Laser technologies and the next industrial revolution

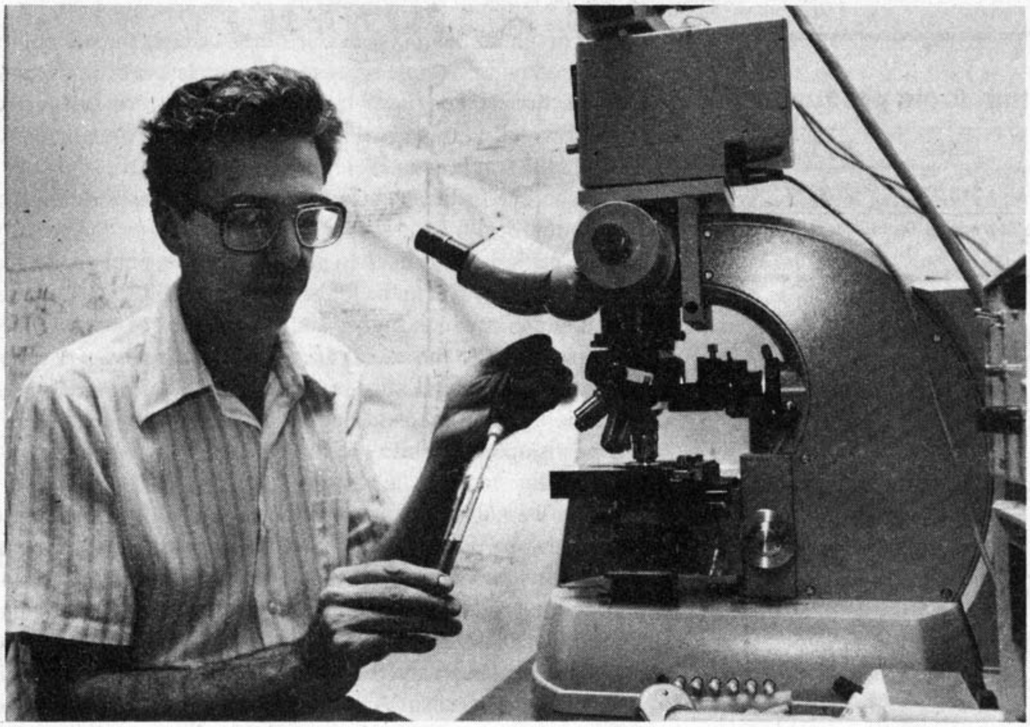
by Carol White

Nearly two years ago, in June of 1983, *EIR* issued a report, *The Potential Economic Impact of Relativistic Beam Technology*. The research team of economists and scientists anticipated that a massive influx of productivity into the economy would follow from implementation on a crash basis of what is now known as President Reagan's Strategic Defense Initiative (SDI).

The study compared the revival of the U.S. economy during World War II to the anticipated economic stimulus from the widespread introduction of lasers into the production of capital goods—in particular the production of machine tools. From 1939 to 1945, the output of goods production more than doubled. While it is true that some of this was accomplished through the use of idle capacity, the ability to achieve a total war mobilization at that time was accomplished primarily because of the widespread electrification of the economy. This not only allowed significant increases in agricultural productivity, but also the development of the highly energy-intensive aluminum industry. Materials such as magnesium and synthetic rubber were developed, as well as the potential for the civilian use of nuclear power.

We estimated that a crash program for the development of beam weapons would be the peacetime equivalent of the World War II economic mobilization, so that over the next decade the array of technologies associated with lasers and plasmas would cause a four-fold increase of economic productivity. A rough estimate suggested the increase of four million jobs per year, elimination of the U.S. trade deficit within a two-year period, and a rise in real per capita income by 5% per year.

However, as the study pointed out, only a cheap credit policy would allow spinoffs from the beam-weapons program to have a significant impact on the economy—turning the present worsening recession into a real economic revival. Over the past two years, the Strategic Defense program itself has achieved impressive successes both in intensifying the frequency and power of lasers, and in solving certain key problems in focusing and targeting. *EIR*'s original study warned of the need for a spectacular increase in electrification of the economy by the sixth



The technological spinoffs from the beam-weapon defense program can transform the world economy, extending the frontiers of research into materials processing and medicine. Shown is a scientist from Los Alamos Scientific Laboratory removing a sample from a test tube, in a technique for precise measurement of minute substances.

Los Alamos/Fred Rick

year of a program to reorganize production around laser and plasma technologies. Even with the automated production of nuclear plants and the introduction of magneto-hydrodynamic augmentation of electricity production, a huge bottleneck was foreseen.

Now, of course, as the nuclear industry itself is virtually being shut down, this problem will assume even graver proportions. In fact, even a modest upswing in production based upon existing technologies will reveal an immediately dangerous shortfall in the production of electricity. We must look to scientific breakthroughs in energy production, using fusion as well as fission reactors, to give us a solution to this serious bottleneck. Here again, the monetary policies being imposed upon the country have led to the short-sighted practice of cost-cutting by reducing government sponsorship of the non-military fusion and space budget, thereby slowing down or even halting the pace of developments which might otherwise bail us out of the impending power shortfall.

It is clear from the overall continued decline in productivity of the U.S. economy, that the continued high-interest and associated policies of Federal Reserve Board chairman Paul Volcker have in fact blocked the kind of takeoff which we might have anticipated from the stimulus generated to the economy by the President's SDI. These policies have hindered the assimilation of the spinoff benefits from the SDI program, which would more than pay for the program through the increased tax revenue which would become available as the economy received a "shot in the arm." Conversely, the failure to provide for the assimilation of these technologies is symptomatic of the destruction of the nation's in-depth war-fighting capability. It was the interplay of military and domestic policy which defined the military and industrial hegemony of the United States during the Second World War.

The report which follows assesses the actual impact of laser and related breakthroughs on the economy, and the potential which these give for an industrial takeoff—provided the vicious policies of Paul Volcker now suppressing industrial growth are reversed.

The assimilation of new technology

Lasers are a key element in any effective antiballistic-missile system because of the speed with which they can deliver energy on target, their ability to concentrate that energy to deliver a knock-out punch, and the more subtle effects which are possible by "tuning" the delivery of a graduated series of shock waves to a target in order to render it disfunctional through induced phase changes. One of the key elements of laser targeting is of course the alignment and focusing of the beam. These systems demand the most advanced computer controls and diagnostic capabilities. Not only must the beam be able to pinpoint its target, but it must be able to discriminate between live missiles and drones. All of these elements of the system, applied to production, imply greatly enhanced capabilities.

As the Japanese experience presently shows, we are on the verge of a revolution in robotics which can introduce the automated factory. The wedding of advances engineered through the SDI to these systems will continually upgrade

FIGURE 1

Number of U.S. machine tools produced

1972	1980	1981	1982	1983	1984
132,889	203,193	188,769	118,172	150,837	164,590

Sources: U.N., National Association of Machine Tool Builders

FIGURE 2

Number of units of lasers sold worldwide

Type of laser	*1983*	*1984*
HeNe	113,285	212,395
Ion	10,387	10,765
HeCd	1,077	1,430
Dye	655	739
CO_2	1,664	2,224
Solidstate (YAG and Ruby lasers)	4,203	4,451
Diode	496,400	979,300
Excimer	355	397
TOTAL	628,026	1,211,791

60% of laser sales worldwide are by U.S. companies. Source: *Lasers and Applications*

FIGURE 3

Number of lasers sold to metal-working industry

Laser Type	*1982*	*1983*	*1984*
CO_2	550	725	942
Solidstate (YAG)	600	630	733
Excimer	3	6	
TOTAL	1,150	1,358	1,681

FIGURE 4

Laser system consumption by type of industry (worldwide)

(in millions of dollars)

Type of industry	*1983*	*1984*
Printing/xerography	805	1,095
Optical communications	797	1,067
Color separations	505	570
Tactical military	307	316
Therapeutic medical	199	261
Metrology	203	248
Materials processing	186	233
Audiodisk	105	160
R&D	94	109
Agriculture and construction	76	86
TOTAL	3,442	4,376

their potentialities. At the same time, we have the possibility of introducing a whole array of new metals and ceramics into production. To engineer most efficiently the kind of industrial revolution this implies, will demand real time diagnostics of the sort being developed through the SDI.

The health of any economy is immediately dependent upon the health of its capital goods sector—and especially those capital goods used to produce more capital goods and infrastructure. But in the longer run, its viability is a function of the rate at which higher and higher rates of productivity are infused into the economy, through a rapid rate of introduction and assimilation of new technologies. Each new technology is in a sense a singularity. Whether or not it "flies" depends upon the ability of the system as a whole to assimilate such.

As we noted, the present financial manipulations of the economy by Paul Volcker and the Eastern Establishment banking strata which he represents, are deliberately strangling the productive economy in order to favor the speculative "black" economy typified by the illegal drug trade, the gambling casinos, and the real estate swindles through which they launder its cash. And this of course is coupled with the depression of world trade through the same policies by the World Bank and the International Monetary Fund. The effect of these policies on machine-tool production can be seen in **Figure 1.**

To judge the impact of high interest rates, look at the cost of leasing laser equipment today. The standard leasing arrangement is for a three to five year period, at an average cost of 2% over the prime rate—a leasing cost today of about 12.5%. For the entire period between 1940 and 1960, interest rates did not rise above 4%. If we compare the cost to industry of a laser leased at today's prices, with that at a reduced 4% rate, the result is that the "tax" which industry is now paying to financial speculators is preventing any rapid modernization from taking place. Financed over five years, a $200,000 machine now costs $376,714, as compared to $243,331 at the lower rate. The additional $133,381 is a 55% add-on to the cost of the machine. Similarly a $500,000 purchase today costs more than a quarter of a million dollars extra.

But there are other factors which also determine the rate at which new technologies are assimilated into an economy. Chief among them is perhaps the morale of the population. During the Second World War, the urgency of the task of meeting the goals of war production introduced a "crash program" mentality which mobilized the creative energies of the whole population. Countless inventions at the shop-floor-level must take place to upgrade the efficiency of any new invention and adapt its design to the specific tasks at hand.

Also there is a necessary density which must be reached before a new technology really takes hold. There was a phase change at the end of the 19th century from a steam-powered economy to one dominated by electricity, but this only occurred over time. It was first necessary to introduce a sufficient number of motors into the economy to cheapen the cost of production and allow their assimilation on a volume basis. It would seem that we are at the point now where, provided the appropriate changes are effected in credit and related policies, laser technology is at a takeoff point—with the potentialities much as we predicted them two years ago. The laser industry is still small, but in the last two years, by any measure, it has registered real growth. People in the field estimate that about 20-30% of lasers used in machine tooling are used in the aerospace and defense industries, while the rest are spread throughout the economy.

Between 1983 and 1984 total laser output doubled—although it should be borne in mind that most of the growth was in diode lasers, which are the cheapest, costing between $10 and $100 apiece. Nonetheless all areas of laser production were up. One of the fastest growing areas for lasers is in the field of communications. AT&T has replaced copper-wires by 700 miles of fiber optics on the east coast of the United States. This fiber optic carries a laser beam which transmits sound at a greatly reduced cost and enhanced speed of transmission. This system will be extended to the west coast.

While metal-working consumes only a small amount of world laser output (it ranks only seventh among laser users in industry), the rate of growth in this sector was 18% in 1983 over 1982, and it increased 24% in 1984 over 1983. Total sales for worldwide laser systems (i.e., machines incorporating lasers) were $3.442 billion in 1983 and $4.376 billion in 1984. The United States would then have produced $22.50 billion in laser systems in 1984. Since total machine-tool sales were $2,650 in 1984, a fair estimate would be that laser machine tools accounted for 4% of these sales. The automation of laser production itself, which depends upon the total parameters of laser use, will of course benefit every particular application. One way of cheapening the cost of using a laser machining device is the proliferation of laser job shops around the country, particularly in the northeastern United States. This makes lasers available for the small batch, 10,000 parts-to-be-welded per month, type of job.

The laser tool

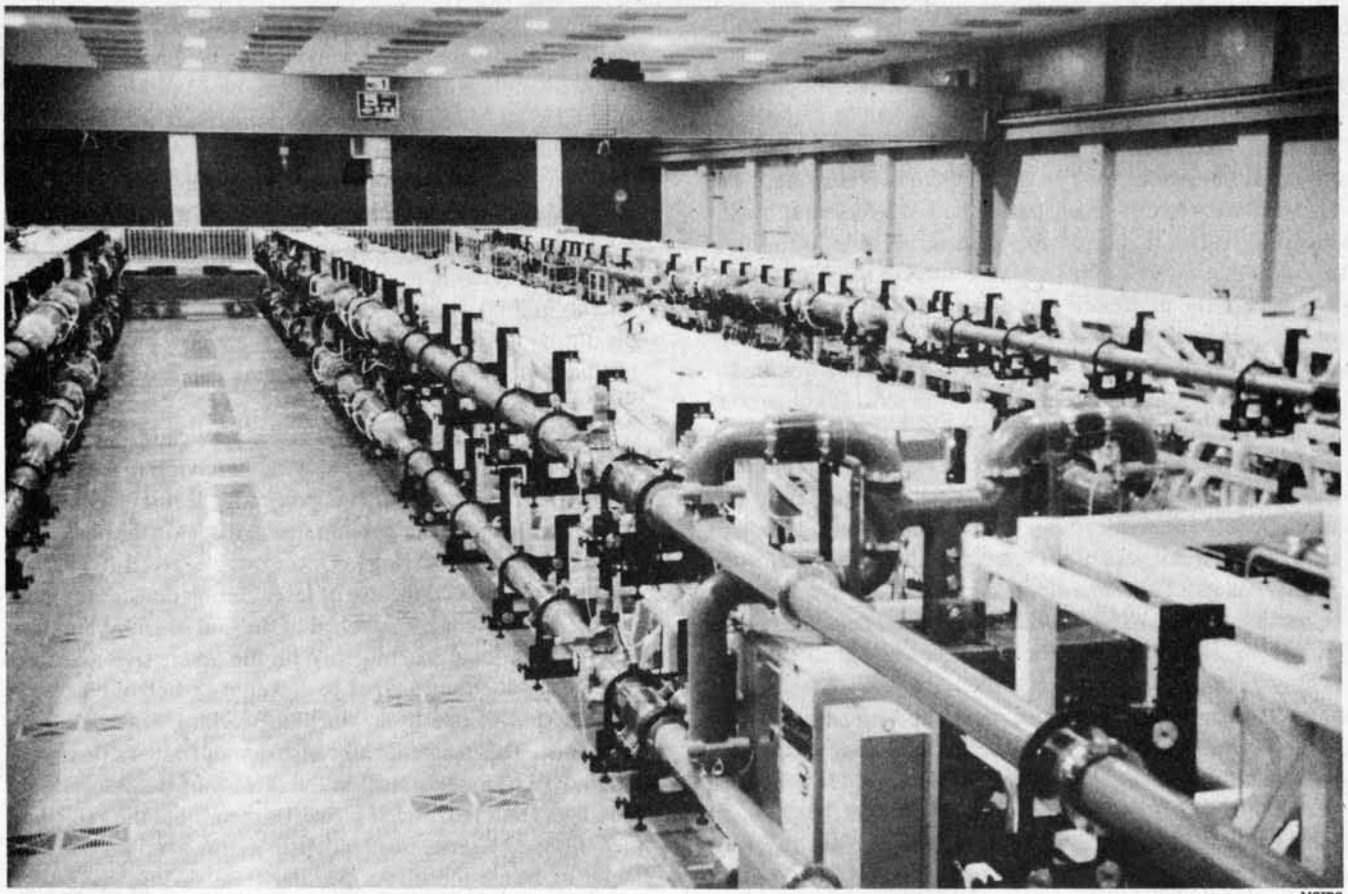
While lasers in themselves would not now be the tool of choice for many cutting jobs, they are already demonstrating their value not only for their ability to concentrate energy at high densities, but for their ability to be applied flexibly to varied jobs, from cutting to welding and plating. Best of all, this same flexibility can be put to use in designing and redesigning machine tools with minimum effort. For example, where a punch press is designed to punch holes in pre-assigned places, based upon the dies which are inserted in the press, the die itself must be changed at a cost of several weeks' time and several tens of thousands of dollars, in order to modifiy the distance between the holes. With a laser, one need only insert a new program into the machine console.

And of course the laser is capable of extraordinary precision. Laser machines now in use can drill holes that are 3/1,000 of an inch in diameter. A drill bit would break were it applied to such small holes. One application which is under proprietary wraps at the moment is the making of semiconductor chips for computers, which benefits from the capability of a laser to etch lines at hair thickness. At the moment they are operating in the range of a couple of micrometers. What is needed is an etching line of less than a micron in thickness. To do this it is necessary to go beyond the ultraviolet range. Excimer lasers are now producing cuts of a half micron in width. This is being pursued in the United States and Japan.

One immediate advantage of the application of lasers to machining is the ability to cut without having to adapt a die to the shape being cut. This is especially useful in the case of etching rectangular shapes into steel balls, as in the placement of stems on ball bearings. One example given to *EIR* researchers contrasted the use of laser cutting devices for making the blades that are attached to the end of jack-hammers, with conventional machines. With the latter, five machines worked for 40 hours a week to make up a batch of blades, as compared with one laser machine working only one eight hour shift. This laser machine also demonstrates a flexibility which will become typical in the factory of the future.It not only cuts teeth into sliced pieces of metal, but the same tool then fuses the serrated metal strip into a straight piece of metal to create the blade. Similar time savings have been reported by General Electric, up to as much as 98%. Lasers can also be used to make nugget welds, which, unlike electric-arc welding, do not require copper flux. With frequent welding, a $150,000 laser will pay for itself in one year simply by eliminating the copper.

Laser cutting of aluminum and copper has been especially problematic, since these metals tend to absorb the applied heat. But during the past year, with enhanced laser focusing, a YAG laser (a neodymium-doped yittrium-aluminum-garnet laser) has been developed which can cut these metals. It is superior as a cutting instrument to its more high-powered cousin, the carbon-dioxide laser, because of its higher frequency. Coherent-General laser of Palo Alto has found a method of concentrating the energy of the YAG laser at its center, thereby considerably magnifying the energy density which its beam can develop, while maintaining a fine incision. In the coming period we can anticipate large-scale adaptation of methods now being developed to achieve precision targeting of beam weapons, and to achieve further energy densification of lasers at the point of production.

In the area of robotics, while the Japanese are in the lead, Westinghouse has devised a laser-robot hookup which works along a monorail 40 feet long. Another Westinghouse experimental set-up uses a 25 kilowatt laser to feed six work stations. As a metal-working tool, the laser beam is piped throughout the shop from one central laser source.



NSIPS

The Gekko XII glass laser in Osaka, Japan.

New materials: the case of zirconium

One of the most significant elements of the new industrial revolution will be the introduction of new materials into production. One of the main bottlenecks preventing leaps in productivity comes from the limits imposed upon the efficiency of machines by the inability of the materials of which they are composed to tolerate high temperatures or extreme variation in temperature. Other problems are durability and resistance to corrosion. It is the latter, for example, which prevents the use of hydrogen as a replacement for petrochemicals.

Materials are also the limiting factor in a large array of higher-temperature processes using lasers, plasmas, and advanced nuclear technologies, which should otherwise be commercially available, but are not economically attractive under current depression conditions. The SDI program and its space infrastructure will push currently available alloys and ceramics to their limit, while also requiring the development of new materials. The nuclear reactor in space program, for example, demands reactors that are both compact and efficient. This means that they must be able to operate at a higher temperature. This program is already transforming the state of the art in materials.

Over the past two years, this nuclear reactor development program has again become a focus for NASA, the Department of Defense, and the Department of Energy. Not, as in the past, for propulsion, but for space-power production for laser, particle beam, radar, and other military systems. This tri-agency SP-100 program, and a parallel effort which will develop power sources larger than the 100 kilowatt SO-100 program, are resurrecting the materials work stopped in the early 1970s. One material coming to the fore is partially stabilized zirconium, a ceramic originally developed in 1977 by an Australian firm, Nilcra Ceramics, and patented in the United States in 1981. The three U.S. government agencies are presently considering use of some form of zirconium to strengthen refractory metals slated for use in the SDI space nuclear reactors, against thermal shock.

Pure zirconium is a ceramic with a high melting point. While it is immune to chemical attack, in its pure form it is very brittle. At 1,090° centigrade it undergoes a change in its crystal structure, which usually results in cracking and then the decomposition of the material. Recently it has been found that alloying zirconium with magnesia, calcia or yttria produces a material which can withstand 300,000 pounds per square inch of pressure. Materials such as zirconium can only be introduced into production as methods of handling them become available. Lasers are an essential element in this configuration, because they are able to cut through such materials. For example, the ribs of aircraft are made with the super-hard metal titanium, which is easily cut with a laser, but otherwise requires the exertion of tremendous force.

The SP-100 program has plans to use one of two heat-resistant metal alloys for the fabrication of heat pipes. One of these, tantalum, will be doped with zirconium. This metal has a melting point at 3,269° centigrade. The application of the design features developed by the SP-100 program to the development of a second generation of commercial nuclear reactors, particularly in the design of high temperature gas reactors, to give greater efficiencies of power generation, is essential if we are not to be held back by a severe power shortage. And of course the greater thermal efficiencies would significantly cheapen the cost of power generation.

Energy efficiency would also be achieved by the use of hydrogen gas as a fuel. The cost of cracking water to produce hydrogen is directly dependent upon the heat at which the process takes place. This in turn depends upon a heat source as well as upon the availability of heat- and corrosion-resistant materials. It is foolishly wasteful to burn petrochemicals, which are potentially limited and are only now in apparent oversupply because of the present severe contraction of production. Partially stabilized zirconium (PSZ) has recently shown in successful laboratory tests that it can withstand the necessary high temperatures. What is lacking is the heat source itself. The present sabotage of the commercial nuclear power program has not only stopped the building of nuclear reactors in general, but it has prevented the development of the high-temperature gas reactor, which could provide a cheap source of high-temperature process heat.

One immediate spinoff from this work is the development of internal combustion and Stirling cycle external combustion engines which could at least double the efficiency of current engines, because they operate at higher temperatures. The U.S. Army Tank and Automotive Command is funding research and development at Cummins Engine Co., in Columbus, Indiana for the development of an adiabatic diesel engine. The goal of this research is the production of 70% thermal efficiency as opposed to the 30% efficiency of current diesels.

This advance is made possible by the development of ceramics which have properties like those of steel, except that they can withstand the higher operating temperatures required to attain the desired thermal efficiencies. The optimal ceramic for use in engines and the one that the Army-Cummins program is built around turns out to be partially stabilized zirconium.

In laboratory tests so far, the Cummins engine has achieved a thermal efficiency of 48%. Cummins drove a truck with one of these engines 10,000 miles, with reportedly excellent results. The engine does not require a radiator to carry away heat. Cummins has dispensed altogether with 360 parts in addition to the radiator, by making cylinder linings, piston caps, valve guides, valve seats, and so on out of PSZ, so that the engine can operate with cylinder head temperatures of 760-870° centigrade. This produced a savings of 420 pounds in the weight of the engine, as compared to a water-cooled diesel of the same power.

The Army is interested in the engine because radiators are the most vulnerable spot in a tank. In order for the radiator to dissipate heat from the engine, it cannot be heavily armored. The result is that a single projectile into the lightly armored radiator stops a tank dead. Reportedly the temperatures in the combustion chamber are so high that one could use rags for fuel, not to mention kerosene. Cummins is now trying to use the PSZ to eliminate the need for oil, to further reduce heat loss, and to raise the thermal efficiency even more. They plan to use solid lubricants for point contact and leave the lubrication of the pistons and other moving parts to the circulating fuel itself. The Japanese are already making replacement engine parts out of PSZ, but do not appear to be working on a new engine design.

Making new alloys with plasmas

High-quality metal alloys are made today in electric arc furnaces which operate at about 1,650° centigrade. Research in fusion energy and plasma physics over the past two decades has opened up the use of plasmas at an order of magnitude higher temperature, where more materials can be alloyed to steel. The most advanced plasma steelmaking process in the world is nearing commercial demonstration in New Jersey by a private company. Only the underinvestment in the steel industry over the last decade, and now the current outright demolition of capacity by the major steel producers, has prevented this revolutionary new technology from placing the United States in world leadership in this crucial materials field.

The plasma furnace uses a high-temperature inert gas that has been ionized, consisting of positively and negatively charged particles. At 20,000°, no material could contain this hot gas, so as in fusion experiments, magnets surround the furnace to hold the plasma in the shape of a cone. Pellets of the materials to be refined are dropped into the furnace from the top, and in the 45 hundredths of a second it takes the pellet to fall to the bottom of the furnace, the material has been refined. At these increased temperatures, alloys with barium and tungsten can be created.

These super-hard materials can be used for tool steel, which cannot be cut even with a diamond. Rather than changing the tool in an automatic lathe, for example, after each eight-hour shift, this new alloy enables you to extend the life of the tool from seven to ten times. The barium and tungsten alloys can withstand temperatures up to 2,210° centigrade, compared to the 1,650° of today's tool steels, and are oxygen-resistant.

As the Japanese experience shows, we are on the verge of a revolution in robotics which can introduce the automated factory. The wedding of advances engineered through the SDI to these systems will continually upgrade their potentialities.

We can expect a significant stimulus to the design of new materials to come from the need to improve laser optics in beam weapons. In the middle of February, the Los Alamos National Laboratory began a joint $3 million program with other laboratories and industry to develop improved optical coatings for use in defense weapons systems. In order to at least double the currently available power of lasers for military applications without damaging their optics, basic research in materials, laser-material interaction, and chemistry will have to be performed.

As in many other fields of SDI-funded research, there will be numerous applications in industry from the technology developed through this program. An understanding of how lasers interact with the coating materials on their optical components in different kinds of environments will allow the development of new coatings tailored for specific uses. These new materials will extend the range of lasers used in industry. Lasers depend upon mirrors which amplify the reflected laser beam in their internal design. Large mirrors located in space will also be used to target laser beams propagated through space.

The SDI office has asked Los Alamos to develop materials that will enable mirrors to withstand a factor of two or more power than laser optics can withstand today. In order to do that, scientists will have to first develop an understanding of how coatings which are less than a millionth of an inch thick, react when exposed to corrosive chemicals and intense radiation, since SDI lasers and external mirrors could find themselves in hostile environments. Scientists estimate that the thin-film coatings, which are usually metallic oxides and fluorides evaporated onto a base material, can be made from 10 to 100 times more damage resistant.

Of course, the converse is also true. Increase in knowledge of how lasers interact with materials will improve the ability to kill missiles efficiently, which after all is the point of the SDI program. In some industrial processes such as laser welding, laser-induced "damage" is also the aim of the process. In many cases today, getting the weld desired is a hit-or-miss estimate, in terms of the length of the pulse or power level of the laser itself. If materials specialists understood more precisely how the laser "damages" the materials being welded, the laser pulse could be shaped for precision applications.

For example, when the laser is applied to a material, it creates a plasma vapor at the surface. At high power densities, a plasma wave propagates back up the laser beam. Up to a certain level, this plasma wave radiates heat back to the target material, enhancing the welding. Too high a power density can form that plasma into a shock wave, which can block the laser and reduce the efficiency of the energy coupling between the laser and material. It is also the case that the functioning of lasers themselves for industrial purposes could be improved by an in-depth understanding of laser-materials as the carbon dioxide laser, which produces its coherent light through a chemical reaction. The reaction can damage the optical components of the laser, causing clouding and other problems.

There could also be significant improvements made in the use of lasers in chemistry—such as isotope separation, creating more powerful agents to clean up radioactive waste, and other processing techniques. In these situations, the chemical interaction of the laser and material to be processed can produce a drift of chemical reactants out of the chamber where the laser chemistry is taking place, back to the laser, causing damage. The use of lasers in chemistry and the use of chemical lasers would both benefit from a scientific understanding of how the laser couples its energy to create various chemical reactions. Although industry may not use lasers at the power level that the SDI program is examining, if the one-shot threshold for optical damage is improved for military applications, it will also improve the reliability of multi-shot industrial processes at the lower power levels.

Other spinoffs

While superconductors have existed for the past two decades, the expanded demand for their development inconnection with the use of large accelerators to project electron beams, should have a revolutionizing impact on production similar to the earlier development of semiconductors. A superconductor, when cooled to near absolute zero, is capable of transmitting large electric currents without any significant level of resistance. The mechanical analogy would be to a frictionless machine, because without resistance there is no heat loss in the operation of the circuit. The only loss in transmitting the electricity then would come from the energy cost for maintaining the superconductor at cryogenic (near zero) temperatures. At 99% efficiencies, this can be made practicable.

The SDI program depends upon vastly expanded computer capabilities, in order to process the vast amount of information necessary in real time. One line of development is in optical computers, and along with this is further development of what are called systolic systems, that is computers which can carry out many parallel functions at one time. A further line of development would be use of organic chips; however, these have such fine-scale gauges that messages would have to be conveyed at x-ray frequencies. The development of organic material capable of sustaining x-ray irradiation without damage is now being worked on with genetic engineering techniques. For more than two decades, the power of computers has been increased every year by about a factor of 10. This steady advance in computing power has been almost entirely due to improvements in computer hardware, by reducing the scale of circuitry. Obviously, any such computer developments immediately impact the potentialities for the fully automatic factory.

A new development has recently occurred within the domain of linear programming, which may vastly improve the speed of computation. The claim is made by the author of this new system, Narenda Karmarkar, a mathematician now working at Bell Labs, that while the number of computations needed to solve linear programming problems with the simplex method can grow exponentially with the number of variables involved, with this new method the number of calculations only grows in direct proportion to the number of variables involved.

It was of course the Apollo project which gave the greatest stimulus to the computer revolution, with the development of semiconductors cheaply enough to become commercially feasible. It has been estimated that for every dollar spent by NASA, $10 was returned to the economy. The SDI has a far wider technology mandate. Over the past year, NASA has once again geared up its apparatus for reaching industry to transfer space-program developed technologies. The SDI office, on the NASA model, has started to hold workshops with potential industrial contractors who will be researching and building the future defensive systems. In addition to briefing the contractors themselves, the SDI office could begin to establish pathways for non-defense corporations to become involved in the transfer of new technology as it develops.

All of this can and will occur only in an economic climate in which new capital investment is being made at an accelerated rate, as opposed to the present system, in which existing capital infrastructure, as in the steel industry, is being destroyed without replacement.

The staff
ed Marsha Freeman, Richard Freeman, Charles Stevens, and Robert Gallagher.