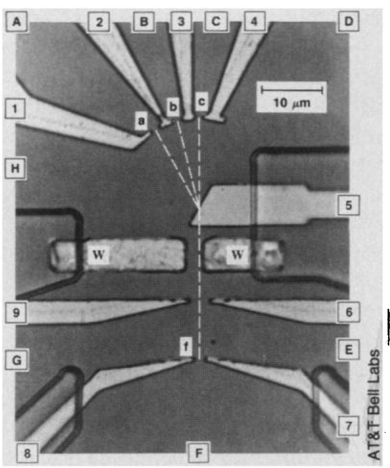
A Prism for Electrons

Treating electrons like photons opens up a world of electronics that is not restricted to the simple on/off states of transistors

A TEAM OF RESEARCHERS at AT&T Bell Laboratories has developed a new type of electron switch that works on a fundamentally different principle from the transistors in today's electronics. Instead of switching a current on and off as a transistor does, the device deflects a beam of electrons in much the same way that a prism refracts light, heading the electrons in a direction that depends on an applied voltage. The switch's inventors say that such devices could eventually lead to "another type of electronics," although it's too early to predict just what forms the new technology might take.

The switch, reported in the 11 June issue of *Applied Physics Letters* by Joe Spector, Horst Stormer, Kirk Baldwin, Loren Pfeiffer, and Ken West, consists of an arrangement of metal electrodes (see photo) on the surface of a semiconductor made of a 0.6-micrometer layer of $Al_{0.3}Ga_{0.7}As$ atop a base of GaAs. The free electrons in the switch are two-dimensional—they are constrained to a stay in a thin region of GaAs next to the $GaAs/Al_{0.3}Ga_{0.7}As$ boundary.

The electrons are also "ballistic"—they move through the switch without colliding with the atoms in the material and are affected only by the electric fields of the switch. Normally, electrons move only about 50 nanometers in bulk GaAs before colliding with an atom, but by keeping impurities out of the GaAs and by cooling the switch to below 2 K, the researchers are able to increase the mean free path to 64 micrometers, enough so the electrons can traverse the entire switch without a collision.



Refractive switching. *Electrons are deflected by the prism into one of three collectors.*

The switch operation is simple. An emitter creates a beam of ballistic electrons, which are deflected by a tunable "prism." Three collectors measure how far the beam has been deflected.

The prism, although it has the familiar acute angle shape of an optical prism, is not made of glass. It is a metallic electrode that sits on the surface of the switch and deflects the electrons passing underneath it.

This refraction is caused by a mechanism analogous to what causes light to bend when passing through a glass prism. The speed of light is less in glass than in air, and when a beam of light is at an angle to the prism, it bends as it passes into and out of the glass. The electron prism works by creating a region that has a different potential energy than the rest of the switch. When an electron passes into or out of this region, its kinetic energy changes, which alters its velocity. As with light going through an ordinary optical prism, this change in velocity results in a bending of the beam. By changing the voltage on the prism electrode, the researchers alter the velocity of the electrons passing underneath it and thus their angle of refraction. "It's electronics of a different kind," Stormer says. "We're essentially using electrons like photons."

The electrons also act like photons in other ways, Spector adds. In March, the group reported focusing ballistic electrons with an electrostatic lens, and now "we're looking to see if beams of them interact when they cross," he says. "We expect they won't." In a normal electronic circuit, if two electronic signals must cross each other, the circuit must have one wire running underneath the other, which complicates circuit design. But the Bell Labs switch uses such a low current that the few ballistic electrons are a distance of a micrometer or more apart, so several beams should be able to pass through the same region without the electrons coming close enough to affect one another. If all this works out, it should be possible to produce circuits that take advantage of both the electrical and the optical characteristics of electrons.

■ ROBERT POOL

Circuit Boards: Heal Yourselves

Julian Chen, a physicist at IBM's T. J. Watson Research Center in Yorktown Heights, New York, has come up with a way to repair defects in the wiring between computer chips on a circuit board "blindfolded"—you don't even have to know where the defect is to correct it. The company expects this "self-induced repair" technique to reduce significantly the manufacturing costs of printed circuit boards.

Repairing defects in circuit board wiring is one of the most expensive and time-consuming tasks in building today's large computers. A board may have thousands of metal interconnects weaving through a couple of dozen ceramic layers, and a flaw in any one of the connections can cause the computer to fail. In the more complex boards, a large percentage have at least one defect that must be located and repaired. But even finding where a defect lies along a troublesome wire is difficult.

The trickiest to find are the constrictions, or "near opens," which can be small cracks, places where the wiring is too narrow, or sites where impurities have built up. Physical stress or excess current can break these partial defects, creating a full "open" and ruining the entire system. Up to now IBM has corrected these latent defects during manufacturing by first running a high current through them to make an open, locating the open, and then soldering it—all in all, a tedious business.

Chen's patented repair technique, described in the 11 June *Applied Physics Letters*, makes clever use of the fact that near-open defects have a higher resistance to electric current than the rest of the interconnect. When Chen submerges a copper circuit in a copper sulfate solution and runs a current through it, the extra resistance at the constriction causes it to heat up more than the rest of the circuit, creating a negative potential that attracts copper ions from the solution. These copper ions build up along the constriction until it conducts current as well as the rest of the circuit.

The process avoids the necessity of locating the defect, can repair several constrictions in one wire at the same time, and automatically shuts down when the defect is repaired. Also, Chen notes, the patch is of the same material and just as good as the rest of the wiring. The technique will be particularly valuable in the manufacture of complicated circuit boards with very narrow interconnects, Chen says, since complexity and small size inevitably lead to a greater number of defects.

■ R.P.