ogy called ion implantation. Named after the method by which it is accomplished, it promised the modern metallurgist an opportunity to construct the operative surfaces of materials, literally, atom by atom.

The technology had been demonstrated in principle as early as World War II. It was already in operation in certain limited applications by the 1950's. Despite these successes, however, its further development lagged.

In the ensuing decades, from the 1950's through the present, Basic Energy Sciences researchers pioneered much of the evolving research on ion implantation. Their early results stimulated research by others and broadened considerably the scope of applications. Their continued research, along with that of others, contributed significantly to the eventual emergence of ion implantation as an established production technology.

Today, implantation is a worldwide enterprise valued at several billions of dollars per year. Thousands of ion implantation machines are at work around-the-clock producing speciality parts vital for business, medicine, science, and defense. Products range in diversity from long-lived surgical bone implants to some of the most sophisticated semiconductors for computers.

Technically, ion implantation is simply a means of inserting atoms of one kind or another into the surfaces of solids. Any species of the Periodic Table of Elements can be selected for implantation with almost absolute purity. Precisely controlled, the technique affords good reproducibility, an important feature for commercial applications.

Ion implantation is accomplished in two steps. First, sources of atoms selected for implantation, or molecules containing such atoms, are placed in a vacuum and given an electrical charge, using a number of standard ionization techniques. The charge-carrying atoms, or ions, are then accelerated in an electrostatic field to the desired energy and impinged onto the surface of the material to be modified.

Depending upon a variety of factors, the ions come to rest in the solid at predictable depths, densities, and distributions. Once embedded, the ionized atoms return to their neutral state.

A principal advantage of ion implantation lies in its ability to construct materials by design. It can position atoms precisely where one might want to have them. It can mix elements in ways otherwise unachievable. It is not subject to constraints imposed by solubility and equilibrium considerations of normal elemental chemistry. Under such constraints, for example, tin must be soluble in molten copper to form bronze, and likewise carbon in iron to form steel.

A graphic example of its unique capabilities involves the element of nitrogen. Nitrogen, as it turns out, is often an excellent element to mix into the structural matrix of certain metal alloys, giving the bulk material added toughness and resistance to corrosion. Yet, nitrogen is a gas and naturally escapes the molten metal environment of most metallurgical processes. In ion implantation, such problems are irrelevant. Atoms of nitrogen can be implanted directly into solids as easily as any other kind of atom.

In the same way, ion implantation can create materials in supersaturated and metastable states. This is done by implanting "excess" numbers of atoms, that is, more than those allowed by solubility constraints, into the atom structure of the implanted solid. The excesses cause the atoms of both to interact in new and often beneficial ways.

Such features are important in materials science, because small quantities of foreign elements, or so-called "impurities," when introduced into solids, can alter or dominate the electrical, chemical, optical, and mechanical properties of the original material. These properties, such as strength, hardness, resistance to corrosion and wear, electrical conductivity, and others, often impose the crucial constraint limiting further advances in technology.

The emergence of ion implantation as a practical technology is scientifically rooted in the early days of atomic energy research and related studies of energetic particles and their interactions with solids. This field of research, then known as radiation damage, was motivated by a need to understand the effects of radiation and their implications for reactor engineering and materials design.

The radiation damage of interest was mainly that caused by neutral particles, or neutrons. The use of ions came into being because they proved to