

LASER SYSTEMS

Snapshot: Roessler and Coady

examine the role of lasers in automotive

materials processing and microelectronics manufacturing.

By David M. Roessler and Michael G. Coady

The U.S. automotive industry is celebrating its centenary this year and the 27th year since it first used lasers on an automotive production line. In 1995, the dollar value of worldwide industrial laser sales passed the billion dollar mark and about 15% of these sales went to the auto industry. However, lasers are still far from realizing their full potential in automotive manufacturing.

This overview contains a brief sketch of the past, gives examples of some of the more popular current automotive laser applications, and concludes with a discussion of some of the barriers limiting implementation.

Growth

The earliest automotive applications of lasers ranged from the scribing of ceramic substrates and trimming of

ing of components ranging from air-conditioners to transmissions.

Over 98% of all automotive materials processing lasers are either CO₂ or Nd:YAG. Until the late 1980s, only CO₂ lasers were available for output powers above a few hundred watts and these dominated high-speed cutting and welding applications. Since then, the remarkable increase in power available from YAG lasers, together with the potential for fiber optic beam delivery, has greatly increased their scope. Today, production line applications involve CO₂ lasers with output powers of up to 14 kW and Nd:YAG lasers with output powers of over 3 kW.

Figure 1 shows the increase in the number of lasers installed for automotive materials processing purposes worldwide since 1969. The U.S. was the first country to use them but, by the late 1980s, had been overtaken by Japan as the country employing the most lasers in automotive

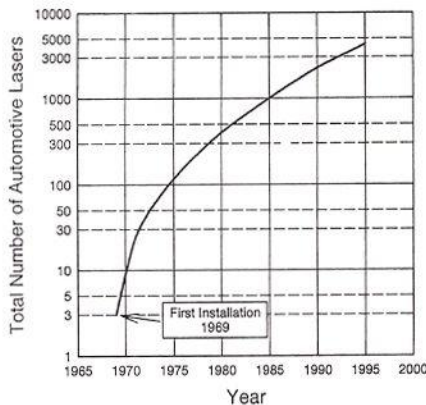


Figure 1. Number of lasers installed worldwide for automotive use.

in the AUTOMOTIVE INDUSTRY

resistors in integrated circuits (ICs) to the cutting of paper ignition coils and the marking of circuit boards and fuel pumps. By the late 1970s, much higher power lasers were being installed, particularly for surface treatment and welding applications. By the early 1980s, multi-kilowatt CO₂ lasers were being used for the weld-

manufacturing. About 5,000 lasers are now in use worldwide (this excludes the many used for measurement or inspection), over 60% being for the Japanese automotive industry. This is particularly remarkable in that there was negligible automotive laser processing in Japan until the early 1980s.

Figure 2. Laser-cutting of roof rack mounting holes (courtesy of Robomatix).

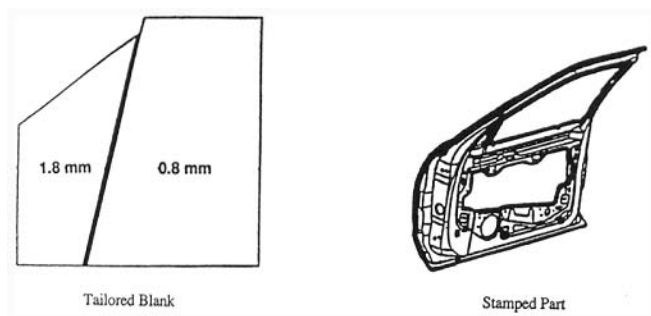


Figure 3. Laser-welded tailored blank for a front door inner panel.

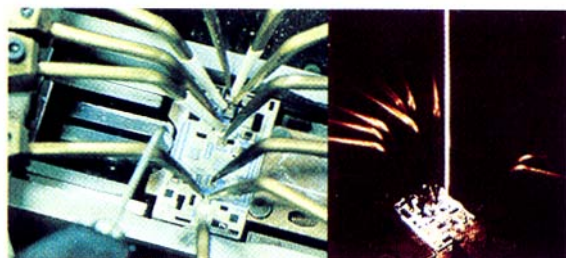


Figure 4. Functional adjustment of active integrated circuit components.

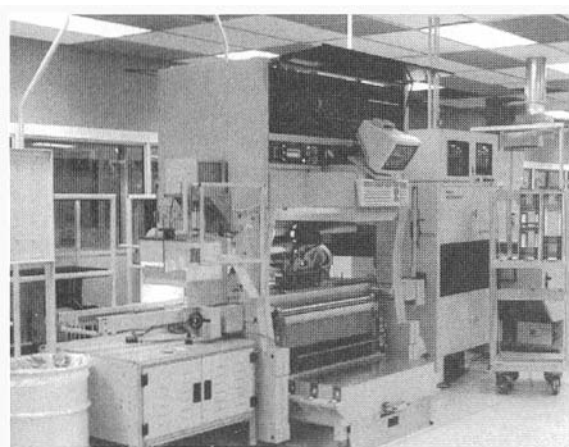


Figure 5. Component assembly with vision inspection.

Current applications

This brief survey cannot be comprehensive but will give the flavor of a few typical automotive laser applications, demonstrating their diversity and range, from high power uses in sheet metal machining to low power uses in microelectronics and inspection.

Cutting

The dominant automotive laser process worldwide is cutting. About 45% of the world's automotive lasers are used for cutting, primarily because about two-thirds of the activity in Japan is cutting. Laser cutting offers several benefits: a narrow kerf width (reducing waste and allowing close nesting of parts), low heat input and a small heat-affected zone, lack of mechanical contact (and possible distortion), access to difficult-to-reach locations, absence of tool wear or dependence on the material's mechanical hardness, easy automation, high cutting speeds (in thin materials), and so on. In low volume applications, such as prototype work or niche marketing, the ease with which a laser cutting path can be reprogrammed greatly reduces the need for die modifications and trials and may eliminate some dies altogether.

Similar benefits are obtained in "late-option" cutting. Costs can be reduced if small differences in the vehicle assembly or style, such as customized options, can be left until a late stage in the manufacturing process. Rather than have a variety of dies and other expensive pieces of hard tooling to make all the vehicle variants, common equipment is used to make as much of the vehicle as possible. A laser is then used to make the various cut-outs or holes that provide the customer options. For example, about 40% of Ford Aerostar vans are ordered with roof racks, and these require mounting holes in the roof. A 400 W, CO₂ laser is mounted above the production line and used to make these holes only in those vans for which they are needed (see Fig. 2, page 16).

Another popular use is the modification of vehicles depending on the handedness required. The dominant markets for U.S. and German automobile manufacturers are in countries where vehicles are driven on the right hand-side of the road. Only small numbers of some cars may be exported to countries with the opposite convention. Dedicating stamping dies to such low volumes is not economically viable and a laser can easily make the required cutouts in those blanks that will be used in the export vehicles.

Welding

In Europe, welding is comparable to cutting, in terms of the numbers of lasers involved, but welding has long dominated the U.S. auto industry. Lasers are used to weld automotive components as small as integrated circuits and sensors and as large as automotive roofs and side frames. In the past, hybrid integrated circuits required resistance welding of wires between the housing lead frame and large triangular shaped pads soldered to the circuit. Laser interconnect welding reduces the size of the pad required, thus increasing the density and number of circuits on a substrate, and thereby

reduces the cost of the circuit. However, laser interconnect welding does require an intermediate lead-frame called a spider, an additional part that must be specially manufactured and therefore adds cost. This has stimulated interest in alternative joining techniques such as compression wire-bonding from the lead frame to a pad on the circuit. While wire-bonding is flexible and software-programmable, it is slower than, and neither as flexible nor robust as, the laser welding it is currently supplanting.

Higher-power welding applications encompass both press-fit components (such as transmission gear parts) and large sheet metal parts. The laser has proved extremely successful in press-fit components, primarily because of high productivity rates, consistency of the welds, easy automation, and the lack of thermal or mechanical distortion. A single laser can service several workstations, the beam being shuttled between them while parts are being loaded or unloaded.

In the case of welding stamped, 3-D sheet metal parts, such as hoods, doors, and so on, the traditional approach is to use resistance spot welds. These require wide flanges (to accommodate the weld gun electrodes), adding material cost, weight, and complexity. Laser welding not only eliminates wide flanges, but also offers higher speed and greater weld consistency. Implementation, however, has been modest largely because of mechanical difficulties and the failure to design the assembly process to take advantage of the laser's unique benefits.

The most dramatic inroads currently being made by laser welding involve the use of customized blanks. This is the term for a sheet of metal made from individual, smaller, flat sheets having different thicknesses, coatings, and alloy compositions such that, when butt welded together, the resulting sheet has just the properties (strength, corrosion protection, etc.) needed in a given region. First implemented in Europe in the 1980s, and then very aggressively pursued in Japan (primarily by Toyota), laser-welded blanks were first used by the U.S. auto industry in 1992. The advantages include reduction in scrap material, use of less expensive material, elimination of reinforcements (and corresponding dies), greater component integrity, and so on. Figure 3 shows how steel blanks of different thicknesses can be welded together before the composite result is stamped to form a door inner panel. The process eliminates the need for separate reinforcements in the hinge and mirror regions.

Surface treatment

It can be much cheaper to use a laser to modify the surface characteristics of a material than to purchase a more expensive material having the desired properties such as hardness and temperature stability. Surface treatment generally uses high power lasers to treat large areas at high speed. Treatment ranges from the hardening of certain ferrous alloys by thermally induced solid-state phase transformation (surface remelting) to the creation of new material surfaces by cladding or alloying.

Examples range from the transformation hardening

of power steering-gear housings by 1-kW CO₂ lasers to the cladding of valve seats in high performance engines. The former enables the housing to withstand the high stress incurred as a piston slides through its bore. The latter enables engine components to withstand high temperatures. Although having great potential and receiving early attention, there is currently little laser surface treatment in the U.S. automotive industry; however, interest is growing rapidly in Europe and Japan.

Scribing and drilling

The field of automotive microelectronics also uses a wide range of laser powers. Ceramic substrates are machined by 500-W CO₂ lasers. In scribing operations, a series of small holes in a straight line is drilled a third of the way through the substrate. This line forms a fault plane in the material and makes it possible to break the substrate into individual circuits (much like scoring glass before sizing to fit a window.) Although these operations are fast and flexible, they incur very high investment costs and are extremely expensive to operate. As a result, extensive research is being done on an alternative technology called "green scoring," in which the ceramic in its green or unfired state is scored with a blade. This lowers cost, but it cannot place the lines with the accuracy of a laser and so sacrifices circuit density.

Laser drilling of holes in ceramics is performed with equipment similar to that used for scribing. The competing technology, mechanically punching holes in the ceramic in its green state, costs less but, as with mechanical scribing, is not as precise as the laser and similarly results in reduced circuit density.

Marking

Laser marking is a common automotive application that uses low-power (< 100 W) lasers. Examples range from CO₂ lasers used to engrave much of the dashboard instrumentation, including backlit displays, to 60-W, Q-switched Nd:YAG lasers for marking the alphanumeric and bar-codes on the vehicle identification number (VIN) tags mounted on top of the dashboard.

The speed, flexibility, and easy automation of laser marking systems has led to their wide use for the labeling of automotive microelectronic components. Increasing needs for product traceability are leading to the serialization of parts. The noncontact nature of the laser process allows the part to be completely assembled, including label, before being marked. The product is interrogated for its calibration and tested for quality before the final step of laser marking and serialization prior to shipping. The primary disadvantage of laser marking is its initial capital investment, which is high compared with other methods.

Functional adjustment

In a microelectronics product, it is often necessary to adjust or calibrate the output of a circuit while under operating conditions. The process by which the values of printed circuit components, such as resistors or capacitors, are modified by the removal of part of the

material, is called functional adjust of the circuit.

From the mid-1960s to the mid-1970s, this was accomplished for voltage regulator circuits by use of sand-abrading or sand-blasting. This process was slow, messy, and expensive and did not lend itself to high volume manufacture. In the mid-1970s, a YAG laser was developed that could adjust printed resistors rapidly and in a clean room environment (see Fig. 4, page 18). The cost per unit decreased encouraging the development of other products such as electronic ignitions, electronic spark controls, and pressure sensors.

Glossary

Butt weld: A weld between the ends of two components that are "butted" together and lie in approximately the same plane, as opposed to a lap weld, in which the parts overlap each other.

Hard tooling: The fixturing equipment used to position, clamp, or hold components that are being machined or processed in a manufacturing operation.

Wire bonding: The method used to attach very fine wires to semiconductor components to connect these with each other or with package leads.

Zener diodes: A semiconductor diode, usually of silicon, that acts like a rectifier until the applied voltage is large enough to produce avalanche breakdown. The diode then becomes conducting and the voltage remains constant.

Because of the high capital investment and operating costs of the YAG operation, the industry has examined other methods of functional adjust. New ICs are being designed so that the circuit output can be adjusted by zapping zener diodes in a logarithmic ladder configuration. Zener zap eliminates the high costs of the laser process and will also enable some microelectronics products to become all-silicon devices in the future.

Rapid prototyping

Several factors are compelling the automotive industry to shorten the time required to bring new products to market. Rapid prototyping (or free-form fabrication) is an enabling technology and several of its methods use laser processing. They range from the use of low-power He-Cd and Ar⁺ lasers for hardening photocurable polymeric liquids (stereolithography) to higher-power CO₂ lasers for sintering powdered materials (selective laser sintering) or cutting thin paper or metal sheets (laminated object manufacturing). Since its inception in 1987, this type of application has resulted in dramatic savings: reductions of 50% or more in time and costs are commonly cited.

Inspection

The automotive industry uses large numbers of lasers in non-machining applications, such as measurement, alignment, and testing. We will discuss only one example, vision inspection in microelectronics manufacturing. Here, lasers have allowed the use of larger substrates and automated statistical process control. A 3-D image is acquired by the raster-scanning of an infrared laser over the surface of the substrate. Optical detectors are then used to triangulate the exact position of the beam

spot. In one system, the volume of solder screen printed on the circuit pads (a key process characteristic) is monitored and used to control the process. This has dramatically reduced the defects at the component reflow process. In another vision inspection system, the image is used to determine the presence and position of surface mounted components before they are soldered (see Fig. 5, page 18). Since the component assembly machines vary in their placement of components over the course of time, the statistical process control system can stop the machine before the variations become large enough to cause defects. The use of such vision inspection systems has reduced defect levels to a few parts per million.

Overseas competition

Despite the early implementation of laser processing in the U.S. automotive industry, this technology is being exploited more vigorously overseas. The number of lasers used by U.S. industry and the number of U.S. laser suppliers are both losing ground relative to overseas competition. In fact, there are very few wholly U.S.-owned laser vendors left. Some have collapsed, but most have been bought up by foreign companies.

There is also a startling disparity between the U.S. and overseas in terms of national support for laser technology in manufacturing and in providing centers of excellence to train of personnel in this technology. With some notable exceptions (such as the Technology Reinvestment Program on Precision Laser Machining), the U.S. has nothing to match programs such as Eureka in Europe or the early MITI program in Japan. In Germany, both federal and state support has been remarkable. Institutions such as the Laser Center in Hannover, the Fraunhofer Institute in Aachen, BIAS in Bremen, and the Center at the University of Stuttgart ensure that Germany's technological lead in this area may increase.

Needs

To remain competitive in a global market, automotive manufacturers must respond more quickly to cultural, political, and other changes, driven both by consumer and regulatory climates. This means greatly decreasing the time it takes to move a vehicle from the design stage to the production line and accepting a much shorter lifetime before a particular model becomes obsolete.

Changes in materials composition and manufacturing methods will be needed to accomplish such a task. Large capital investments in traditional hard tooling will no longer be economically viable and much more flexible techniques, appropriate for low volumes and rapidly changing vehicle models, will be required. The laser can play an important role but greater acceptance by the automotive industry will rely on progress in several areas.

Successful "optics-based" manufacturing systems have two basic characteristics. First, they must live up to technical expectations: They must deliver what they promise. Failures here not only shut down a given application but also seriously prejudice the future of other

automotive laser applications. Second, such systems must satisfy the twin criteria of high reliability and low cost. Both may seem obvious but both remain barriers to wider implementation of laser-aided manufacturing in the automotive industry.

Despite the remarkable success of vendors in restraining or even reducing costs over the years, the initial cost of a typical automotive laser processing system is usually substantially higher than that of traditional manufacturing tools. This is a major hurdle because would-be purchasers are often skeptical of the argument that reduced operating costs will ultimately offset the initial capital cost.

Both CO₂ and Nd:YAG lasers are now reliable in factory floor environments over long periods of time. Uptimes (*i.e.*, the amount of time the laser functions as desired) routinely exceed 95% and failures may often be traced to ancillary systems rather than to the laser itself. Nevertheless, there must be proper training of personnel and a thorough preventive maintenance program.

Laser systems must be both "smart" and simple. The former implies that the system is capable of self-diagnosis and can give early warning when maintenance or component replacement is needed. The latter requires that such procedures are carried out easily and quickly by personnel on site. The cost of shutdowns on automotive production lines is so severe that delays of 24 hours in receiving replacement parts or in waiting for laser service personnel to arrive cannot be tolerated.

Other needs are more subtle. There is increasing awareness that the efficient deployment of what remains a very expensive source of energy requires a much better understanding of the very nature of laser-material interactions. A much greater appreciation of the roles of beam quality, pulse shaping, assist and shield gas controls, and so on, is now needed to optimize processes. Little progress toward such understanding is being made, at least within the U.S. automobile industry, largely because the resources and skills required are not those normally associated with automotive engineering. Further, the research needed is at too generic or fundamental a level for auto companies to fund it. Similar arguments are made with regard to the real-time, *in situ* monitoring and control of laser processing.

The most effective use of lasers depends on consideration at an early stage in the manufacturing process. Lasers are often used as direct replacements for traditional techniques and seldom considered in terms of their impact on design for manufacturing. This will change as engineers learn that the laser merits a place in their tool kits. There is inadequate knowledge of optics by the public in general and by production personnel in particular. An outreach program, whether via educational institutions or other means, would significantly help in the appreciation of optics-based systems and their potential in manufacturing. There is little doubt that the massive penetration by personal computers in our culture has been a major asset in the acceptance of PC-based manufacturing systems. Similarly an increased national awareness and technical literacy in

optics will help dispel the notion that lasers and optics are *exotic toys* rather than "economic tools."

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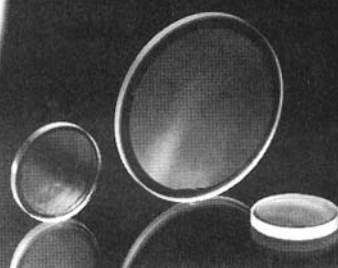
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