Jack Kilby demonstrated the working of the world's first integrated circuit in September 1958. He was awarded the Nobel Prize in Physics in the year 2000 for his part in the invention of the integrated circuit. The following paper which is reprinted from the July 1976 issue of the *IEEE Transactions on Electron Devices*, describes the developments that led to the invention of the integrated circuit. It is from the pen of the inventor, Jack Kilby himself.

Y N Srikant

Invention of the Integrated Circuit

Jack S. Kilby, Fellow, IEEE

BACKGROUND

The first electronic equipments were composed of a few dozen components and could readily be assembled by hand-soldering techniques. Each component was manufactured separately by a process optimized for the purpose. As electronic equipment became more complex, shortcomings in this procedure began to appear. The cost of the equipment increased more rapidly than the component count, and equipment reliability suffered a corresponding decrease.

Because of their interest in complex electronic systems, the problem was particularly apparent to the military. Each B-29 required nearly a thousand vacuum tubes and tens of thousands of passive devices. Its electronics equipments were among the most complex systems in being at the time.

By the end of World War II it was apparent that future systems would be limited by the cost, bulk, and reliability of the electronics.

One of the first attempts to simplify the manufacturing process was carried out under National Bureau of Standards sponsorship. Their proximity fuse requirements necessitated compact rugged electronic subsystems. The Centralab Division of Globe-Union, Inc. proposed a design in which ceramic substrates would carry metal interconnections

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and chip capacitors, with miniaturized vacuum tubes attached. This proposal was developed by Rubenstein, Ehlers, Sherwood, and White of Centralab [11, and was probably the first attempt to form components *in situ*.

After the war, NBS and Centralab continued to work in this area. The Centralab effort, under R. L. Wolff and A. S. Khouri, developed high-volume screening techniques for production. Centralab built substantial quantities of amplifiers for hearing aid applications, with several dozen passive components and three or four tube sockets for active device attachment. They further simplified the concept by the use of a substrate with a high dielectric constant, permitting the fabrication of low cost *RC* networks for radio and television applications. About 140 million circuits of this type were produced by 1962.

The NBS effort, originally led by Brunetti and later by Franklin [2], also continued to develop two-dimension (2-D) circuit assemblies. A complete in-house fabrication capability was established. In the early 1950's, Robert Henry of this group, working under Navy sponsorship, abandoned the 2-D concept and produced a novel design in which ceramic wafers with one to four passive components per wafer were stacked and interconnected with vertical riser wires. A tube socket was mounted above the assembly so that each module was a complete functional unit. The concept was christened "Tinkertoy" [3], and a mechanized line for production of finished assemblies was established by a division of Illinois Tool Works. More than 5 million modules were produced by the time the line ceased operation.

Other attempts to simplify the manufacturing process focused on the interconnection of components. In 1949 Danko and Abrahamson of the Signal Corps announced the "Auto-Sembly" process [4], in which component leads were inserted into a copper foil interconnection pattern and dip soldered. With the development of board lamination and etching techniques, this concept evolved into the standard printed circuit board fabrication process in use today.

During the period, electronic designs were limited by the facts-of-life of the vacuum tube. Tubes were large and expensive in comparison to most of the passive components. Their life was limited, so that frequent replacements were necessary. They dissipated a significant amount of power, requiring provisions for cooling. All of these factors changed dramatically with the invention of the transistor in 1948.

Although it required several years, the existing technologies were modified to accept the transistor. The Tinkertoy approach was abandoned, and replaced by the Micro-Module program under Signal Corps sponsorship. The Micro-Module program was a major effort [5]. RCA was selected as the prime contractor, and more than $25 million was spent. Most was spent within RCA, but small contracts were let to encourage other component manufacturers to repackage their parts into wafer format.

DOFL and Centralab adapted their two-dimension designs for transistors. DOFL proposed to insert transistors into the substrate and connect them to the substrate with a photolithographic technique [6]. This process, developed by Lathrop and Nall, was one of the first applications of photolithography in the electronics industry. The Centralab work will be described in a later section.

At about this time several companies began to propose the use of evaporated films as a substitute for the screened components of Centralab and DOFL. Varo and G.E. were particularly active in this area. One of the dimly seen advantages of the evaporation technique was that it would some day permit the fabrication of thin-film active devices. This concept was supported by the Navy, although few contracts were let.

The transistor also suggested concepts based on semiconductor technology. The first to perceive the possibility was G.W.A. Dummer of the Royal Radar Establishment in England.

Addressing the Electronic Components Conference in 1952, he said, "With the advent of the transistor and the work in semiconductors generally, it seems now possible to envisage electronics 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 remarkable statement was not explicit as to how such devices might be realized. The use of terms such as "insulating" and "amplifying" layers does not suggest the use of circuit techniques. In 1956 Dummer let a small contract to a British manufacturer. They were unsuccessful in realizing a working device, primarily because they were working with grown-junction techniques.

In the early 1950's, perhaps as a result of Dummer's comments, the Air Force began to define an approach which would be called "Molecular Electronics." This approach [7] proposed to depart from the electronic circuits of the past, and to develop new structures which would perform the desired functions more directly. A quartz crystal was the preferred example of a molecular device, performing the functions of an inductance and capacitance without a part-for-part equivalence. Resistors were to be avoided because they wasted power. Although the effort was not limited to semiconductors, it was expected that these materials would play a large part.

In 1957 and 1958 the Air Force discussed this concept with Westinghouse, and a contract was awarded in 1959. Representative Air Force equipments were to be examined, and new devices to perform the desired functions were to be systematically invented. The program was funded at a $2 million per year rate, over the strenuous objections of the other services.

By the beginning of 1958 each of the three services had chosen a position. The Army was heavily committed to the Signal Corps Micro-Module, although DOFL still favored 2-D circuits and continued to work on them. The Navy did not have a program, but clearly favored thin film technology. The Air Force was committed to Molecular Electronics, an approach which was considered hopelessly far out by the other services. Small R & D efforts existed within the major electronic firms, most supporting the Signal Corps or the Navy.

PERSONAL EXPERIENCE

In 1947 I graduated from the University of Illinois with a degree in electrical engineering. I was hired by A. S. Khouri of Centralab to work on screened circuits. My duties included design and product engineering work on hearing aid amplifiers and *RC* networks.

In 1952 Centralab acquired a transistor license from Bell, and R. L. Wolff and I attended the first symposium for licensees. When we returned I was made leader of a three-man project to build transistors and to incorporate them into Centralab products. We built a reduction furnace, crystal puller, and zone refiner and began to make germanium alloy devices.

The proposed design was novel, in that the unprotected transistors were mounted in a plastic carrier. Environmental protection was to be provided using the ceramic substrate as a part of the hermetic seal. For audio applications, large-value capacitors were required. These were provided by the development of the reduced titanate capacitor [8],

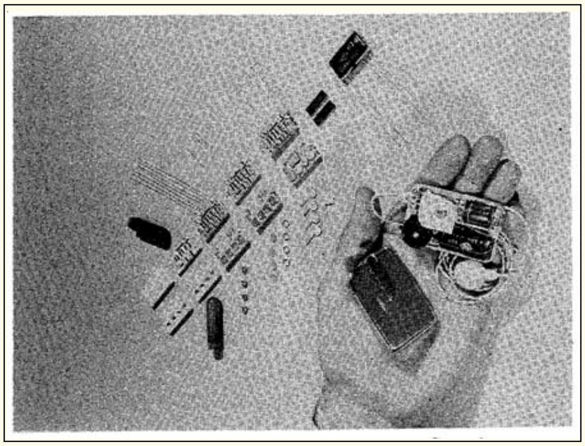

Fig. 1. Thick film circuit produced by Centralab in 1957. Germanium alloy transistors were sealed into recesses in substrate. Deposited resistors and reduced titanate capacitors were used.

also basically a semiconducting device. A unit of this type is shown in Fig. 1. I reported to and was encouraged in the project by R. L. Wolff.

By 1957 a small production facility had been established, and we were selling small quantities of amplifiers for hearing aids and some other applications [9]. The operation was marginally profitable, but it was clear that major expenditures would soon be required. The military market represented a major opportunity, but required silicon devices. The advantages of the diffused transistor were becoming apparent, and its development also would have required expenditures beyond the capability of Centralab. I felt that changes were coming so rapidly that it would not be possible for very small groups with limited funding to be competitive. I decided to leave the company.

After several interviews, I was hired by Willis Adcock of Texas Instruments. My duties were not precisely defined, but it was understood that I would work in the general area of microminiaturization. Soon after starting at TI in May 1958, I realized that since the company made transistors, resistors, and capacitors, a repackaging effort might provide an effective alternative to the Micro-Module. I therefore designed an IF amplifier using components in a tubular format and built a prototype. We also performed a detailed cost analysis, which was completed just a few days before the plant shut down for a mass vacation.

As a new employee, I had no vacation time coming and was left alone to ponder the results of the IF amplifier exercise. The cost analysis gave me my first insight into the cost structure of a semiconductor house. The numbers were high—very high—and I felt it likely that I would be assigned to work on a proposal for the Micro-Module program when vacation was over unless I came up with a good idea very quickly. In my discouraged mood, I began to feel that the only thing a semiconductor house could make in a cost-effective way was a semiconductor. 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.

I also realized that, since all of the components could be made of a single material, they could also be made *in situ,* interconnected to form a complete circuit. I then quickly sketched a proposed design for a flip-flop using these components. Resistors were provided by bulk effect in the silicon, and capacitors by p-n junctions.

These sketches were quickly completed, and I showed them to Adcock upon his return from vacation. He was enthused but skeptical and asked for some proof that circuits made entirely of semiconductors would work. I therefore built up a circuit using discrete silicon elements. Packaged grown-junction transistors were used. Resistors were formed by cutting small bars of silicon and etching to value. Capacitors were cut from diffused silicon power transistor wafers, metallized on both sides. This unit was assembled and demonstrated to Adcock on August 28, 1958.

Although this test showed that circuits could be built with all semiconductor elements, it was not integrated. I immediately attempted to build an integrated structure, as initially planned. At that time Texas Instruments had a very strong capability in grown-junction devices but had just begun to work seriously on diffused structures. One silicon transistor, a power device with alloyed emitter, was in production, as were several small-signal germanium devices. At that time the germanium transistors were made with about 25 devices on a 0.4-in-square wafer. Emitter and base contacts were evaporated through metal masks. Mesas were etched after hand masking with black wax.

I obtained several wafers, diffused and with contacts in place. By choosing the circuit, I was able to lay out two structures that would use the existing contacts on the wafers. The first circuit attempted was a phase-shift oscillator, a favorite demonstration vehicle for linear circuits at that time. Technicians "Pat" Harbrecht and Tom Yeargan cut the wafers into bars about $^1/_{16}$ in wide and 0.4 in long. Metal tabs were alloyed to the back of the bar to provide contacts to the bulk resistors. Black wax was applied by hand to mask the mesas, one for the transistor and a larger one for a diffused region forming a distributed *RC* network. This structure is shown in Fig. 2. A flip-flop was also built in this manner as shown in Fig. 3.

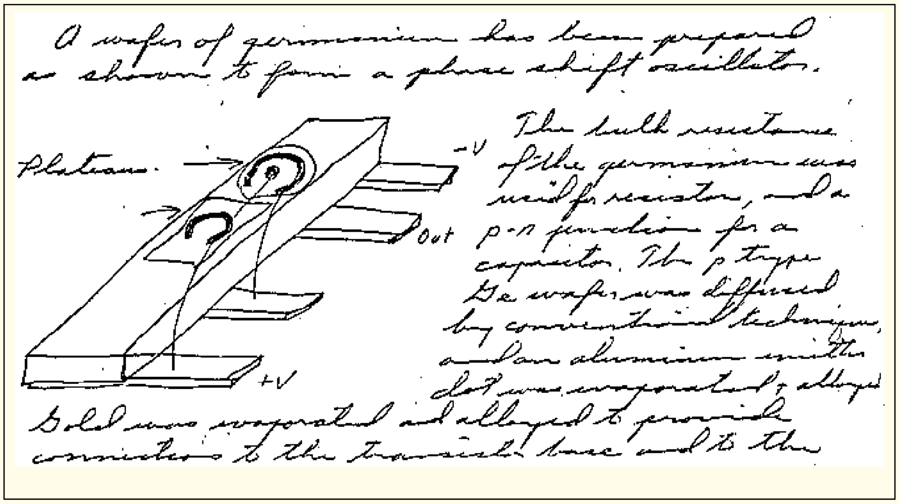

Fig. 2. Page of Kilby engineering notebook describing a phase shift oscillator built from an existing diffused germanium wafer.

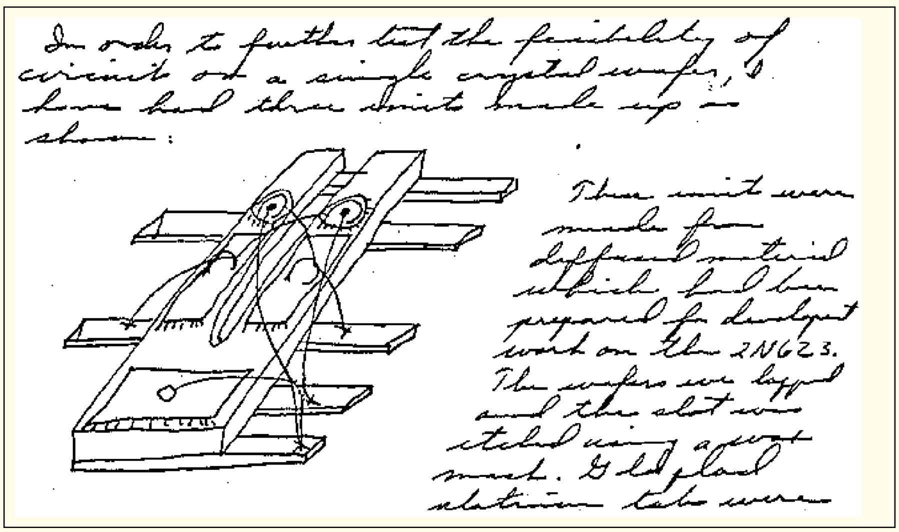

Fig. 3. Page of Kilby engineering notebook describing a flip-flop built from an existing diffused germanium wafer.

REDUCTION TO PRACTICE

On September 12, 1958 the first three oscillators of this type were completed. When power was applied, the first unit oscillated at about 1.3 megacycles. This test was witnessed by Mark Shepherd, Cecil Dotson, Willis Adcock, and several others.

To show that digital circuits could be built, the same techniques were used to build a flip-flop. This unit was completed on September 19. Both the phase-shift oscillator and the multivibrator were thus built from existing materials. The only “tooling” for these units consisted of small graphite jigs used to position the metal tabs used for back contacts.

At about this time, J. W. Lathrop had started work in TI’s Research and Engineering Department. Jay had been at DOFL, where he and James Nall pioneered in the use of photolithographic techniques for semiconductor devices. Lathrop quickly set up a small facility for making photo-masks and began to develop the necessary device processing techniques. Although his primary responsibility was the development of processes for discrete devices, his experience at DOFL made him highly interested in my work, and he became quickly involved in preparation of masks for the new integrated designs.

I soon expanded the concept by the addition of more stable components. In November, capacitors were built using oxide layers on silicon, and early in December, the first diffused-layer resistors were built and tested. The improved stability of these components was recognized as being of basic importance to future design. During this time, consideration was also given to packaging techniques, and the now familiar $^1/_8 \times {}^1/_4$ in flat-pack dimensions were chosen. This form factor was chosen deliberately, to emphasize that this technique was new and basically different from those which had been proposed previously. During this period it was also recognized that metal resistors of high precision could be evaporated on an oxide layer on the surface of the silicon. This technique is now used in some radiation-hard circuits.

Early in October the design of a new germanium flip-flop was started. This unit was the first to be built from scratch. It used bulk resistors, junction capacitors, and mesa transistors as shown in Fig. 4. Diffusions were made by Dub Little, and photo-etching techniques were developed by Jay Lathrop and Lee Barnes. The first working units of this type were completed early in 1959 and were later used for the first public announcement of the “Solid Circuit” (integrated circuit) concept at the IRE show in March 1959.

Although the group working on the project during this period was small, TI management supported the project enthusiastically. P. E. Haggerty, then President of TI, in discussions with Willis Adcock as early as 1955, had suggested that it should be possible to do more with semiconductors and felt that the concept was an excellent way to do so. Mark Shepherd, then responsible for all semiconductor work in the company, was also highly supportive. Charles Phipps contributed to refinements of the concept and kept us in touch

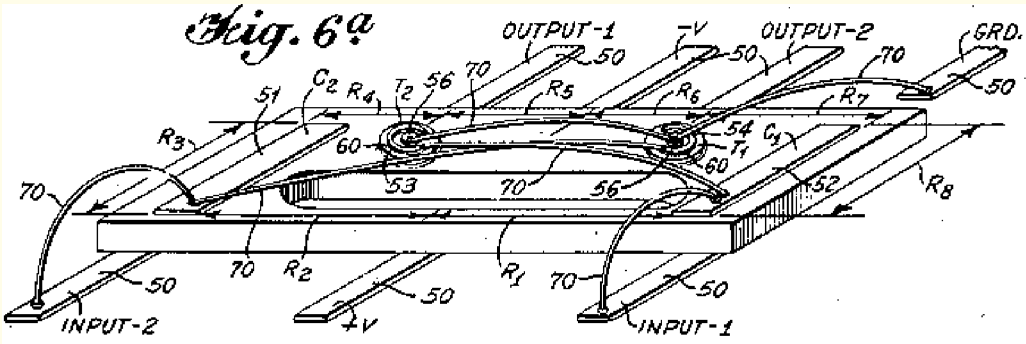

Fig. 4. Germanium flip-flop using mesa transistors, bulk resistors, diffused capacitors, and air isolation of the components. From US Patent 3,138,743.

with economic reality. Work on other microminiaturization techniques, particularly the Micro-Module, was continued for several months. But it was allowed to die out, and the full support of the company was given to the "Solid Circuit."

REACTION OF POTENTIAL USERS

During the fall, we began to inform the military services of the concept. Reactions were mixed. The Navy had little interest, and no programs were established. The Signal Corps expressed some interest and began to define a contract which would show that the technique would be fully compatible with the Micro-Module. Unfortunately, the demonstration they had chosen required silicon p-n-p transistors. These proved quite difficult to fabricate, and by the time the techniques were mastered, the Micro-Module program was in serious trouble.

The "Solid Circuit" concept caused a major debate within the Air Force. A substantial budget had been established for work in Molecular Electronics. If the "Solid Circuit" was indeed a Molecular Electronics concept, support was assured. But most of the strong Molecular Electronic supporters felt that the TI approach did not qualify. It was a circuit, and they were not going to have circuits any more. Worst of all, it even had resistors, and resistors wasted power.

Fortunately, a small group within the Air Force, led by R. D. Alberts of WADC, was able to prevail. They felt that the concept provided an orderly transition to the new era, and that by providing a systematic design approach, it eliminated the need to invent the thousands of new devices which would be required for future equipments.

Albert's group then provided the first of a series of contracts which proved invaluable in sustaining the project during the critical years. These included both research and development efforts to broaden the concept, and manufacturing methods funds which helped support the first manufacturing line. Demonstration vehicles which clearly showed the advantages of these new techniques were also included.

In the middle of January 1959, we began to prepare the first patent application. The basic circuit elements—bulk resistors, diffused resistors, junction capacitors, oxide capacitors, mesa transistors, and inductances were described, and the design parameters were given for each. Several techniques of isolation of components were described, including air, use of intrinsic material, and use of p-n junctions to provide a barrier to current flow. Two embodiments were chosen to illustrate the concept. One was basically the phase-shift oscillator of Fig. 2, and the other, the flip-flop shown in Fig. 4. These choices were basically mine and proved to be poor ones. No complete circuits showing diffused resistors, oxide capacitors, or inductances were included.

In particular, the omission of an embodiment with several diffused resistors was to have serious consequences later. The application- was filed on February 6, 1959.

ANNOUNCEMENT

The concept was publicly announced at a press conference in New York on March 6, 1959, during the IRE show. Shepherd said "I consider this to be the most significant development by Texas Instruments since we divulged the commercial availability of the silicon transistor." Haggerty predicted the circuits first would be applied to the further miniaturization of electronic computers, missiles, and space vehicles and said that any application to consumer goods such as radio and television receivers would be several years away.

The announcement was widely reported in the press. Over the next few years debates on the merits of the integrated circuit provided much of the entertainment at major technical meetings. Three main objections were foreseen:

1) The concept did not make optimum use of materials. Nichrome made better resistors and Mylar better capacitors. Performance of the transistors might be degraded by the inclusion of other components.

2) Circuits of this type were not producible. Component yields were always low, and if

20 components each with 90-percent yield were fabricated monolithically, the overall yield would be about 12 percent. Similar arithmetic was performed on the large number of process steps involved.

3) Designs would be expensive and difficult to change. Circuit designers would be out of a job.

These objections were difficult to overcome because they were all true. They were persuasive enough that most of the larger laboratories were slow to react, and none actively endorsed the concept for several years. By then, integrated circuit volumes were large enough and production costs low enough to make it clear that these objections were simply irrelevant.

Although the larger companies did not react, several smaller groups did. Within a month, Kurt Lehovec of Sprague had filed a patent application (Fig. 5) describing structures in which active devices were separated by multiple p-n junctions. The patent proceeded rapidly through the Patent Office, and Lehovec was allowed claims on "a multiple semiconductor assembly comprising a semiconductor slice having a plurality of regions of *alternating* p and n conductivity types to . . . provide a plurality of p-n junctions . . . thereby achieving electric insulation of said components ... by the impedance of said p-n junctions." In an interference proceeding, the Patent Office held that Lehovec was entitled to claims of this type since they were not disclosed in any of the drawings of the Kilby patent. Whether the "alternating p-n junctions" exist in modern circuits is not clear. The question has not been tested in court.

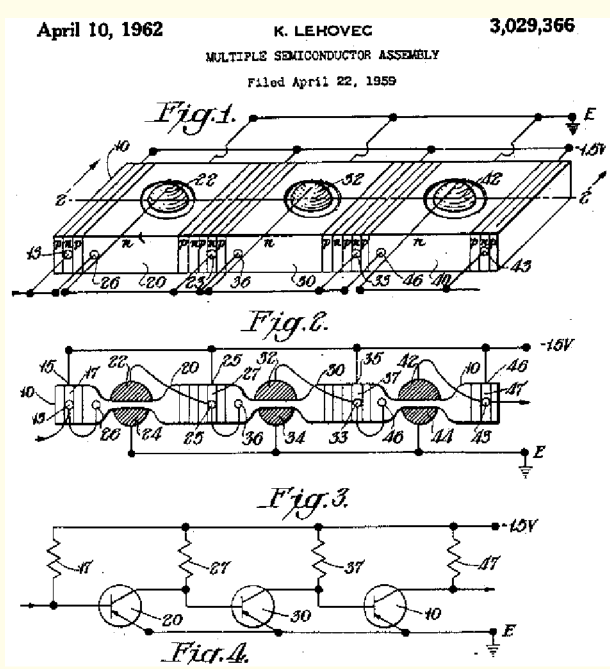

Fig. 5. US Patent 3,029,366, describing Lehovec's alternating p-n junctions for isolation.

In the fall of 1958 a team led by Jean Hoerni at then newly formed Fairchild Semiconductor had begun a program to develop an improved core-driver transistor. When the device was announced in August 1959 it provided a landmark in semiconductor history, since it represented the first modern diffused transistor. It used the production photolithographic techniques and a compatible set of diffusion processes previously developed by R. N. Noyce and G. E. Moore, to produce dished junctions extending to the surface. Oxide passivation of the surface protected the junctions and provided a reproducibility that assured more consistency than any previous manufacturing process. This was christened the "PLANAR" process.

After the TI announcement Bob Noyce, then manager of R&D at Fairchild, began to consider the application of their new technology to it. Noyce's ideas were disclosed in a patent application filed July 30, 1959. His design is shown in Fig. 6. Two transistors with three diffused regions were formed on a common substrate, with one of the transistors used as a pair of diodes. Junctions were also used for capacitance, while metal leads over an oxide layer were used to provide interconnections and some of the required resistances.

When the patent issued, several broad claims had been allowed, covering a device with "a body of semiconductor . . . containing adjacent P-type and N-type regions with a junction therebetween extending to said surface . . . two contacts upon opposite sides of said junctions, an insulating layer consisting essentially of oxide or said semiconductor on and *adherent* to said surface . . . and an electrical connection to one of said

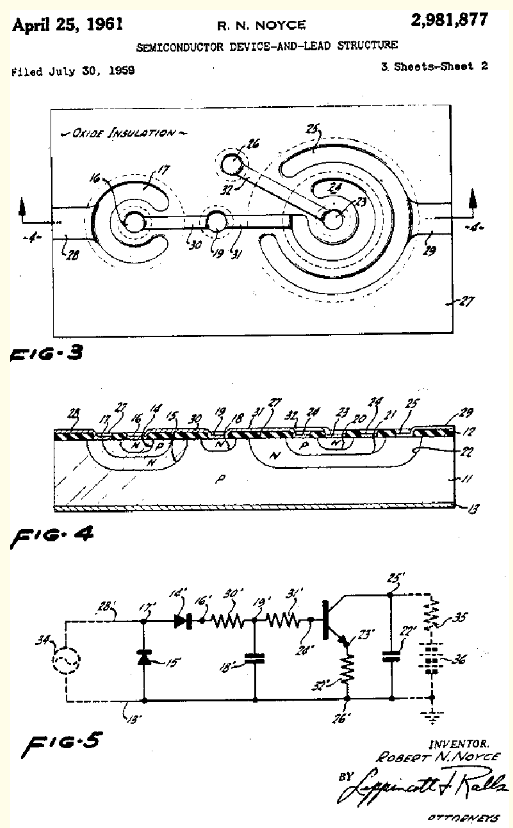

Fig. 6. Noyce patent 2,981,877 showing planar structure with evaporated aluminum interconnections adherent to the surface.

contacts comprising a conductor *adherent* to said layer . . . ."

In an interference, Kilby relied on the structure of Fig. 4 and a statement in the application, "Instead of using gold wires 70, in making electrical connections, connections may be provided in other ways. For example, an insulating and inert material such as silicon oxide may be evaporated onto the semiconductor circuit wafer through a mask . . . to cover the wafer completely except at points where electrical contact is to be made . . . Electrically conducting material such as gold may then be laid down on the insulating material to make the necessary electrical circuit connections." The patent examiner and the Board of Patent Interferences awarded priority to Kilby. The ruling was overturned by the Court of Customs & Patent Appeals. The court ruled that Noyce had been the first to teach the technique of applying interconnections adherent to the oxide.

LARGE-SCALE PRODUCTION

If all of the structures illustrated seem crude and primitive, it should be noted that one of the great strengths of the integrated circuit concept has always been that it could draw on the mainstream efforts of the semiconductor industry. It was not necessary to develop crystal growing or diffusion processes to build the first circuits, and new techniques such as epitaxy would be readily adapted to integrated circuit fabrication. Similarly, new devices such as MOS transistors and Shottky barrier diodes would be phased in as they became available. Even today, it is difficult to identify a process that is used only for integrated circuits.

Another strength of the concept was that it could draw on existing circuit technology to produce a broad range of useful devices. Other early approaches to the problem, such as those at Westinghouse and others by Johnson [10] and Wallmark [11] of RCA, and Stewart, Aitken, and Holmquest of TI were directed at specific configurations useful only for specific applications.

Because of the commonality with existing processes, integrated circuits moved rapidly into a production status. The first TI device for customer evaluation was announced in March 1960. In March of 1961, Fairchild announced the Micrologic[1] family, a compatible set of digital circuits incorporating junction-isolated diffused resistors and evaporated interconnectors. In October of that year, TI delivered to the Air Force a small working computer complete with a few hundred bits of semiconductor memory, and

[1] This family was designed by Bob Norman and built by a group headed by Jay Last.

announced the Series 51. The Series 51[2] also used junction-isolated components and used variations in the evaporated interconnection pattern to produce six different circuit types. Since a portion of the Series 51 effort was supported by NASA, these circuits were designed for low-power applications.

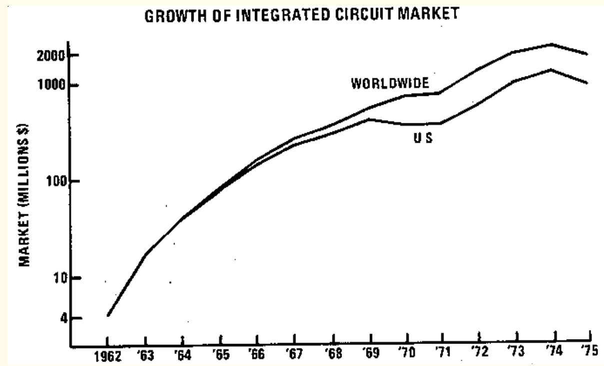

Fig. 7. Growth of the integrated circuit market since 1962 expressed in millions of dollars.
Source: Texas Instruments.

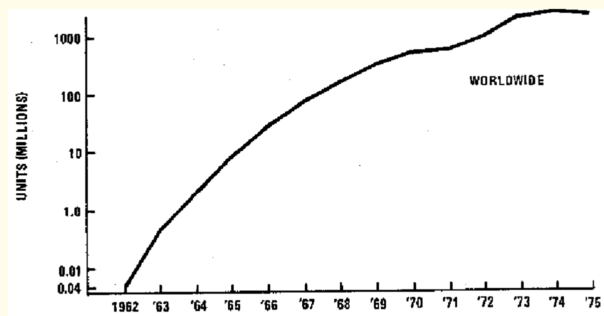

Fig. 8. Growth of the integrated circuit market in units built since 1962.
Source: Texas Instruments.

In 1962 TI was awarded a large contract to design and build a family of 22 special circuits for the Minuteman missile. Fairchild received substantial contracts from NASA and a number of commercial equipment makers. Although only a few thousand units were delivered in 1962, the year represented the beginning of mass production. The growth of the integrated circuit market since that time is shown in Figs. 7 and 8. Integrated circuits now represent about 46 percent of the total semiconductor market.

Units sold in 1962 were priced at \$100 in small quantities and at \$50 for larger volumes. Since that time, the average price has decreased dramatically and was less than eighty cents per unit in 1975. This is plotted in the form of an experience curve in Fig. 9. In such

[2] The Series 51 was designed by Bob Cook. Process Technology was developed by a group under Jay Lathrop.

plots, a straight line means that the price decreases by a constant percentage each time the cumulative number of units produced is doubled.

The 1962 units were simple devices with two to four digital gates per package. The 1975 circuits were produced with more than 2000 gates or 4000 bits of memory per package. Complexity can be measured in terms of active element groups, or AEG. An AEG is a digital gate, a bit of memory, or a single-stage amplifier. The selling price of an AEG has of course decreased much more rapidly than that of the average unit and is shown by the broken line in Fig. 9. Even this line represents an average; an estimate of the *lowest* price per AEG in each year is also shown in Fig. 9. By the end of 1975 this price was probably about \$0.001 per AEG.

Such remarkable changes have increased the requirements for electronic circuits. It is estimated that the demand for circuits increased at about 10 percent per year during the vacuum-tube era. This was increased by the advent of the transistor to a growth in demand of about 19 percent per year, and by the early integrated circuits, to about 38 percent per year. It is anticipated that the availability of present low-cost digital logic and memory circuits will cause the demand to increase to a growth rate of 50 percent to 60 percent per year in the near future, as shown in Fig. 10.

This progress is not the work of any single individual or small group of individuals. It has come about because of the contributions of thousands of engineers and scientists in laboratories and production facilities all over the world.

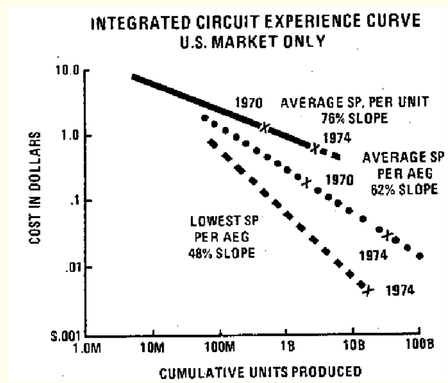

Fig. 9. Integrated circuit selling price, showing cost per unit, cost per AEG, and estimated cost of lowest priced AEG since 1962.
Source: Texas Instruments.

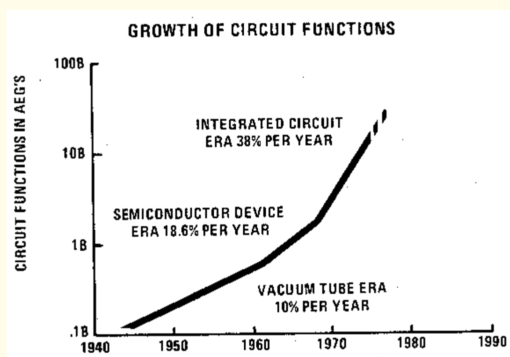

Fig. 10. Expansion of the demand for electronic circuit functions since 1940.
Source: Texas Instruments.

REFERENCES

[1] R. L. Wolff, personal communication.
[2] "New advances in printed circuits," National Bureau of Standards, Washington, DC, publication 192; Nov. 22, 1948.
[3] R. L. Henry and C. C. Rayburn, "Mechanized production of electronic equipment," *Electronics,* vol. 26, pp. 160–165; Dec. 1953.
[4] S. F. Danko, "New developments in the Auto-Sembly technique of circuit fabrication," in *Proc. National Electronics Conference* (Chicago, IL, Oct. 22–24, 1951), pp. 542–550.
[5] S. F. Danko, W. Doxey, and J. P. McNaul, "The micro-module—a logical approach to miniaturization," *Proc IRE,* vol. 47, pp. 894–904, May 1959.
[6] J. W. Lathrop and J. R Nall, US Patent 2,890,395.
[7] "Molecular Electronics-Dendritic Approach," WADD Tech Notes 60–97 and 60–295 (Reports by Westinghouse Electric Corp., DYD 45106 and DYD -45158, dated Feb. and July, 1960, prepared for WADD, USAF).
[8] R. R. Roup and J. S. Kilby, US Patent 2,841,508, issued July 1, 1958.
[9] —, "Transistor amplifier packaged in steatite," *Electronics,* Oct. 1956.
[10] H. Johnson, US Patent 2,816,228, issued Dec. 10, 1957.
[11] J. T. Wallmark, US Patent 3,038,085, issued June 1962.