fundamental knowledge upon which others built.

The primary focus of the Seed Money project was on the development of so-called metastable materials, wherein the concentration of implanted atoms of a foreign kind in a base material greatly exceed that allowed under normal solubility constraints. Such materials, it was hypothesized, might be used to create so-called superconducting materials, wherein the resistance to electrical current drops to zero under certain conditions, or very efficient solar (photovoltaic) cells, wherein sunlight is converted directly into electricity.

As is often the case in the path of research, the Seed Money success in this area was initially born of failure. The story of this success is also one of R&D leadership sensing an opportunity, pulling together the capabilities of equipment and human resources from different arenas, and moving quickly into new and uncharted territory.

In the summer of 1975, in anticipation of the arrival of a new piece of equipment, the leadership of the solid state research division at the Laboratory saw developing a unique confluence of technical capabilities. The new device was to be a low-energy, high-current ion accelerator, capable of manipulating a broad range of atomic species, or elements. This device would be used as the ion implanter. It was to be integrated with a complex array of other equipment, the most important of which included a high-energy positive ion accelerator with an ultra-high vacuum scattering chamber, which would be needed for diagnostics.

The combined capabilities of this facility would allow *in situ* creation and modification of precisely specified and varied materials through ion implantation. Simultaneously, they would provide a battery of sophisticated diagnostic tools, traditionally used in the fields of atomic and nuclear physics, such as Rutherford scattering, ion channeling, and electron transmission microscopy. Hence, the Seed Money researchers could probe the atomic structure of the created materials and analyze the results.

The Seed Money project provided an opportunity to study in fine detail the effects of ion implantation on the atomic structure of the underlying material under varying conditions. Importantly, it also allowed the temporary hiring of a visiting scientist from Australia, experienced in the use of ion accelerators, to contribute to the work and help build the technology base for further applications.

As mentioned earlier, the first part of this effort resulted in failure. While the ion implantation objectives were met, namely, the specified materials had been exquisitely constructed with higher purity, greater concentrations, and more homogeneity than previously attainable, neither material performed as expected.

The ensuing investigation of the detailed atomic structure of the material revealed the reason why. Extensive damage had been done to the crystal structure of the underlying base material as the ions had been implanted. This necessitated a heat treatment process to repair, or anneal, the damage. But the process of heating the material in the oven (bulk-mode heat treatment) allowed the excess atoms to escape (precipitate), thus destroying the sought after metastable or supersaturated condition.

This finding pointed out the limitations of bulk-mode heat treatment. It also set the stage for the successful search for an improved annealing process, (see Laser Annealing), one which might be carried out in a flash or pulsed-mode so quickly that the atoms did not have time to escape.

This is in fact what happened. Using laser annealing, the researchers were able to create a new solar cell, which at the time set unprecedented records of efficiency.

The study of the damage and the use of the laser created enormous excitement in the field. The laser's fast pulse and precise control over depth of penetration provided a means for both studying structural damage in detail and overcoming (repairing) a key problem (structural damage) which had limited ion implantation's more broadened application. Based, in part, on the knowledge stemming from the use of such methods, ion implantation, in conjunction with laser annealing, became an exploding field of research and a growing commercial venture.

The underlying research performed by this Seed Money project unveiled to the scientific community a deeper physical understanding of ion implantation as a means for creating and modifying materials. It also highlighted the unique combination of diagnostics available at the Laboratory and the valuable insights that could be gained by their use. These insights helped other researchers in commercial firms pursue their own developments. Today, ion implantation, apart from laser annealing, is a thriving and expanding industry.

Research at the Laboratory, for example, performed as an extension of the initial Seed Money project, found that the implantation of nitrogen in the surface of surgical bone implants made of a titanium, aluminum, and vanadium alloy, reduced wear rates by a factor of 400. This proportionately increased the implant's practical life. Prior to this, implants were not generally used for patients with more than 10 years left to live, because they would wear out, breakdown, and cause internal poisoning.

Spire Corporation, a Bedford, Massachusetts firm, has manufactured hundreds of nitrogen implanted hip prostheses for a major health product manufacturer currently performing clinical trials. Potential applications for hip joint replacements and other purposes are estimated at 150,000 per year.