Chilling Logic

Japanese researchers continue to work toward Josephson junction computer technology, undismayed by IBM's withdrawal

By DIETRICK E. THOMSEN

The development of computers has been driven by two main desires: for greater speed and smaller size. It is hard now to remember that the earliest computers involved rooms and rooms full of vacuum tubes. Silicon technology has brought both great speed and an almost incredible compactness of integrated circuitry. In principle, a move to superconducting electronics would provide even greater speed, but could it match the ease of manufacture and compactness of silicon integrated circuits?

A group of researchers at the Japanese government's Electrotechnical Laboratory at Ibaraki thinks there is a possibility. At the recent Applied Superconductivity Conference in San Diego they showed examples of integrated circuits using Josephson junctions. The circuits are not yet at the stage technically called large-scale integration, but they are working toward it, they say.

In the United States several laboratories, notably IBM and AT&T Bell Labs, have made significant contributions to Josephson junction logic technology. Among American computer manufacturers IBM was noted for persistently pursuing the goal of a Josephson junction computer. However, about a year ago, IBM announced that it was dropping that line of research (SN: 11/26/83, p. 345). IBM representatives at the San Diego meeting spoke mostly of seeking superconducting analogs to the transistor, which the Josephson junction is not. The leader of the Japanese group, Hisayo Hayakawa, was introduced by the session chairman with a question about why the Japanese still pursue Josephson junctions now that IBM has quit.

"It's difficult to answer," Hayakawa replied. "We still have a lot of work to be done to realize a Josephson digital system. We can't say whether it is realizable or not. That's why we are doing it."

A Josephson junction connects two superconductors through a thin piece of insulation. A supercurrent will flow through the insulator from one superconductor to the other even if there is no voltage across the junction to drive it. It goes by the process known as quantum mechanical tunneling. However, if a voltage is applied, it can stop the current. The junction can thus have definite on and off states and so acts as a switch. Logic circuitry is based on switches.

The Josephson junction is not, however, an exact substitute for the transistors that perform switching duties in silicon circuitry. A transistor has three terminals. Whatever the circuitry does to the third terminal controls the flow of current between the other two, the input and output terminals. A Josephson junction has only two terminals and so requires a different kind of circuit design. To change the output, you have to meddle with the input.

"It's 'latching' logic," says Theodore van Duzer of the University of California at Berkeley, "which means that when the switch is on, it stays on until you shut the power off. Circuit designers are not accustomed to that."

Indeed, IBM people at the meeting seemed to regard latching as a drawback, and some of them are now searching for superconducting elements with the three-terminal property — that is, "superconducting transistors." In a review of efforts in superconducting electronics up to now, most of which featured Josephson or other kinds of junctions in one form or another, William J. Gallagher of IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y., concluded, "We need to look in new directions."

The Japanese Ministry of International Trade and Industry would like to see a new very high-speed computer by 1990. Hayakawa cites three technologies that are in competition for it: gallium arsenide, a new kind of transistor called a high electron-mobility transistor (HEMT) and Josephson junctions. "We still think Josephson [junctions] or use of superconductors has attractive or useful properties for making high-speed digital systems," he says.

As attractions Hayakawa cites speed (less than 20 picoseconds per gate), low power (0.6 watts per square centimeter) and high density (10,000 to 100,000 gates on a 5-millimeter chip). Van Duzer estimates that a Josephson junction computer would be two to three times as fast as present silicon, but apparently even that was not enough for IBM to justify the expense of development.

Difficulty of fabrication was one of the drawbacks cited by IBM in its 1983 statement that it was getting out of Josephson junction computer research. Here the Japanese claim a definite advantage, especially with their technique using all-refractory materials and what they call reactive ion etching. Integrated circuits are made by laying down layers of conductor and insulator in the proper order and etching each layer appropriately so that the end result is the arrangement of junctions and interconnections specified by the circuit plan. The manufacture has to be done at high temperatures (around 300°C), but Josephson junctions have to work at very low temperatures, within a few degrees of absolute zero. The properties of the material have to be stable over that range. The Japanese say that use of refractory — that is, heat-resistant — materials, primarily niobium and niobium nitride on a silicon substrate, makes it possible.

Another member of the group, S. Kosaka, described a 4-by-4-bit adder made by the all-refractory process. It uses 2,800 Josephson junctions to make 652 gates in a space 3.5 millimeters square. A combination of OR and AND logic cells, it will add four-digit binary numbers together. Kosaka gave the example 1111×1001 (15×9 in decimal numeration). The chip does the addition in 1 nanosecond, which, Hayakawa says, is five times as fast as gallium arsenide technology can do. Hayakawa adds that they have more recently built and operated an 8-by-8-bit adder by the same process. They now want to go on to apply the all-refractory process to memory circuits.

The Japanese are just on the threshold of large-scale integration, says Hayakawa. In the future they hope to go from integrated circuits on a chip to integration on a whole wafer, which is much larger. After that they are planning to try to go from the present two-dimensional integrated circuits to three-dimensional ones. "It's very important for the future," says Hayakawa.

Van Duzer, who was one of a committee set up by the U.S. National Academy of Sciences to review high-speed computer research in both countries, says he got the impression that Hayakawa's group is not very sanguine that their technology will be chosen for the 1990 application, but if so they do not appear dismayed. "They have a different attitude [from Americans]," van Duzer says. "They're very patient. [Even if there is not a prospect of immediate profit] they think it's a good technology and that they should work on it. I think the Japanese approach is the better one." □