The United States Navy contracted with Spire to develop hardened metal bearings for high performance jet aircraft engines. Implantation of common steel with chromium, molybdenom, and boron or alternatively, titanium and carbon has been found to double or triple bearing life, as well as make their manufacture more uniform.

Similar applications are now being pursued to improve the performance of metal working dies, punches and cutting tools, such as those used to stamp out the precision cuttings in the top of a soft drink can to make the pull tab work. New dental drills and burrs are being designed, with the hope of making trips to the dentist a painless experience. Spinneretts, which are nozzles used to extrude glass or organic polymer fibers and are made of cobalt superalloys or chromium carbide, have been treated with silicon, titanium, boron and other ions to reduce deformation under pressure and oxidation of their surfaces, two common modes of failure.

Even organic polymers are being modified with ion implantation processes to give them certain electrical properties, heralding the potential advent of plastic electrical wires. Ceramic materials, which are known to have extraordinary resistance to high temperatures but are usually too fragile for reliable use, are being treated with ions of chromium (another Seed Money project) to make them superhard and less prone to fracture and wear.

Proposed applications of ion implantation are simply too many to enumerate. The current state-of-the-art must be credited to literally hundreds of researchers around the world who have made important contributions.

The Seed Money research in 1975 and 1976, however, may be credited with establishing the basic research program at the Laboratory that gave rise to renewed and broadened interest in ion implantation, and also to the unique combination of ion implantation and laser annealing. It also provided the technology base for many subsequent advances at the Laboratory and elsewhere. These early breakthroughs, published in *Science*, heightened worldwide interest in related technologies, which led to an avalanche of applied research and commercial product development.

Laser Annealing

Today, the unique capabilities of laser technology are being applied to selected manufacturing processes in ways that have significantly reduced costs and improved product quality in some of America's most important and fastest growing industries. The laser's capability to deliver an intense concentration of energy in the form of light with surgical precision, for example, is now being used to heat treat or "anneal" the microscopic metal surfaces of semiconductors, the basic components of microprocessors and computers.

This process, called laser annealing, and a related process, called rapid thermal annealing, involve the rapid heating and cooling of a microscopically thin layer near the surface of the material. The process eliminates thousands of both naturally occurring and manufacturing induced defects and, in the case of semiconductors, improves dramatically electrical performance. It also eliminates the need for cumbersome and potentially damaging furnace-type heat treating of the entire part, speeds the manufacturing processes, improves product uniformity, and lowers production costs.

The origin of laser annealing can be traced to a seemingly unrelated Seed Money project funded in March of 1975. The focus of this research was on increasing solar cell performance by improving the distribution of phosphorus in crystals of silicon, a combination of elements which gives rise, in part, to the unique and valuable properties of semiconductors. Conventional methods of manufacture typically result in unevenness in the distribution of phosphorus, called inhomogeneities, which adversely affect electrical performance. The technique proposed to solve this problem took advantage of certain fundamental nuclear relationships between the elements of silicon and phosphorus.

As it appears in nature, there is a natural abundance of about 3 percent of one particular variety of silicon, called Si^{30}, an isotope which is slightly heavier than silicon's other naturally occurring isotopes (Si^{28} and Si^{29}). With the addition of one neutron from a nuclear reactor, however, Si^{30} becomes Si^{31}, which shortly thereafter decays to a stable (i.e., nonradioactive) isotope of phosphorus, P^{31}. Hence, neutron activation of silicon presented a means of evenly distributing phosphorus, *in situ*, after the silicon crystal had been formed.

With funding provided by the Seed Money program, this line of research, called neutron transmutation doping (NTD) of silicon, was pursued successfully. NTD silicon has a number of critically important applications in the transmission of high voltage power in rectifiers and thyristors, in certain defense applications, such as in infrared detectors and other devices, and in the field of nuclear science as sensitive radiation detectors.

Fortuitously, as later events proved, the funding also allowed the temporary hiring of a young scientist, Rosa T. Young, to help out on certain aspects of the work, namely, the fabrication of the solar cells into a working device. She concentrated on one important step in the process of modifying materials by particle bombardment—the repair of the damage done to the crystal lattice structure of the original material by the impinging particles.

Standard practice was to heat, or anneal, the modified material in hot ovens for hours at a time. In the case of NTD silicon, this