Microelectronic Packaging Handbook, (edited by Rao R. Tummala and Eugene J. Rymaszewski, Van Nostrand Reinhold, 1989) a nearly 1200-page volume covering all aspects of electronics packaging. In 1980, the number of university research programs devoted to electronic packaging could be counted on one hand. University degree programs in electronic packaging began after Motorola joined with CPMT to offer a major graduate scholarship to interested students. By 1995, there were more than 40 universities involved, some with major centers devoted to electronic packaging research, and several offering advanced degrees (M.S. and Ph.D. programs) in electronic packaging.

CPMT Society Vice President, Paul Wesling (right) carries the Olympic Torch in 1996.

22 Wesling, Paul, various discussions and emails with, Nov. 1999

In industry, new tools were developed for precise, high-speed alignment and placement of components. After components were placed, a single reflow operation joined them simultaneously. By 1998, this technology became so efficient and pervasive that the cost of a personal computer dropped by almost a factor of three in a single twelve-month period. The technology is now used for practically every newly designed electronic box, and over 70% of all boards manufactured are in SMT technology.

The design and manufacture of integral resistors and capacitors has been revised with technology that puts these components into both organic and ceramic interconnection boards, and multi-chip modules now recognized as having superior cost/performance to very large IC chips. The progression to larger and larger chips has reached a point of no return, and this is the victory of the packaging engineer over the silicon manufacturer. 4-chip modules with copper interconnections provide higher performance than the single chip four times as large. ECTC publication will help decide the future with the latest papers on this issue.

Today, "Moore's law"[24] continues to forge ahead, and the packaging challenges involve handling smaller interconnections in higher numbers. We have progressed from simple single chip peripheral leaded packages to area array packages. Chip Scale packages approach flip chips in size and I/O density. Until now, lowering the voltages at which the semiconductor operates has kept power dissipation under control. But as devices become smaller and denser, power is on the increase. The next generation of devices contemplates wafer scale integration or "System on a Chip," which may involve more than one chip on a silicon carrier. Whatever the future may hold, CPMT and its technical committees will be leading the way.

"And still the reduction of dimensions continues. The limit is set on the one hand by the wavelength used in the lithographic process and on the other by the electrical and physical effects that occur on miniaturization.[23]"

23 Van Vessem, J. C., "From Transistor to IC." Philips Technical Review, Vol 42, No. 10/11/12, Sept., 1986, pp 327-335

24 Gordon Moore's prediction, from a paper in *Electronics* magazine, that the complexity of integrated circuits – as determined by the number of their components – would continue to double annually. Moore, G.E., 1965. "Cramming More Components onto Integrated Circuits." Electronics (19 April), pp. 114-17.

Sources

The oral-history transcripts referred to were all conducted by staff of the IEEE History Center at Rutgers University, except for the oral history of Jack Kilby, which is part of the collection of the The Charles Babbage Institute of Computer History at the University of Minnesota. Many of the oral histories were conducted as part of the project supported by the IEEE Components, Packaging, and Manufacturing Technology Society as part of its 50th Anniversary celebrations.

Air Force Systems Command, 1966 *Integrated Circuits Come of Age*, Washington, DC, United States Air Force

Balde, Jack, Oral History, June 1999

Burbank, Danield P., "The Near Impossibility of Making a Microchip" *Invention and Technology*, Vol 15, #2, Fall 1999, pp 44-52

Riordan, M. and Hoddeson, L., 1997 *Crystal Fire: The Birth of the Information Age*, New York, W. W Norton

Gedney, Ron, Oral History, June 1999

Henney, K. (ed.) 1956 *Reliability Factors for Ground Electronic Equipment*, New York, McGraw-Hill

Kilby, Jack S., "Invention of the Integrated Circuit" IEEE Transactions on Electron Devices, Vol 23, #7, July, 1976, pp 648-654

Kilby, Jack S., Oral History, Babbage Center for History of Computing

Lack, F. R., "Why Not Dependability in Electronics?" *Proceedings of Symposium on Improved Quality Electronic Components*, 1950, Washington, DC

Paul, Floyd A., "Report of the Chairman" *Transactions of the IRE Technical Group on Component Parts*, April 1955,

Schlabach, T. D. and Rider, D. D., 1963 *Printed and Integrated Circuitry: Materials and Processes*, New York, McGraw-Hill

Sprague, Robert G. "The Components Engineer – His Place and Importance." *Proceedings of Symposium on Improved Quality Electronic Components*, 1950, Washington, DC

Van Vessem, J. C., "From Transistor to IC." *Philips Technical Review*, Vol 42, No. 10/11/12, Sept., 1986, pp 327-335

Wenger, Floyd E., "A Message from the Chairman". *IRE Transactions on Component Parts*, Vol. CP-7, #3, Sept. 1960, pg 69

Wolff, M. 1976. "The Genesis of the Integrated Circuit." *IEEE Spectrum* (August), pp. 45-53

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