process worked adequately in repairing some types of damage, but not all types of damage.

Frustration with conventional annealing processes led Rosa Young to request a comprehensive, worldwide literature search of alternative methods. This search uncovered a single citation on laser annealing in a Russian physics journal.

Motivated by this suggestion, Rosa tried a number of different types of lasers available at the Laboratory, all of which failed, until she struck upon a ruby laser borrowed from the Laboratory's fusion energy research division. With a single pulse lasting only 50 billionths of a second, she was able to repair virtually 100 percent of the structural damage in her sample materials, enabling them to become semiconducting at unprecedented levels.

Follow-on research revealed a number of important advantages of this new process over thermal annealing in a furnace. A principal advantage is that the laser light is heavily absorbed only in the thin surface layer of the solid. This produces very high temperatures (even melting) in the surface region, which are necessary for annealing the lattice damage. Yet, the absorbed energy is insufficient to raise the temperature of the undamaged substrate significantly. This avoids the deleterious effects of high temperatures in the rest of the part, such as warping and localized deformation, associated with bulk-mode heat treatment methods.

Another advantage for some applications is that laser annealing can be carried out in ordinary air, rather than vacuum, because the surface region subjected to high temperatures cools so rapidly that introduction of significant amounts of impurities from the atmosphere is minimized. This feature is particularly attractive for highly automated device fabrication.

Research stemming from these initial studies eventually led to six patents for the improvement of the properties of semiconductor materials, to an IR-100 Award, and to solar cells with efficiencies comparable to those made by the most complex conventional manufacturing procedures.

Although the focus of the Seed Money research was on solar (photovoltaic) cells, the scientific knowledge gained in developing laser annealing, proved to be of even greater value to manufacturers of advanced electronic microcircuits and computer chips. Pulsed laser annealing consists of exposing prepared materials to extremely short pulses of laser light. Lasers were chosen because they allow precise control of the extremely high intensity light required for the most complete annealing. However, from the theoretical and experimental framework developed to describe the laser process, it became apparent that certain conventional sources of light and heat could be substituted for lasers to obtain annealing results suitable for a number of applications.

Industry built upon these insights gained at the Laboratory and other laboratories, finding that arc lamps and high-intensity halogen lamps provide annealing nearly comparable to that obtained with conventional furnaces and at greatly increased rates. The commercial process has become known as rapid thermal annealing.

Sales of rapid thermal annealing equipment have grown in volume from $100,000 in 1979 to $10,400,000 in 1984 and are projected by industry sources to continue to grow rapidly over the next 5 years. The laser industry is following the developments in the field of laser processing with keen interest and several lasers specifically designed for laser processing of semiconductors are now on the market and selling well.

The technological applications of the new processing techniques are of great importance, but it may be that the opportunities they have provided for the study of fundamental problems in materials science are of even greater long-term significance. For example, the pulsed laser melting of doped semiconductors is followed by resolidification at rates much greater than those that can be obtained by any other methods. This has not only allowed detailed studies of how the atomic structure of a liquid is transformed into the structure of a solid, it has also provided a practical means (see Ion Implantation) for making totally new materials whose properties are now being intensively studied.