be more convenient for some experiments. Ions created damage similar to that caused by neutrons, but they had other advantages. They did not cause the samples to become radioactive, were cheaply produced, and easily focused and controlled using electrostatic and magnetic fields.

A pivotal point in the development of ion implantation occurred in the early 1960's. Basic Energy Sciences researchers simulated mathematically the ordered atomic lattice structure of a solid and its interactions with a penetrating particle. As an approach to particle-solids modeling, this was a departure from prevailing practices.

At the time, most experimentalists assumed that solids were satisfactorily represented as homogeneous masses, like pudding. In the pudding models, impinging particles entered the solid and slowed down, all in the same way, through a series of collisions with atoms in the solid in a process called scattering.

By introducing the concept of ordered lattices, the researchers predicted that some particles, if they entered the solid from certain angular directions, would behave much differently. Their penetration depth, called range, might be as much as one or two orders of magnitude (10 to 100 times) greater than that predicted by the pudding models.

This phenomenon was called channeling. It was tested experimentally and proved to be correct. This one success, widely repeated at many laboratories, changed the course of future research. It drew attention to the need for more sophisticated analytical approaches and demonstrated convincingly the usefulness of theoretical simulations.

With renewed interest, Basic Energy Sciences research on ion implantation began to diversify and evolve. With continued model development and experimental evidence, it became possible to predict accurately end points, locations, distributions, and damage effects of implanted ions of varying species, energies, and impinging angles.

Conversely, it also became possible to control the implanting process in such a way so as to achieve specifically desired results. Gradually, as knowledge and capabilities expanded, it became clear that surface structure modification using ion implantation, rather than "damaging" materials, could actually "improve" materials in ways not possible using other means.

Throughout the 1960's, these developments were followed closely by private industrial laboratories involved in manufacturing semiconductors, the basic components of computers. The introduction of impurity atoms, such as phosphorous, into a crystalline substrate material, such as silicon, is an essential step in this process. Ion implantation was one of several competing methods for accomplishing this, and Basic Energy Sciences research provided much of the basis for evaluating its capabilities.

In one notable discovery, Basic Energy Sciences researchers, in collaboration with the University of Alabama at Birmingham, found that implantation of nitrogen atoms in the surface material of surgical bone implants made of titanium, aluminum, and vanadium, increased longevity 400-fold. Prior to this, implants were not generally advisable for patients with 10 years or more to live, because the implants would succumb to the corrosive effects of body fluids, breakdown, and would cause internal poisoning.

This discovery was actively pursued by private laboratories, whose follow-on research ultimately brought the application to fruition. Tens of thousands of nitrogen implanted hip prostheses are now in use in human patients, and this number is growing rapidly. The potential market is significant. Hip and knee joint replacements are estimated to occur at the rate of 200,000 per year.

In the 1980's, applications of ion implantation grew explosively. Their diversity is worth noting, even though their links to Basic Energy Sciences research are more removed. The United States Navy, for example, used ion implantation to develop hardened metal bearings for high performance jet aircraft engines. Implantation in common steel of atoms of chromium, molybdenum, and boron, or alternatively, titanium and carbon, was found to more than double bearing longevity, as well as make their manufacture more uniform.

Other surface hardening applications were pursued to improve the performance of metal working dies, punches, and cutting tools. One interesting example is the tool used to stamp out the precision cuttings in the top of a soft drink can to make the pull-tab work.

Spinnerets, which are nozzles used to extrude glass or organic polymer fibers, are made of cobalt superalloys or chromium carbide. These have been