too brittle for most practical applications.

Research funded by Seed Money in 1981 and 1982 set out to solve the problem of brittleness by applying newly acquired knowledge about the behavior of certain impurities positioned at the grain boundaries, or interfaces where different crystals in a material come together. It is at these interfaces where the crystals can slip against each other, causing the material to break.

The Seed Money experiments focused on increasing the adhesiveness at these slip surfaces. This involved varying the proportions of nickel and aluminum, mixing in small amounts of four different alloying metals to be used as the impurities, which would hopefully migrate to and lodge in the grain boundaries, and finally, testing a number of different metallurgical processes.

Through an extensive process of trial and error, guided by new theoretical models and data (see Positron Probe), the optimum combination came to be known. Nickel aluminide was made sufficiently ductile to fabricate successfully without degrading its other desirable properties.

This success, published in *Science*, was pivotal in the development of a whole new field of research on ordered intermetallic alloys. It precipitated much follow-on and continuing research by both Government and industry on nickel aluminide. As one measure of industry's interest, over a half a million dollars in research money was provided by the private sector to the Laboratory in 1985 to investigate related production and processing methods.

The research earned an IR-100 Award from *Research & Development* magazine and is now subject to extensive patent and licensing activity by private industry.

Ion Implantation

Since the dawn of the Bronze Age more than 5,000 years ago, when man discovered that copper mixed with certain amounts of tin could overcome the shortcomings of stone tools, there has been a relentless search to combine the elements of the earth in new and improved ways to better serve his needs.

This search took a dramatic turn with the advent several decades ago of a technology called ion implantation. This technology, named after the method by which it is accomplished, literally enabled the modern metallurgist to construct the operative surfaces of desired materials atom by atom.

Seed Money research funded in 1975 and 1976 played an important role in the further development and expanded commercial application of this technology. Although the technology had been demonstrated as early as World War II, and was already in operation in a number of limited cases, Seed Money research provided valuable insights and new understanding, which invigorated research by others and broadened considerably the scope of potential applications.

The power of this technology lies in its ability to construct precisely materials by design. It has long been known in materials science, for example, that small quantities of selected elements, or so-called impurities, when introduced into solids, can alter or even dominate the electrical, chemical, optical, and mechanical properties of the original material.

These properties, such as strength, hardness, resistance to corrosion, electrical conductivity, and others, often impose the crucial and limiting constraint upon further advances in technology. A material pushed beyond its limit may cause a larger device to fail. Hence, the search for improved materials, largely focused on the introduction of impurities and new combinations of elements, lies at the forefront of intense global competition among both users and suppliers of high-performance technology.

In this search for new materials, ion implantation is a powerful tool. It uses a variety of standard techniques for ionizing atoms, that is, removing electrons from the atoms of the elements to be implanted, and once the atoms are electrically charged as ions, uses an electric field to focus and accelerate them onto, and implant them into, the surface of the material to be modified. Once embedded in the material, the ionized atoms return to their neutral state.

This process can implant selected elements precisely at varying depths in varying concentrations. It is versatile. Virtually, any species in the Periodic Table of the Elements can be selected with almost absolute purity. It is highly reproducible, a crucially important factor in commercial applications.

Perhaps most importantly and uniquely, it is not constrained by solubility and equilibrium considerations of traditional metallurgy. Under these constraints, for example, tin must be soluble in molten copper in order to form bronze, or carbon in iron to form steel. But not all potentially desirable combinations meet these constraints.

Direct construction of materials by ion implantation, by contrast, allows the formation of new combinations of elements heretofore beyond our grasp, such as materials in supersaturated and metastable states. It can forcibly insert any number of atoms of one material into the underlying base structure of another, causing the atoms of both to interact in new and often unique ways.

With hundreds of researchers now working in the field, commercial applications are proliferating. Their initial successes have had a profound impact on new product development in high-tech industries, spanning health, aerospace, defense, computers, and others. Although the Seed Money research on ion implantation cannot be directly credited with these successes, it can be credited with producing new insights and