A BRIEFING ON INTEGRATED CIRCUITS

Finally, here is a newer version using integrated circuits, containing in the upper left-hand corner eight outlined integrated circuits. These eight integrated circuits provide essentially the same function that was provided by either of the previous boards. 24 integrated circuits have been reduced to 8. Notice that the wiring on this newest package is extremely orderly and well organized.

Sello: I see fewer pin connections, too.

Angell: This is perhaps typical. We find that as we make a more complex function in one structure, the number of pins tends to go up only as roughly the square root of the complexity that's provided by the board.

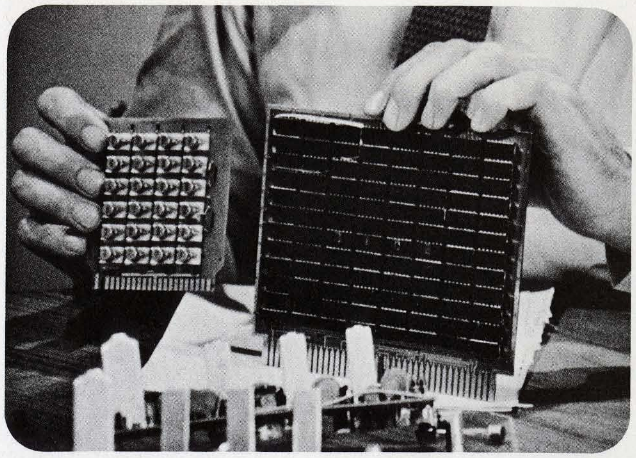
Now you've seen an evolution of transistors to early integrated circuits to modern ones. Here is a series of photographs which shows you what's inside the corresponding cans.

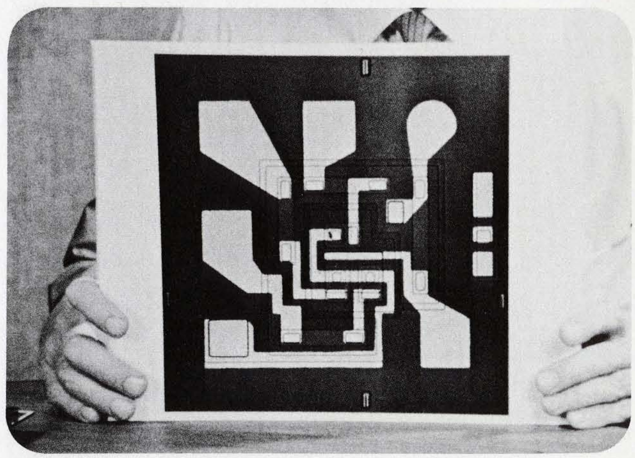
The first is a photograph of a single transistor chip such as we might find in the 1960 version of the computer board.

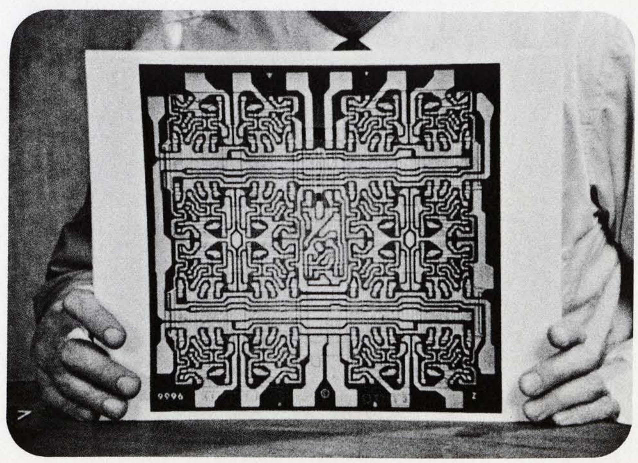
Sello: Old style again.

Angell: Here's the intermediate style. You remember the 1963 integrated circuit packages. Here's what would be in one of them; typically ten transistors.

This is a modern version of integrated circuits with many hundreds of components on this one chip. This particular function provides 16 bits of digital memory in this one package.







This is the edited transcript of a special ½ hour color television program produced by Fairchild Semiconductor and telecast October 11, 1967.

The two principal speakers are Dr. Harry Sello, Manager of the Materials and Processes Department of Fairchild Semiconductor Research and Development Laboratory, and Dr. Jim Angell, Professor of Electrical Engineering and Director of the Solid State Electronics Laboratory at Stanford University, Palo Alto, California.

Sello: Hello. We're here to tell you about a recent revolution in electronics. Of course, there have been many recent revolutions in electronics. You hear about them all the time. Today, we'll tell you what an integrated circuit is; how to design it; we'll tell how it's made; and, finally, about just a few of its uses.

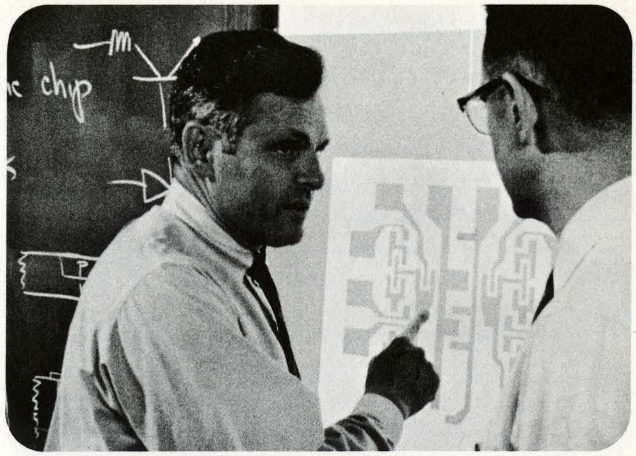
Well let's get started, Jim. What is an integrated circuit?

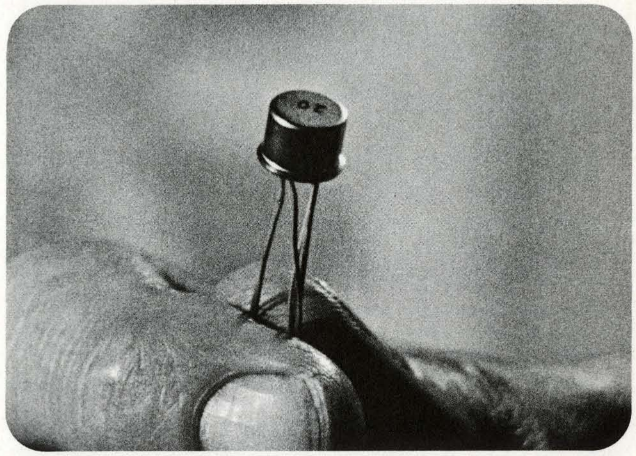
Angell: Here is a packaged integrated circuit. Inside this package is a chip of silicon which provides the electrical equivalent of many transistors, resistors, and diodes all interconnected to provide the desired function. Before we discuss in detail what's inside that package, I would like to show you some evolutionary examples of what integrated circuits can do for the appearance of electronic equipment. First, here's a photograph of a printed circuit board from a digital computer a la 1960.

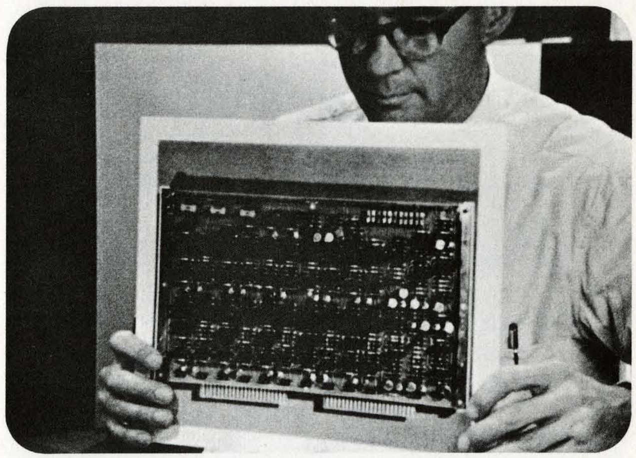
Sello: Prehistoric.

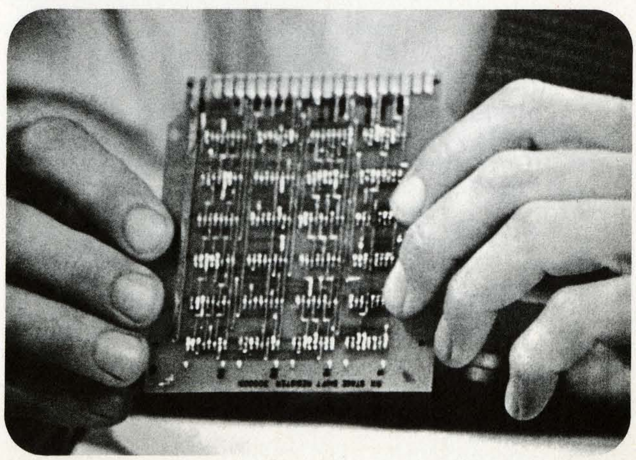
Angell: Right.

It's built out of transistors, separate resistors and diodes wired together on the printed circuit board. Next is the electrical equivalent of the 1960 circuit board, but built with integrated circuits. This one is vintage 1963. Notice how much smaller and simpler this board is.









Now integrated circuits can be used not only for digital but also for linear circuits. Here is an i.f. strip. It's transistorized and hence perhaps three years old. Here is its integrated circuit counterpart, providing exactly the same function. Notice how much simpler it is. The wiring is roughly the same, the simplicity is greater. Hence, we can expect that it will not only be cheaper, but more reliable, and these are perhaps the most important contributions of integrated circuits.

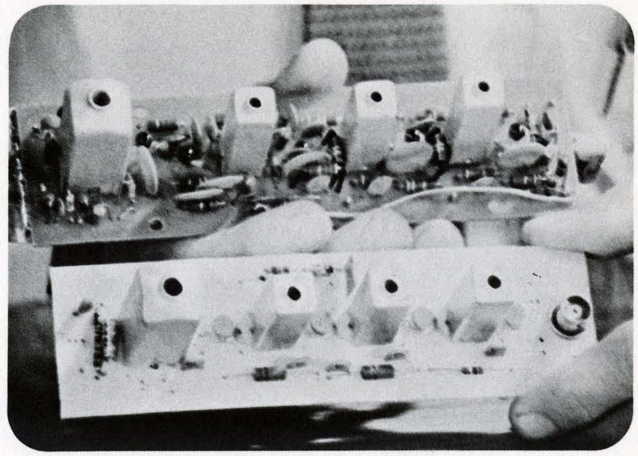
Sello: Let's get on to how to design an integrated circuit.

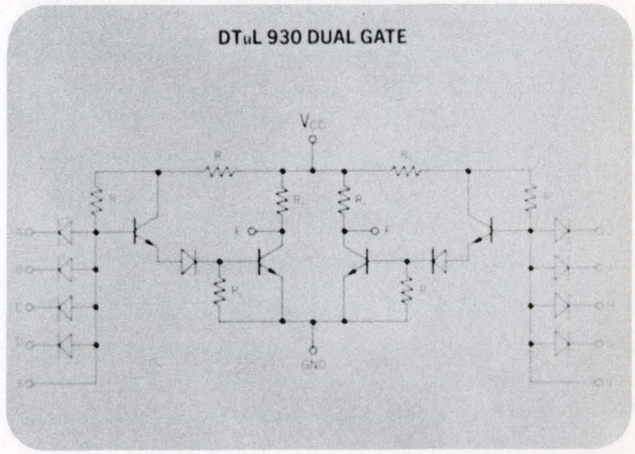
Angell: All right, let's do it by way of an example. Here we have a circuit for a typical structure which might be in integrated form. This particular circuit has 20 components — diodes, transistors, resistors. After the configuration has been chosen by usual techniques, the next step is to build a breadboard model in actual working form. On the breadboard we have separate transistors and other components all actually wired into a working circuit. The purpose of working with the breadboard is to try to optimize the numerical value of each of the components in the circuit. Once this optimization has been achieved, the next job is the design of the masks which will be used to make the integrated circuits.

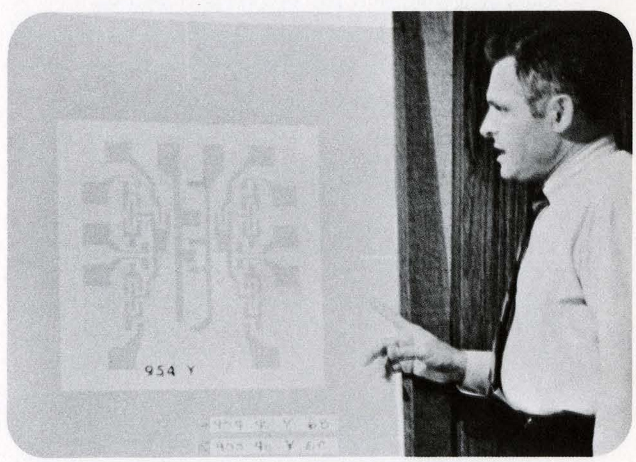
Sello: So, we made the engineer pick up a soldering iron — let's see if we can make an artist out of him by using yet another example.

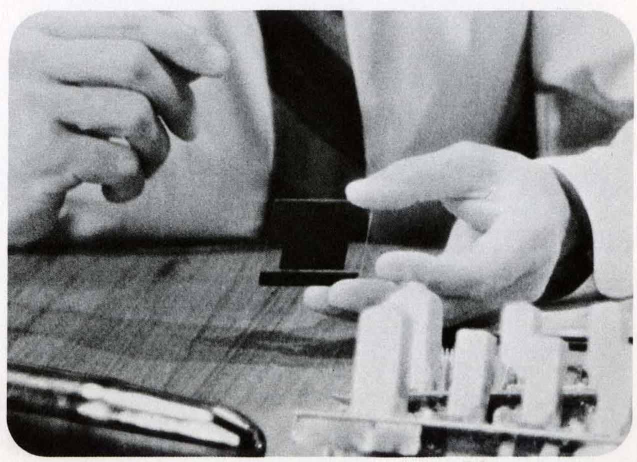
Here's a full-scale 30 x 30 inch piece of typical integrated circuit artwork which represents in a careful, precise form the interconnection pattern of an integrated circuit.

For example: these are the metal pads which interconnect to the outside world. Here we have the transistors and here are diodes and more interconnecting metals. The problem here is to convert this large-scale drawing into a small precise version on a 2 x 2 inch glass plate. This artwork is reduced 500 times by a process of high resolution photography to a glass plate upon which the pattern shown by the artwork is successively stepped and exposed all the way across the glass up to 1,500 times — which means, of course, 1,500 integrated circuits.

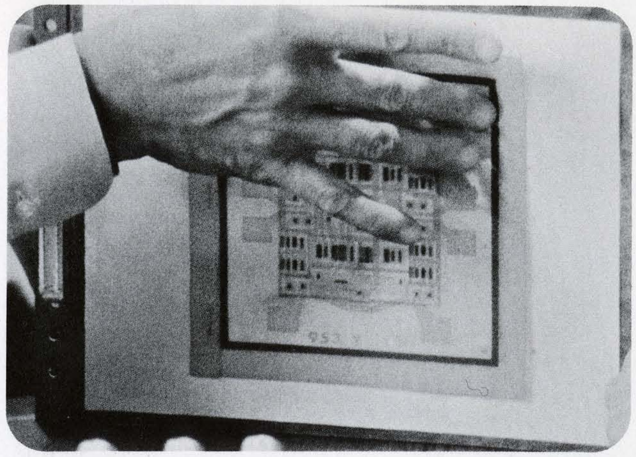




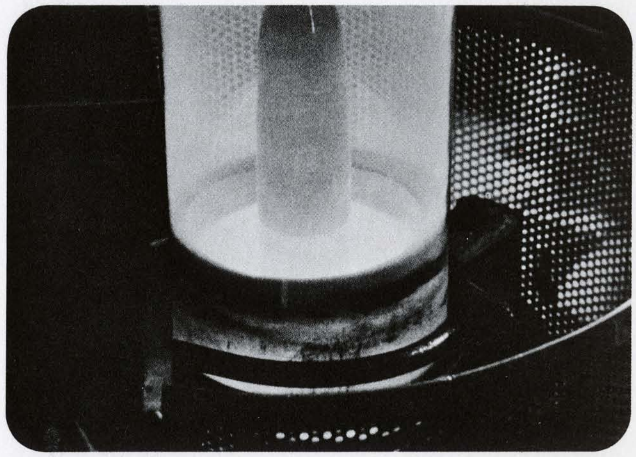


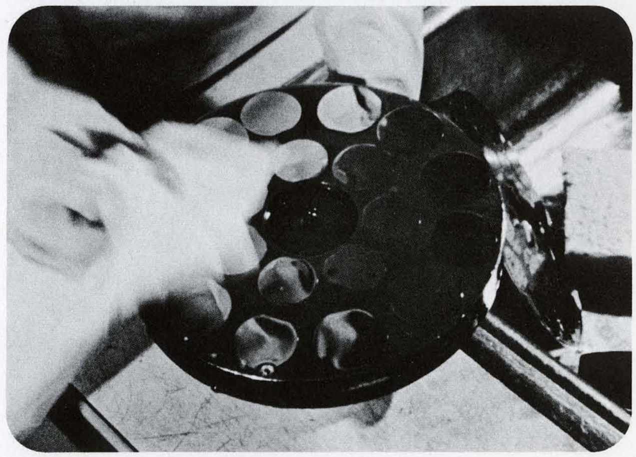


Now the artwork, which I showed, was only one potential mask. Here is the artwork, in reduced plastic overlay version, of a complete set needed to make an integrated circuit. There are five to seven or even more of these potential masks. All of these must align carefully and precisely.

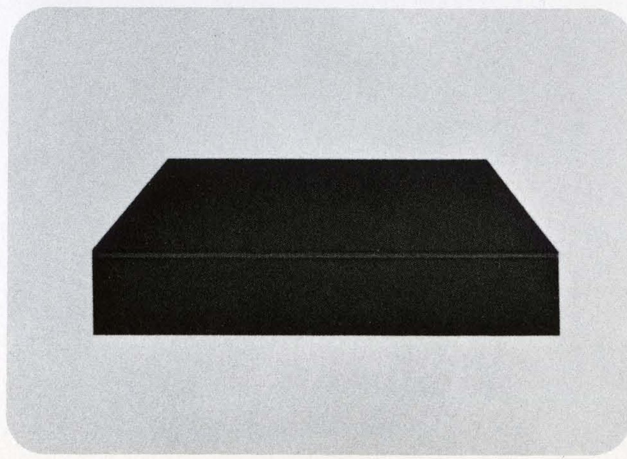


Each of these will then be translated into another set of glass masks which will then be used for contact printing directly onto silicon wafers. In working with silicon, this is what you begin with. A silicon ingot. It's a glass-like material — very brittle, very much like diamond — in fact, it costs about like diamond and is a member of the diamond family. It is made in a series of long rods by a process known as crystal pulling. It cools as it is pulled. However, it is still very hot since it's been grown at a very high temperature — up around the region of 1,400 degrees Centigrade. We cut the rod into thin wafers about twelve/thousandths of an inch thick by using a diamond saw. After cutting, the wafers are very carefully polished so you end up with the mirror-like surface which is essential in the preparation of an integrated circuit. The finished chip is about five/thousandths of an inch thick.



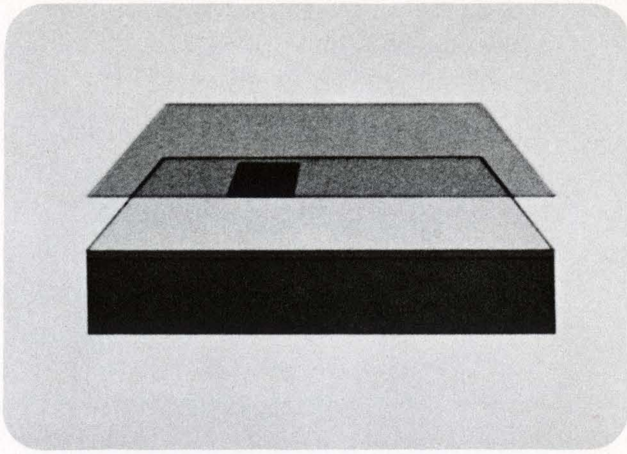


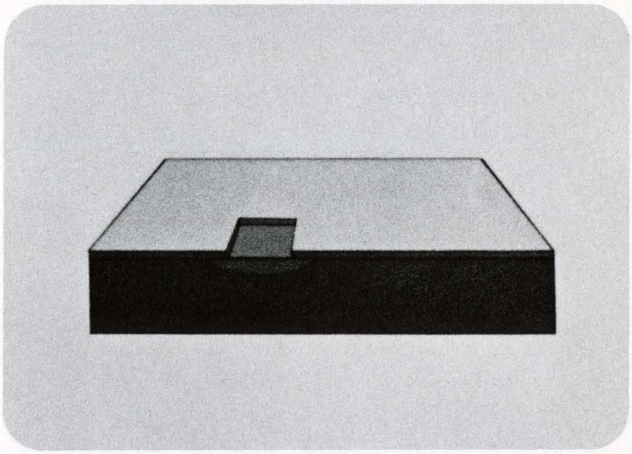
Let's take a look inside the silicon. This is a cross-section of the wafer we've just watched being made. To protect it from the outside world, we allow oxygen to react with the top surface and grow an oxide called the passivating silicon dioxide layer.

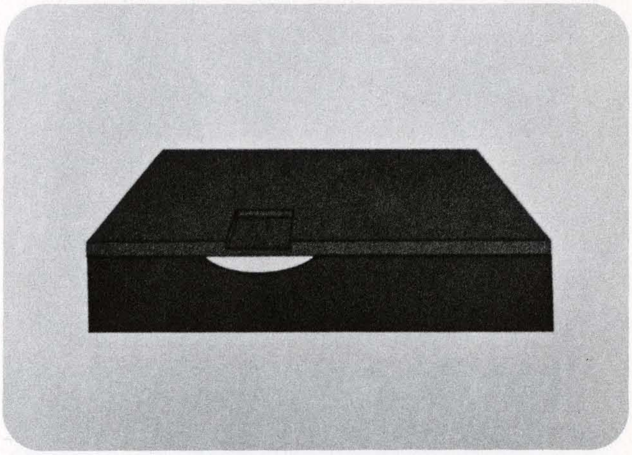


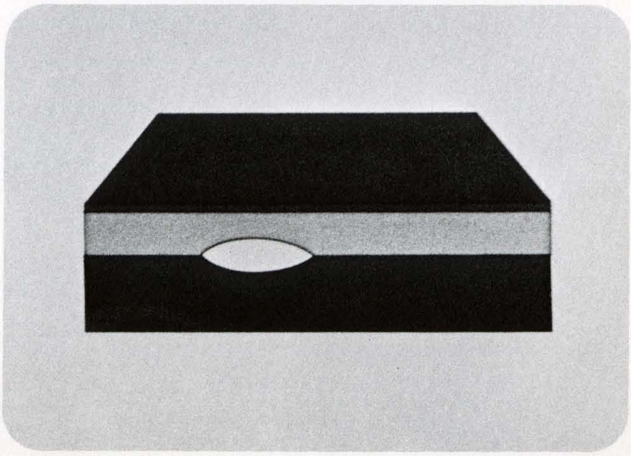
Now we're going to make use of the masks we made earlier. First the wafer is coated with a photosensitive resin; the mask is then placed on the wafer; and the system is exposed to light. As a result, the exposed resin hardens. The remaining resin can be simply rinsed away. The wafer is then exposed to acids. Those areas of the passivating layer not protected by the hardened resin are etched away. In the next operation, called diffusion, the wafer is exposed to a dopant. This impurity diffuses through the "window" just formed and into the silicon below forming the collector of a transistor in our integrated circuit. At the same time diffusion is taking place, more oxide is being formed. This is the essence of the Planar Process.

Now we're going to strip off the passivating layer and grow a new layer of silicon right on top of the diffused wafer by a process called epitaxial growth.



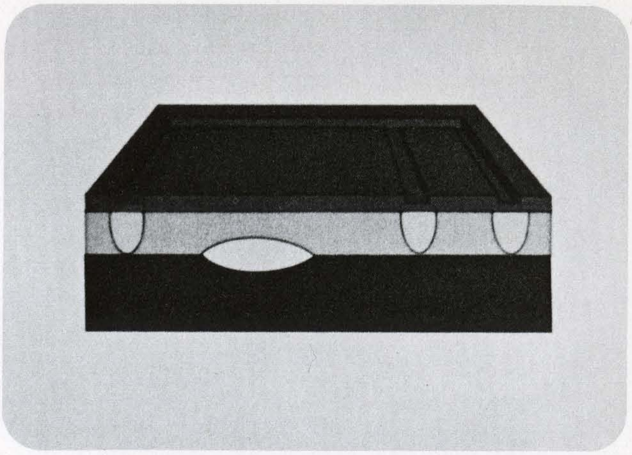


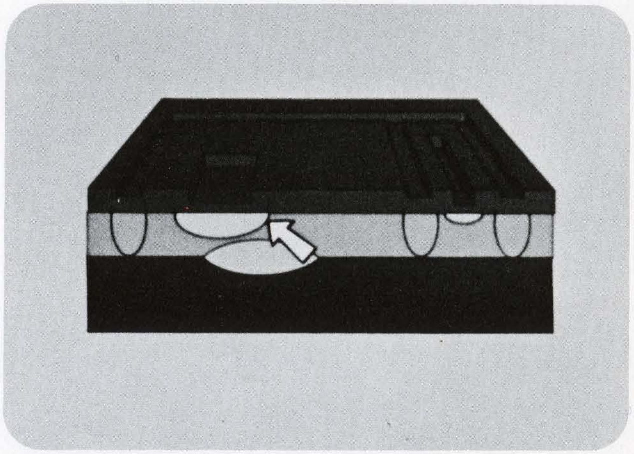


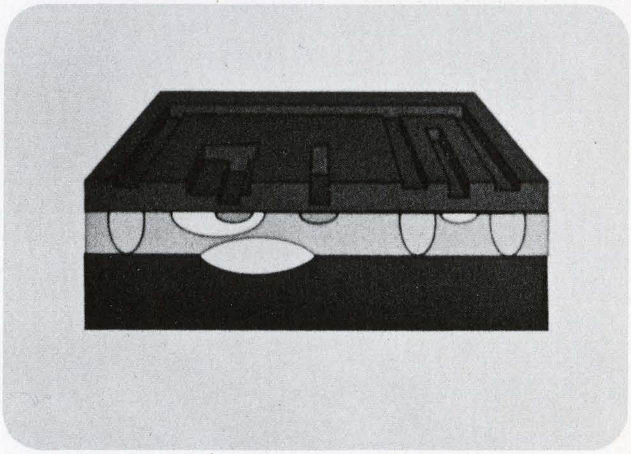


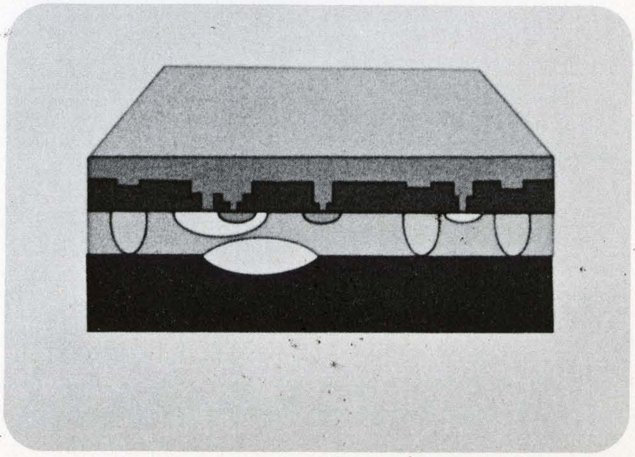
Now we form electrically isolated regions on the wafer by a process of diffusion — photosensitive coating, masking, exposure, rinsing, etching and diffusion. Next we prepare the individual parts of the integrated circuit. First a transistor base and a resistor. The same procedure is followed. Notice, diffusion takes place not only downward but also laterally under the oxide. As a result, the junction is formed beneath the passivating layer where it is protected from the outside world. The next diffusion forms an emitter and a collector contact to complete the transistor. Again, the same process.

The next step enables us to interconnect the various components and to make contact with them. Again, we'll etch windows in the oxide. But, instead of another diffusion, a layer of metal is deposited over the entire surface of the wafer.

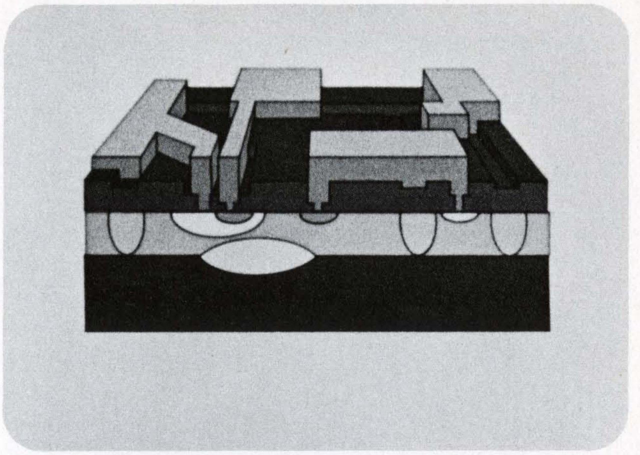




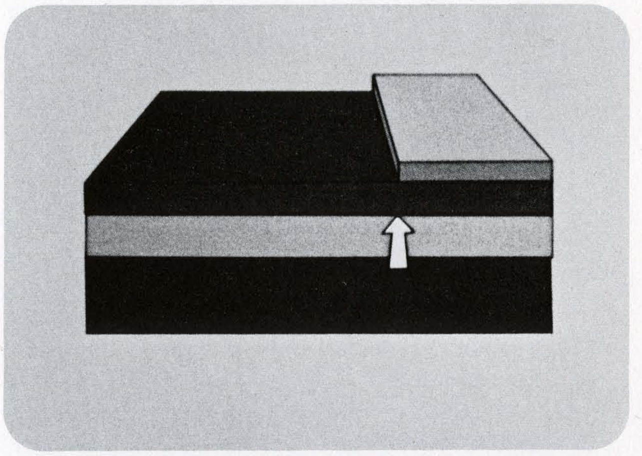




Then, by use of the proper mask, the excess metal can be etched away. Sometimes we like to make resistors a different way — by using the metal interconnection pattern. All you have to do is make the metal pathway a little narrower and it provides higher resistance. If we wish to make a capacitor, we take advantage of the fact that the oxide layer is an excellent dielectric material. A small area of metal is deposited forming one plate of a capacitor. The oxide is the dielectric and the silicon directly below the oxide forms the other plate.

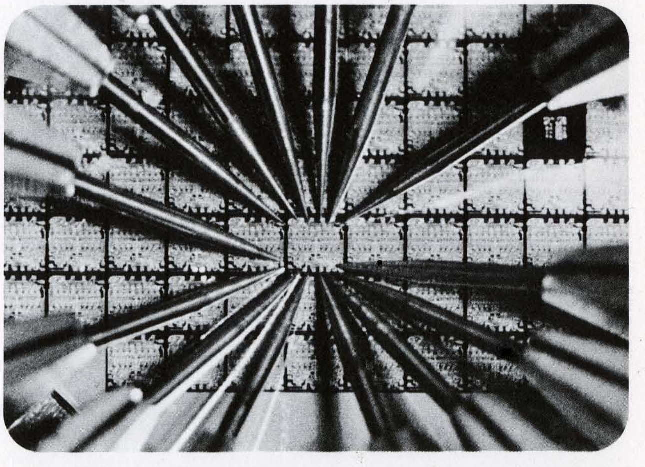


The series of schematic operations taking place on one structure that you just saw, actually takes place across a whole wafer. This results in a wafer containing many integrated circuits — up to 1,500 of them. Now comes the electrical testing of this wafer.



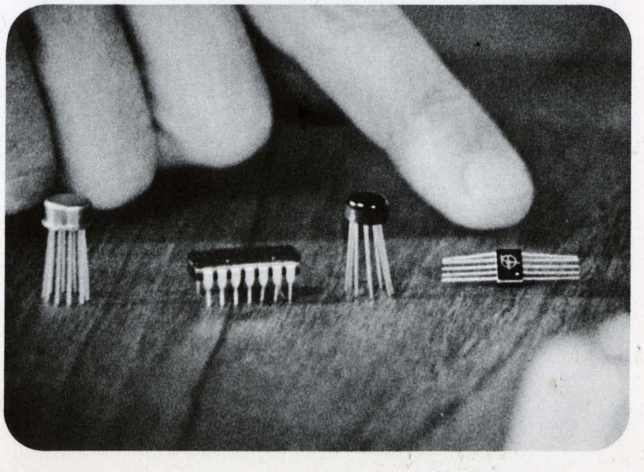
Angell: Even though we have been very careful in fabricating this wafer, containing many hundreds of integrated circuits, not all the circuits on the wafer are flawless. The first job is to determine and mark those circuits which are not good.

We test the wafers in a probe testing machine. We then scribe the wafers using a diamond point in a scribing machine. After separating, cleaning and drying the integrated circuits, we fish out the ones that are bad. If we have been successful to this point, we have a high yield of good ones.



From this point on, we are going to package the circuits. So whenever we throw one away, we are going to throw away a complete package.

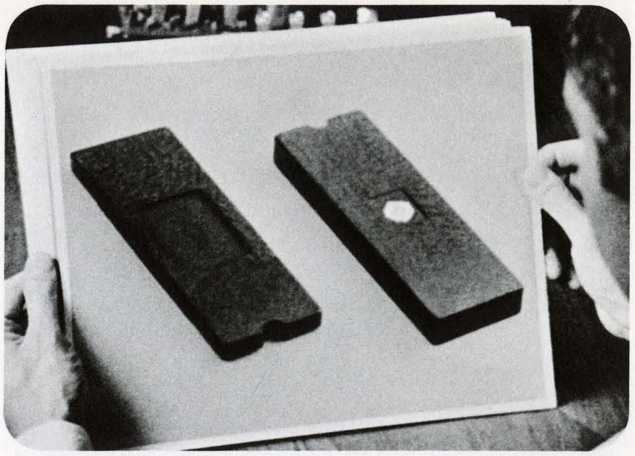
Sello: That's a good point, Jim. Let's look into this matter of packaging a little bit. You know we've exercised a lot of care in bringing the integrated circuit chips to this point in the processing and we've also done it economically because mostly we've processed them as wafers — 1,500 at a time. From here on out, we will be handling them as individuals, as you have pointed out, putting expensive packages around them. So, how we treat the packages is important.

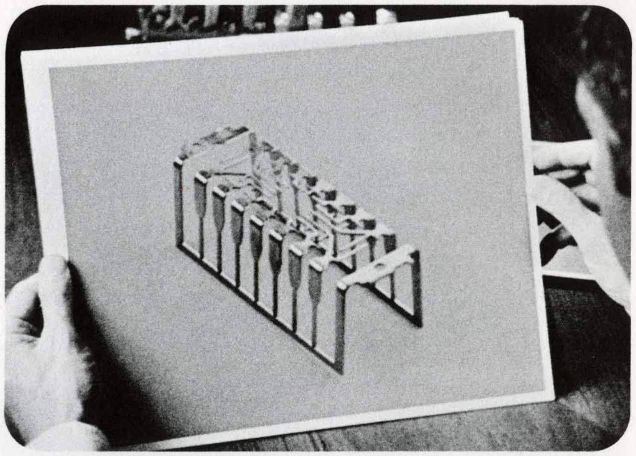


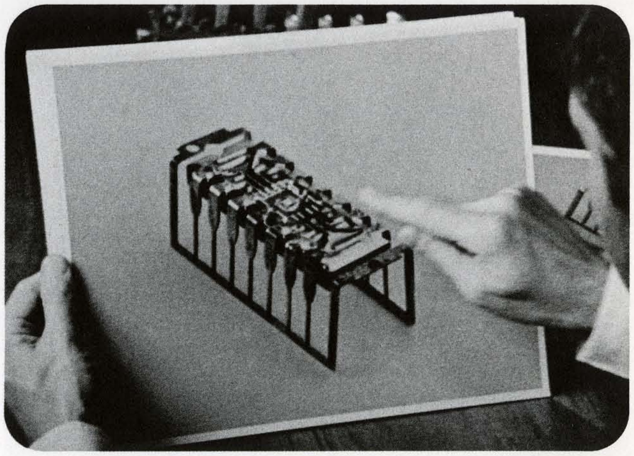
In the old days it was simple. We had a wide choice — two. Large and small. A TO-18, small, and the TO-5, larger. These days we have upwards of 250 varieties of packages, and the user can select any one of them. Here are three examples: a dual in-line package, a plastic package and a flatpak. The most nearly universal of these is the dual in-line package.

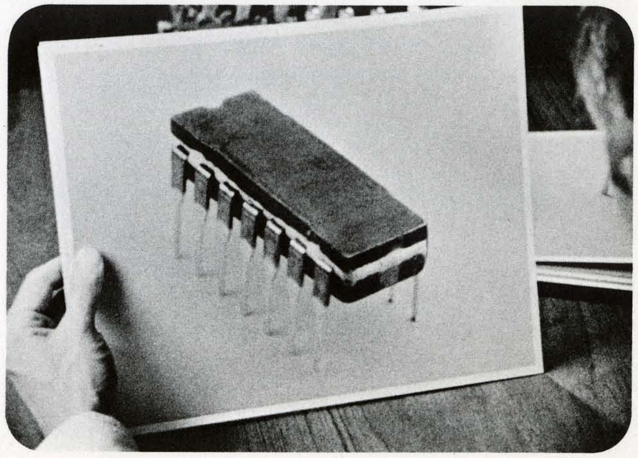
Let's take a closer look at just how it's made. You start out with the idea that you're going to build a tasty but inedible sandwich. Here are the two halves that you begin with: two ceramic parts between which the integrated circuit chip will be placed like meat. The two halves are glassed with a material which will form a solder that glues the two halves together later. A Kovar frame has been prepared in advance and cut out to the pattern necessary to connect the chip to the outside world. This Kovar frame will also be placed in the middle of the sandwich alongside of the chip, and here is the arrangement: chip in the center, Kovar frame around the outside. Notice that the tips of the frame have been metalized. These will be connected directly to the chip — as shown here where the lead bond wires connect each pad on the chip to a metalized tip on the Kovar frame. We complete the sandwich by putting the top half of the package right on top of the frame. The next operation is to clip the end of the frame; the package is now revealed in its magnificent beauty.

Solder glass is peeping out so we clean that up a little bit by sending the part through the furnace (along with many thousands of others) so that the solder glass is all melted and neatly in place. This is the finished dual in-line package.









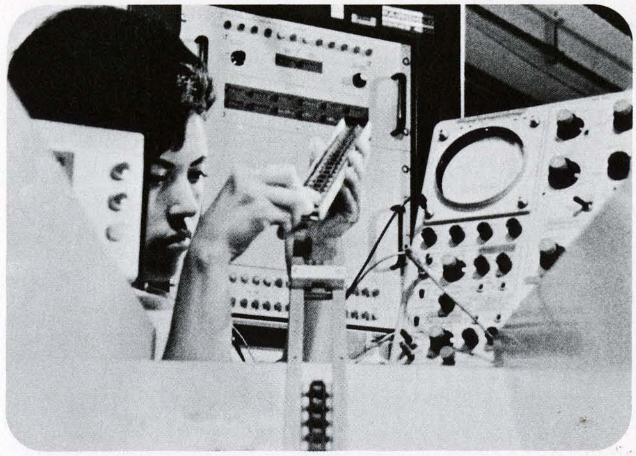
Angell: Now that the circuit has been packaged, we must again test it substantially before we would dare ship it to the user. First there's a series of electrical tests, many of which use special test equipment which is itself built from integrated circuits. Many of the tests made on the integrated circuits at this point duplicate those tests which were made on the wafers. In addition, we must make some special tests such as frequency response (of a linear amplifier) or switching speed (of a digital circuit) before we would dare ship the goods. We can't make these tests on the wafer state due to the limitations of the probe testing machine. In addition to electrical tests, we perform a variety of mechanical tests such as shock, vibration and acceleration. Finally, we run a set of temperature tests at both high and low temperature to insure that the unit will work dependably in service.

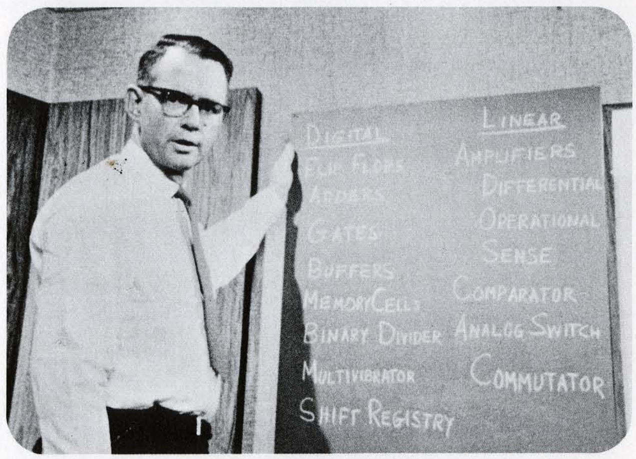
Sello: Now let's look into some of the things we can do with integrated circuits.

Angell: We've talked about how to design, build and test integrated circuits; let's look at some of the functions that are available now in integrated circuit form. Here is a list of readily available digital circuit functions. This list includes about all the circuits which are needed to build the electronics part of a digital computer. This list of linear functions includes a large variety of things. As you probably know, an operational amplifier, for example, is a rather precise amplifier used as the major building block of analog computers. The voltage comparator is a circuit which very accurately compares which of two voltages is the larger.

Sello: You know, it's exciting to think that all of these functions are here today — they can be used — they are available. And it's even more exciting when you consider the number of applications that they can be put to. You couldn't even begin to make a list of all of them. Actually, the uses of integrated circuits are limited only by the imagination of those who are designing their uses.

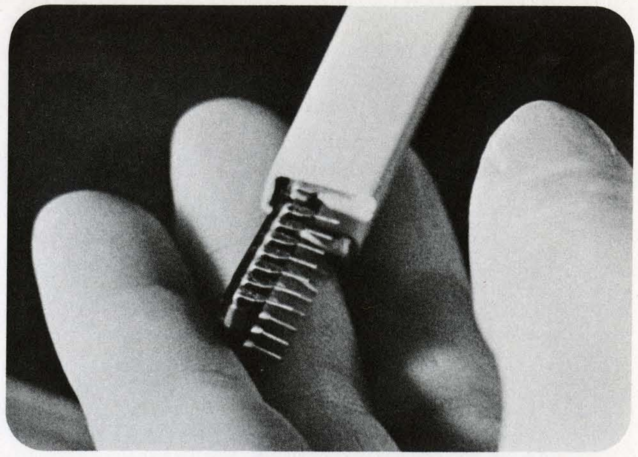
Let's take a deeper look into some of the present day applications of integrated circuits:

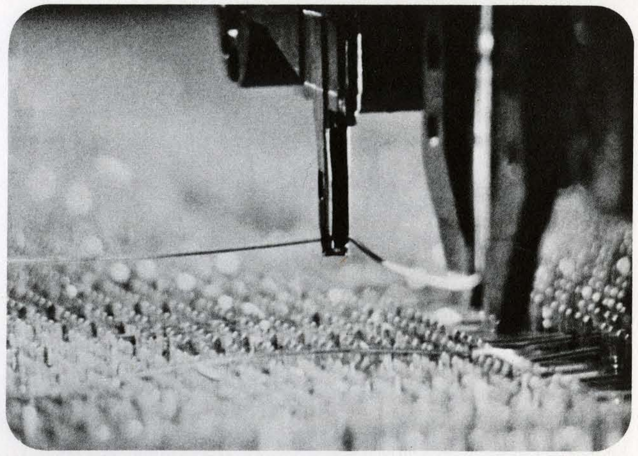


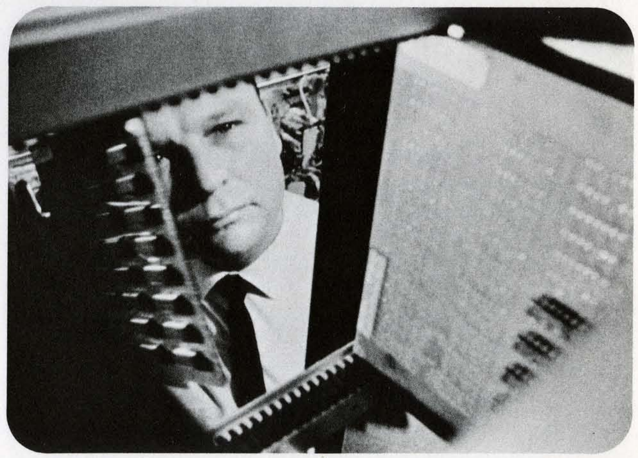


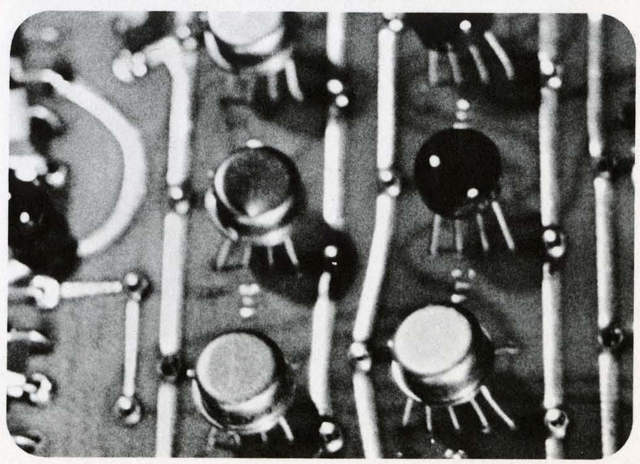
One of the many industrial companies using integrated circuits today is Burroughs Corporation. At Burroughs, integrated circuits in dual in-line packages are inserted in circuit boards automatically, thus affording more efficient production. Using this machine, which is proprietary with Burroughs, a single integrated circuit can be installed for about the same cost it previously took to install a discrete component. In order to automate the entire manufacturing process, Burroughs uses other advanced techniques such as flow soldering. This guarantees reliable connections to each integrated circuit. In addition, computerized wire wrapping machines are used to make the back plane interconnection so that the inherent reliability of the integrated design isn't compromised. The machine automatically cuts each wire to the correct length, strips the ends, routes the wires and makes the connections. Meanwhile, each completed circuit board is tested individually. Finally, circuit boards are installed in the computer frame, and the completed system is thoroughly tested. Burroughs is now committed to integrated circuits and, in fact, recently placed one of the largest single orders ever placed for these devices. For Burroughs, integrated circuits provide a significant cost reduction and a proven increase in reliability, both of which are real benefits to Burroughs customers.

Stromberg-Carlson is another company committed to integrated circuits. Their Data Products Division is now manufacturing the first in a line of new Stromberg-Carlson products built with I/C's. Integrated circuits, in this case in TO-5 packages (both metal and plastic) were used in the SC-1100 because of their low cost, size, reliability and, as Stromberg-Carlson says, "Because integrated circuits are here to stay."

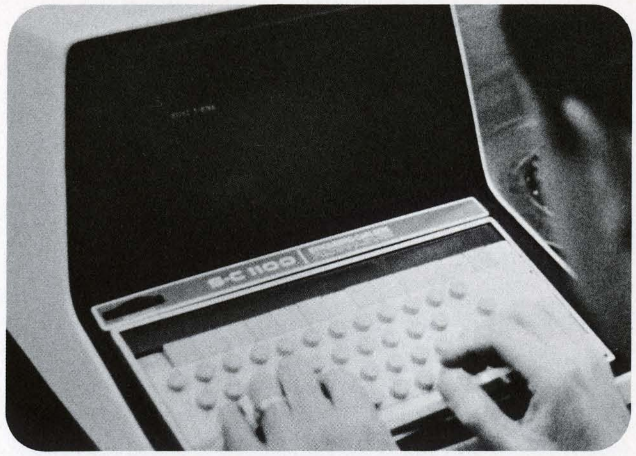








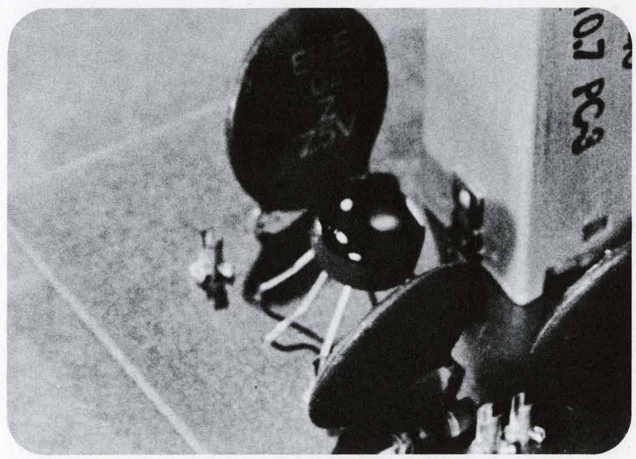
The SC-1100 system consists of up to 18 desk-top interrogators like this one which are handled by a single station control unit which in turn ties into the computer memory. The operator asks the computer a coded question via the interrogator. The computer responds with the requested information almost instantly; for instance, with an employee personnel record.

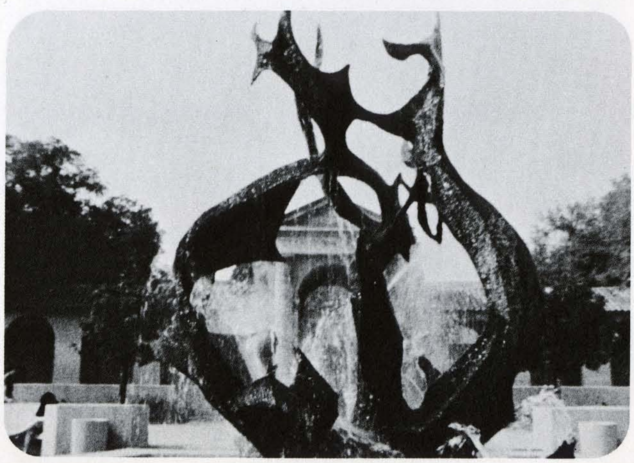


This is the Model 388 AM-FM stereo receiver built by H. H. Scott. It's only one of a new line of hi-fi components in which linear integrated circuits replace discrete transistors. Scott engineers have chosen IC's for one specific purpose — better performance. More stations can be pulled in with less noise and interference. Weak stations become loud and clear and outside interference is drastically reduced. But there are other benefits, too. A total of 37 discrete components in the receiver's i.f. strip have been replaced by only four IC's. This new approach to circuit design promises even more dramatic new products from the people at H. H. Scott.

We've seen some examples of how industry is putting integrated circuits to work today, but how about the future?

Angell: Well, that's a very exciting part of this story. Research is constantly going on to find new ways to use integrated circuits — not only in the R&D labs at semiconductor manufacturers, but also in universities, like here at the Solid State Electronics Laboratory of Stanford University at Palo Alto. The facilities that you see in this integrated circuits lab are made available by funds from many industrial organizations. Our lab at Stanford is a miniature of the production facilities you've seen in industry. It was built with the help of contributions from the majority of our nation's semiconductor manufacturers.





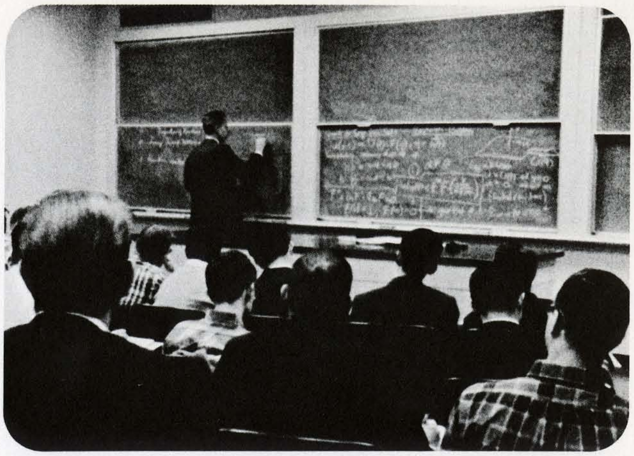
Right now we're working in several areas. We do basic research in integrated circuit technology. We're doing circuit research using the unique capabilities of integrated circuits. We also develop devices which incorporate IC's. And, we conduct research in several peripheral areas.

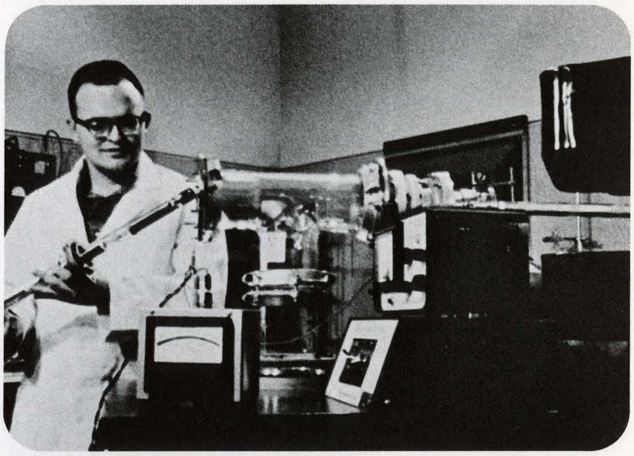
As an example of our research in IC technology, we're studying new ways of getting impurities into semiconductors. Normally, this is done by diffusion. We do the same thing by ion implantation. This machine takes individual ions and accelerates them, ramming them into semiconductor material much the same as you would shoot a bullet into a bale of hay. Right now this is much more expensive than diffusion, but it's a different technique. Here we're not interested so much in developing the technique as we are in learning the fundamentals — how heavily you can dope materials and what kinds of materials you can dope this way.

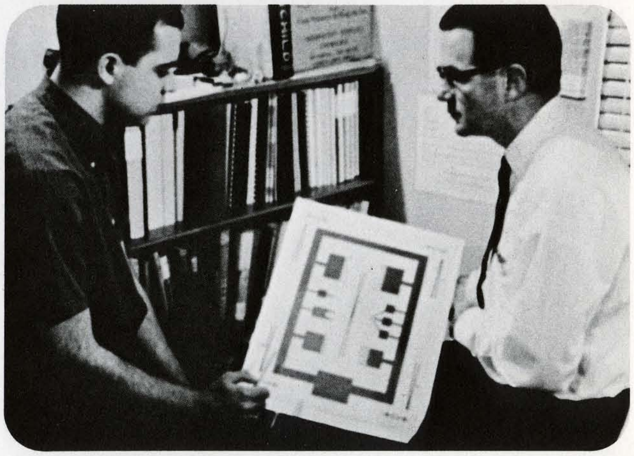
Let's look at an example in the field of medical electronics. Here we're using IC technology to develop an array of fine probes which a neurologist can implant down in a living brain to study the potential at different points on a single neuron.

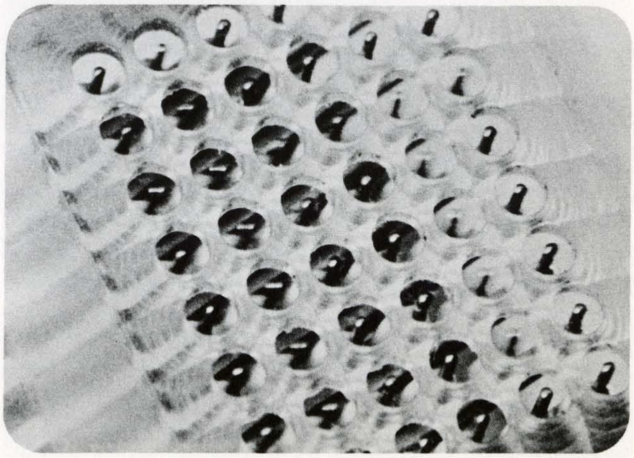
Here, you're looking at one of the masks prepared by the student doing this research. We're developing probes — probably of gold — using the same technology as for the metalization patterns on IC's. This would have been impossible before IC technology.

One of the most dramatic devices being developed is this reading aid for the blind! This is a reading device in which ordinary printed material is converted to a tactile image which is presented by a closely spaced array of 48 piezoelectric reeds. By resting his finger on the vibrating reeds, the blind person can sense a vibrating and grainy facsimile of the material being viewed. The great advantage is that this machine enables a blind person to read the printed page. This version is relatively large, even though it incorporates integrated circuits. Ultimately, one 70 x 90 mil chip will take care of all the necessary electronics to drive one vibrating reed.









Sello: Certainly integrated circuits are used in many present day applications. One very important reason is the reliability of an integrated circuit. It is a reliable device. In the industry, we've logged almost 80-million element hours without a failure. That's reliability.

Angell: We've considered many different things regarding integrated circuits. One question we might ask is, "Why do people care about integrated circuits?" Well, there are many reasons. Certainly one of them is the reliability factor we were just considering. The second one is the fact that they are inexpensive. Even today it is often less expensive to perform a function with integrated circuits than it is with separate discrete components. The fact that they are small is important. This board here contains many functions — many, many more than we could get into this volume otherwise.

Finally, there are new functions which can be achieved with integrated circuits that just plain couldn't be achieved any other way.

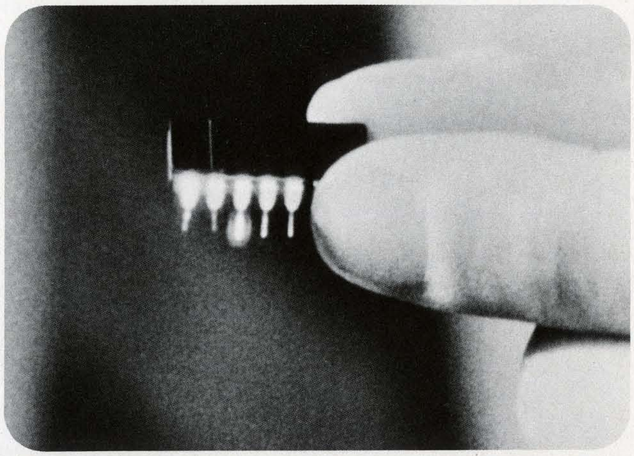
Angell: Harry, we've considered a large variety of topics on this program. I'm wondering if you'd be willing to summarize for us.

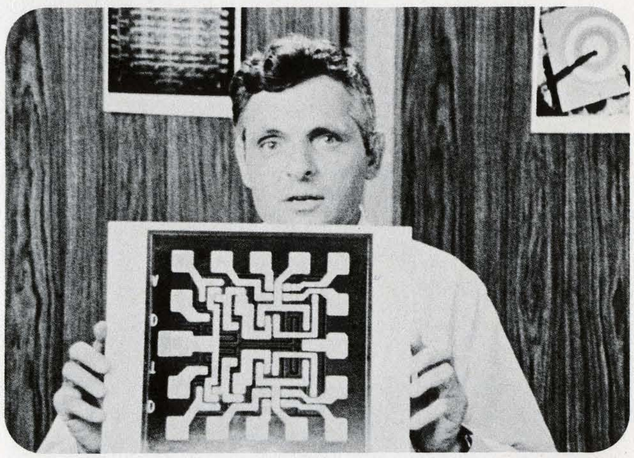
Sello: Yes, let's summarize.

We started off by telling you what an integrated circuit is. This is an integrated circuit. It is a piece of silicon into which have been built all of the necessary components to perform an electronic function. The piece of silicon, in a blow-up picture, looks like this: all of the functions are there.

We've taken you through the design and building of an integrated circuit from a circuit diagram, through masking, to wafer processing, and finally to the final packaging.

We've shown you that it takes a lot of extensive testing to prove out an integrated circuit. And finally, you've seen a lot of the uses — both present day and future — for integrated circuits. Hopefully, we've given you some ideas on how you can put integrated circuits to work for you.





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A Division of Fairchild Camera and Instrument Corporation
313 Fairchild Drive, Mountain View, California 94040 (415) 962-5011 TWX: 910-379-6435