

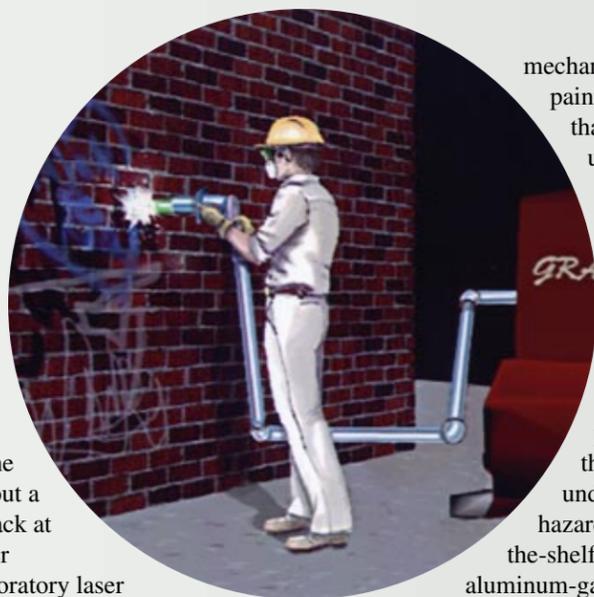
# Graffiti Removal by Laser

**D**OES removing painted scribbles with a high-average-power laser make sense? Dennis Matthews asked himself this question when unsolicited “street art” suddenly appeared near his home in Half Moon Bay, a small town about a half hour south of San Francisco. Back at work at Lawrence Livermore’s Laser Programs, Matthews first used a laboratory laser to test the idea and was astounded by the result. Now development of this laser spinoff application is on its way, thanks to the expertise from the Laser Programs’ high-average-power group, led by Lloyd Hackel. Once the technology is further developed, stripping hazardous and nonhazardous surface layers from a number of surfaces will also be possible.

The concept of using a laser to remove type from paper was demonstrated many years ago. A more serious problem in terms of taxpayer expense and potential environmental hazards is removing paint, such as graffiti and lead-based paint, from structural surfaces. The San Francisco Bay Area annually spends roughly \$10 million to fight graffiti, and New York City spends five times as much; but both are losing the battle.

All of the methods now used against graffiti have shortcomings. Workers painting over surfaces cannot keep up with the vandalism. Sandblasting paint gives rise to airborne sand and paint particles. Chemical methods, such as soda (sodium bicarbonate) blasting, generate large volumes of liquid waste requiring extensive containment and disposal systems. Abrasives scar surfaces under the paint, and more benign methods can be so inefficient that they necessitate multiple treatments.

The basic principle behind a laser paint-stripping system is debonding of the paint by means of photoacoustic stress waves. When a laser, adjusted to the optimal power and pulse length, hits a surface layer of paint, the energy is converted into heat and sound waves. Sound waves travel through the paint layer, strike the underlying hard surface, and rebound. The reflected sound waves collide (constructively interfere) with incoming waves at the paint layer and explode the paint into powder, as shown in the illustrations. The physics



mechanism—tensile failure—pulverizes paint and other types of coatings rather than chemically burning them. The underlying material remains undamaged so that no structural repair is needed. Some lasers that have been used for paint stripping—such as the CO<sub>2</sub> laser used in aircraft paint-stripping applications—operate at relatively long pulse lengths and do not flake or pulverize the paint layer. Rather, they burn paint off surfaces, an undesirable feature because of the hazardous vapor that is produced. Off-the-shelf solid-state, neodymium-yttrium-aluminum-garnet (Nd:YAG) lasers operating at an output power of 10 W are not powerful enough for graffiti removal.

A high-average-power, solid-state, neodymium-doped glass laser or a Nd:YAG laser is much more suitable for cleaning surfaces and is much faster than other methods. The high-average-power group at Livermore had been developing such compact, powerful lasers for several years for applications such as generating x rays for printing advanced electronic circuits and active imaging of objects in space. They already knew that laser wavelength determines the penetration depth of the beam and the depth to which the surface layer is heated. In developing this laser for removing graffiti, the group found that the ideal laser operates at a wavelength of about 1 micrometer, with an output of about 1 joule per pulse, and a short pulse length of 5 to 10 nanoseconds. High pulse-repetition frequencies on the order of several hundred to a thousand hertz (the faster, the better) achieve the best removal rates for large areas. LLNL has built unique lasers approaching these specifications, with up to 100 W of output power. Only a little more development is needed to achieve the target paint-removal rate of about 280 m<sup>2</sup> per hour (about 600 linear feet of freeway soundwall in a 5-foot swath).

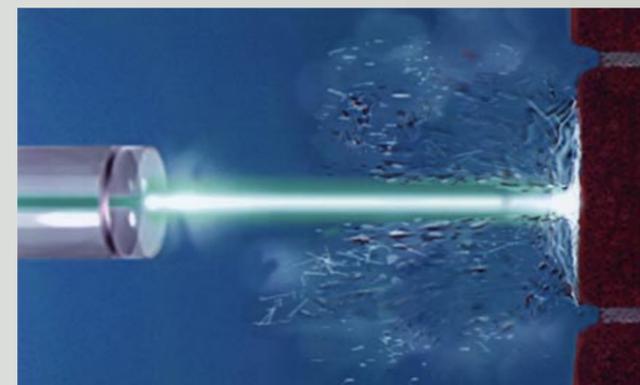
To better understand the principles behind cleanup applications, we tested the method with a Nd:YAG laser. This work showed that paint can be rapidly removed from smooth surfaces including polished granite or marble (as in monuments and works of art), window glass, and plastic, and from porous surfaces including brick, cinder block, and wood. The process leaves only a powdery paint residue that can be vacuumed up as part of the removal process. An unexpected bonus of the method is that it provides an acoustic indication when the work is done. The loud, snapping sound emitted

during spallation ceases when the paint layer is gone, so paint can be removed efficiently even in areas hidden from an operator’s view.

The next step will be to engineer a self-contained delivery and cleanup system that could operate from a truck or van. The portable system we envision would remove paint at least 30 times faster than the current best technology. Actual rates will depend on the coating thickness and porosity of the substrate. As shown in the illustration, left, laser light would be delivered from a telescoping, articulating light tube with a mirror relay. The articulating arm is similar to those perfected for medical use. A telescoping arm solves the challenge of reaching less accessible places, such as ceilings and surfaces above ground level. A vacuum hose within the arm’s “sleeve” would retrieve all residue.

Safety, especially the prevention of eye injury, is a major consideration in development. A lens will be used to rapidly disperse the beam, thus reducing its intensity to a safe level. The beam will be focused a few centimeters from the end of the wand but will rapidly diverge at greater distances. The delivery tip will have a protective shroud made of absorbing glass, and operators will wear goggles and a helmet. A digital access code will prevent unauthorized use, and a proximity switch will disable the device if directed away from a surface.

Beyond graffiti removal, another potential large-scale use for this technology is the safe stripping of hazardous surface coatings, such as lead paint, from public and private structures. In the U.S., for example, 90,000 bridges are currently painted with toxic lead-based paint, as are about half the interiors of residences across the country. The removal methods presently used are costly, and for some structures such as the George Washington Bridge, there is no practical way to guarantee lead containment. Bridge stripping in New



Livermore researchers Stan Mrowka (left) and Peter Celliers do early laser experiments to remove graffiti.

York City was halted when lead residue from paint was found in downwind playgrounds.

By the year 2000, a dozen U.S. commercial nuclear reactors are scheduled to be decommissioned. Laser stripping could make the metals in these facilities suitable for reuse. About 82,000 metric tons of steel and several thousand metric tons of stainless steel and copper could be recovered from these facilities and reused if the thin

layer of radionuclide contamination were removed from the metal surfaces. Moreover, decontamination would aid in the recycling process of other DOE metal stockpiles: 1.3 million metric tons of radioactive stainless steel, 38,000 metric tons of radioactive copper, and scrap nickel valued at more than \$1 billion.

Hackel’s group estimates that they can build and deliver a prototype graffiti-removal system in one year for about \$2 million. The Laboratory recently formed one alliance with an industrial partner who is interested in a commercial prototype system; additional investors or a consortium of municipalities is being sought to match development funds. Commercial units could be made for about \$250,000, a price that compares favorably with that for current soda sprayers, considering the greatly enhanced capabilities of the laser method. Once portable systems are manufactured, municipalities across the country would be able to purchase them to quickly eliminate the eyesores, social statements, and unwelcome property damage caused by graffiti. More development is needed to address the problems associated with removing and handling hazardous coating materials.

**Key Words:** graffiti removal, high-average-power laser.

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Graffiti will soon be removed by laser. With an ND:YAG laser, paint will be debonded from porous brick substrates and other surfaces.

# Adding Agility to Manufacturing

**I**NDUSTRIES depend on machine tools and robots to cut and shape parts into virtually every conceivable product, from pencils and desks to cars and airplanes. Machine tools are operated by devices called controllers, which are dedicated pieces of hardware that typically cannot be changed. Machine tools can last 50 years, but the controllers running them are often obsolete in 5 years or less, especially when product requirements change.

Recently, the U.S. dropped out of the list of the top five countries in machine tool production, and a single Japanese company now sells 80% of the world's controllers. Adding to U.S. manufacturers' woes is the fact that today's consumers are demanding greater choice in the products they buy. To keep up with demand, manufacturers need far more control over the manufacturing process. They need a process that can make a different or unique part quickly and make it right the first time at a predictable cost.

The DOE also must respond quickly to meet the demands for new, lower-cost, higher-quality components. The components at issue are critical in ensuring the safety, security, and reliability of a broad range of tasks the DOE oversees, including weapons manufacturing and disassembly. Thus, both American industry and the DOE are facing many pressures as they seek manufacturing solutions in an era of reduced budgets and dynamic change.

The solution is agile manufacturing, which offers the ability to respond to unanticipated change rather than being driven by a preconceived product made in a fixed sequence of steps.

Lawrence Livermore National Laboratory is part of a program called Technologies Enabling Agile Manufacturing, which has about 40 participants and funding of \$15 million per year starting in 1994. The program's technical lead, Bob Burleson, resides at Livermore. This program brings the DOE's resources, including those at Livermore, into an alliance with private industries and other federal agencies. The goal is to speed the development of agile manufacturing technologies and deliver flexible and modular tools that will form the basis for agile manufacturing. The tools will support modeling and simulation, shop-floor control, a feature catalog, and many other functions to streamline product development.

The central idea is to develop an "intelligent" controller (see the illustration) that can be adapted to various types of machine tools. Such a controller can allow machine tools to be

quickly reconfigured so they can produce different parts on demand. This new controller is the main focus of a separate \$52.6-million Cooperative Research and Development Agreement (CRADA), which brings together a team of LLNL researchers (also led by Bob Burleson), researchers at Los Alamos National Laboratory, and a Louisiana-based company, ICON Industrial Controls Corp. This CRADA will spur development of software for personal computers used to control machine tools.

A software-based (intelligent) controller running on a personal computer can replace the controllers already installed in existing machine tools, and the new controllers can be built into future machines. With this type of controller, a machine tool can be reconfigured in days or even hours rather than months or years.

But the advantages of agile manufacturing do not stop there. An intelligent controller allows a two-way exchange of information, a feature that is not possible with hardware-based controllers. For example, manufacturers will be able to make precise adjustments for variations in the temperature of a part or to compensate for the minute wear that inevitably occurs on tool tips or grinding wheels. Such adjustments today are crude approximations, and many bad parts are discarded. In agile manufacturing, sensors are introduced so that real-time adjustments are based on measurements taken as a part is being made. In addition, many controllers can rapidly communicate over a network for enhanced production coordination. If a single tool breaks in a series of coupled machines, the work-around action can be taken much more quickly.

LLNL researchers have been designing controllers for the DOE for several decades. The Large Optics Diamond Turning Machine at Livermore is a good example of a device operated by a controller with specialized sensors. This machine can routinely cut a few nanometers (one-ten-thousandth the thickness of a human hair) off the surface of materials. What makes our expertise and the idea of a generic controller relevant and practical is the stunning increase in computer power and the decrease in cost of personal computers during the last 10 years. Companies that previously spent up to \$150,000 for controllers will be able to perform more flexible functions for about \$5,000.

Essential to the generic, intelligent controller we are designing is the Manufacturing Operating System (MOS), as shown in the illustration. Redesigning hardware is not

The "heart and brains" of the manufacturing process is the controller, shown in the center. In traditional manufacturing, this component is a piece of prewired hardware. In agile manufacturing, an intelligent controller with replaceable software modules flexibly defines a manufactured part and the entire process by which a product is made. The modules being developed by LLNL are in yellow.

necessary; software is adapted when unanticipated tasks arise. Users can reconfigure their own controller to do the applications they want. Proof of the MOS concept was demonstrated on a three-axis milling machine at Los Alamos in March 1995, just six months after the project was initiated. Ultimately, the MOS will help the U.S. to recapture market dominance in machine tool manufacturing, and it will revolutionize the way most manufacturing is done.

Under the three-year CRADA, which began in late 1994, Livermore is developing the underlying real-time operating software for agile manufacturing. Los Alamos is writing human-interface software, and ICON is writing application-specific modules that can be inserted into the controller. The plan is to divide the controller into well-defined modules that correspond with known functions in current controllers and that provide extended and improved services in future controllers. One module can direct the trajectory of a machine tool, another can solve logic problems, another can coordinate tasks, and so forth. Application modules can be specific to a milling machine, a lathe, or virtually any other manufacturing

process. Third parties—with their own software or specialized modules—can simply plug them in to add new functions. ICON also is working with General Motors, which is interested in more agile manufacturing of auto parts, and Pratt-Whitney, which makes jet engines.

By the fall of 1996, we expect to have the first release of our new software completed and running. In Burleson's words, "Our mission is to help industry move from focusing on a specific product to focusing on the overall process." By doing so, the effort in agile manufacturing will streamline product development in the U.S., reduce costs and make them more predictable, enhance the range and quality of manufactured products, and shorten time to market.

**Key Words:** agile manufacturing, intelligent controller, Manufacturing Operating System (MOS).

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