# Laser Solutions for Soldering

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**Non-contact selective soldering with high-power diode lasers.**

The trends toward miniaturization in the electronics industry and toward automation in the telecom equipment industry have led to the demand for new, highly controllable selective laser soldering technology. In the electronics industry, modern high-density electronic and electro-optic subassemblies frequently include delicate heat- and/or debris-sensitive components as well as complex three-dimensional (3-D) circuit geometries that cannot be soldered using conventional wave or hot air soldering techniques. At the same time, in the telecom industry, the need to lower costs, improve yields and save on real estate is resulting in the automation of many labor-intensive manufacturing operations, including soldering.

To adapt to these trends and market shifts, some electronics and telecom equipment manufacturers have adopted high-power diode laser soldering technology because it offers process controllability, high reliability and ease of automation. Selective laser soldering enables the delivery of precise amounts of energy to specific locations, even those difficult to reach, without causing heat-related damage to surrounding areas or components.

Consequently, it can be used with special substrates, thermally sensitive high-value components and high-temperature and low-lead solders. In addition, laser soldering is compatible with the conventional lead-based (Sn-Pb) and newer lead-free (Sn-Ag) solders used in electronics manufacturing, as well as with the gold-compatible (Au-Sn) solders employed in the telecom industry.

To take full advantage of the precision and controllability offered by lasers, these devices are usually mated to automated precision x-y positioning stages or robotic arms. Further, to provide the high reliability required for manufacturing environments, high-power diode lasers using aluminum-free active area (AAA) technology offer increased operating lifetimes. AAA diode lasers have longer lifetimes because facet oxidation, the primary failure mechanism in conventional AlGaAs semiconductor materials, is absent.

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## Industrial Soldering

Miniaturization of electronic devices used in automotive, consumer electronics, avionics and biomedical applications has led to high-density microelectronics with fine-pitch leads and small pad diameters. These packaging configurations are often 3-D in structure and frequently include thermally sensitive or high-value components, such as sensors, lenses, micro-electromechanical systems (MEMS) and central processing units (CPUs), that cannot be soldered with wave soldering. In these cases, selective laser soldering is a viable manufacturing solution.

Diode laser soldering provides temporal and spatial process control. This control extends to both the location and the metallurgy of connections, resulting in optimized joints for thermally sensitive components, special substrates, difficult-to-reach locations and fine-pitch quad flat packs (QFPs). Furthermore, process control may allow manufacturers to use diode lasers to rework poorly soldered units.

Selective laser soldering typically requires less than 10 watts of average laser power and relatively low power-density (watts/cm$^2$) to produce a single joint. In fact, if excess power-density is employed, spattering can cause poor joint quality. Despite these low power requirements, laser-soldering times are on the order of hundreds of milliseconds per joint. This speed, coupled with the small size, efficiency, ease-of-use, high-reliability and the integrated analog and digital interfaces of

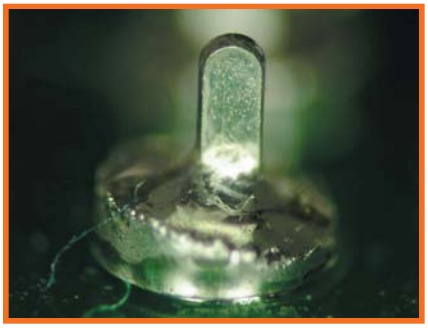

**FIGURE 1:** Severe dry joint; Sn-Ag solder, 6W. 0.8 sec.

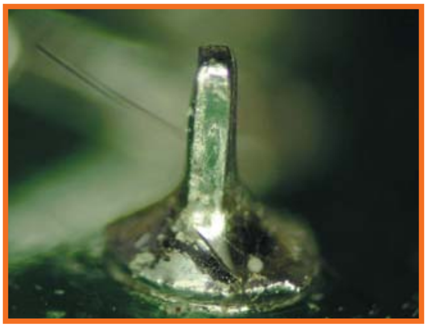

**FIGURE 2:** Dry joint; Sn-Ag solder, 8W. 0.8 sec.

**FIGURE 3:** Optimized joint; Sn-Ag solder, 10W. 0.8 sec.

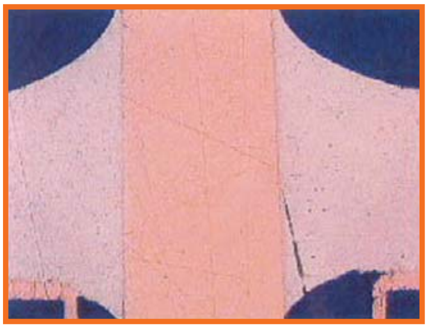

**FIGURE 4:** Cross section of Figure 1.

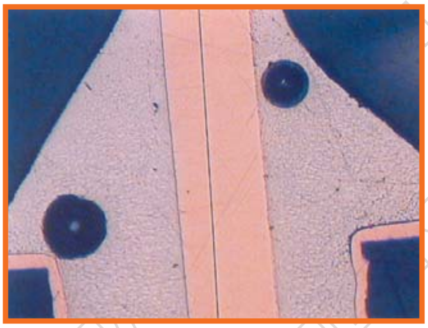

**FIGURE 5:** Cross section of Figure 2.

**FIGURE 6:** Cross section of Figure 3.

the lasers themselves, allows diode laser soldering to be easily automated.

Laser soldering is also replacing resistive radio frequency (RF) soldering, which employs resistive heating elements that are hand-positioned in the nose of some telecom packages. Automated laser soldering using x-y positioning tables and/or robotic arms improves yields and lowers costs because it is more reliable and has a shorter cycle time than RF soldering.

## Lead-Free Soldering Developments

While lead-free efforts have recently made strong headway in Europe, Japan and the United States, Europe has led the banning of lead. Specifically, in 2000, a draft of the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive proposed banning lead dumping in European landfills by 2004[1]. Then, agreement was reached on the WEEE Directive and the Restriction of Hazardous Substances (RHS) Directive at a European Summit meeting in November 2003. These directives prohibit the use of hazardous materials beginning July 1, 2006. These directives make lead free a requirement for products on sale to European consumers after this date. Leading manufacturers are expected to conform to the following timetable one year ahead of schedule, while other manufacturers may reach these milestones two years later.

For components these developments mean:

- some availability of lead-free components since the end of 2001
- complete lineup of components with lead-free terminations since the end of 2003
- complete lineup of lead-free components by the end of 2004.

For assemblies these developments mean:

- manufacturing lead-free soldered assemblies began by the end of 2002
- complete lead elimination from products by the end of 2005.

The roadmap also recommends a solder alloy composed of tin-silver-copper (Sn-Ag-Cu, or SAC) for board assembly and that industry leaders develop a system for labeling.

As a result of these directives, manufacturers are replacing low melting point (183°C) lead-based solders with newer, higher melting point (>220°C) lead-free solders, such as SAC and tin-silver alloys. When engineers at a laser application center compared laser soldering of the 96.5%Sn/3.5%Ag alloy with a Sn-Pb alloy, it was found to be easier to solder! This result is likely due to the ease with which the higher solder temperatures can be reached. Engineers have also demonstrated laser reflow of even higher-temperature gold-tin solders (279°C). Therefore, on the basis of melting temperature, diode laser soldering is likely to be compatible with all solder compositions.

## Soldering with High-Power Laser Diodes

For soldering tasks within the microelectronics industry, an average laser power range of 2 to 80 watts is used, depending on solder joint dimensions and the required speed. For convenience, soldering tasks are usually categorized by size into small, medium and large soldering areas.

***Small, 40 to 100 µm (0.0016 to 0.004 in.) Pads***

Typical applications for soldering these small pads are in high-density packaging. A few watts of average power are usually sufficient to solder these joints. Specific spot size and working distance requirements can be addressed by a host of commercially available optical imaging accessories (OIAs).

***Medium, 100 to 500 µm (0.004 to 0.02 in.) Pads***

In these cases, 25 watts delivered from an 800-µm-diameter optical fiber with an OIA capable of reducing the source size by a factor of 1.8:1 is preferred. Dwell time is approximately 1 second per solder joint.

***Large, 1 to 3 mm (0.04 to 0.12 in.) Pads***

In some cases, scanning several solder joints simultaneously is necessary and can be accomplished by expanding the diode laser spot size. This technique is a viable solution for soldering multiple joints on a densely populated printed circuit board (PCB). To increase the scan time, higher average power diode laser systems (up to 80 watts continuous wave) can be employed.

To demonstrate the high joint quality achievable with laser soldering, in particular the quality of lead-free joints, a series of trials was conducted. The lead-free samples shown were laser soldered with a fixed time of 0.8 seconds, but at different average power levels to determine optimum soldering parameters. The joints were subsequently cross-sectioned using conventional metallurgical techniques.

Figures 1 and 4 show an extreme case of dry joint caused by under-heating; almost no wicking (capillary action) into the through hole is visible. Figures 2 and 5 also show a poorly wetted joint, but at a slightly higher average power. Note the porosity in the joint and the subtle variations in the microstructure that would adversely affect the mechanical properties of the joint. Finally, Figure 3 shows optimum laser parameters for this particular joint configuration. Figure 6 confirms this well-controlled soldering process with clean, non-oxidized joints. Figure 6 also shows a fine-grain, porosity-free microstructure with good solder wicking down into the board and well-wetted contacting surfaces.

Although the majority of these joints has been prepared with a laser emitting at the widely used 810-nm wavelength, new evidence has emerged that some solder mask coatings are more damage tolerant to lasers emitting in the 940- to 980-nm regime.

## Gold Soldering for Photonics Applications

Gold-metallized telecom fibers have also been successfully laser soldered to gold-plated substrates using diode lasers at relatively low average powers. Specifically, engineers tested a standard 80/20 Au-Sn eutectic solder composition with a melting point of 279°C. By pulsing the output of the diode laser for rapid, but controlled, heat input and minimizing process time, laser soldering created high quality solder joints with large-grained, finely divided eutectic or near-eutectic joint microstructures.

Diode laser soldering enables precise amounts of energy to be delivered to specific soldering locations without causing collateral heat-related damage. Hence, even small-diameter, single-mode telecom fibers, which are easily deformed by excess heat input, can be safely soldered. Furthermore, laser soldering creates stable joints that can position the fiber with submicron accuracy to ensure long-term performance and to maximize optical signal transmission of single-mode fibers. Fine fiber alignment is performed while the laser is being used to selectively reflow the joint.

The telecom equipment industry is now starting to use diode lasers to automate the fiber-soldering process in an ongoing effort to reduce high-volume production costs associated with manual labor and to improve product quality, consistency, yield and throughput. In the past, the operator's skill and experience were critical to yield and throughput. Automated and highly controllable diode laser soldering of gold-metallized fibers may offer greater yields, higher precision, reduced cycle time and lowered costs compared to hand soldering.

## Putting Laser Soldering Technology To Use

Typical diode laser soldering systems consist of a laser/control unit and a fiber cable to allow easy delivery of laser light to any desired location. Consequently, the laser/control unit can be located remotely or rack mounted, while the laser light is delivered via armored optical fiber to the production line. As solid-state devices, diode lasers offer wall-plug efficiency (>40%) using single-phase electricity, which results in a low cost of ownership. Furthermore, their ease of operation and integrated analog and digital interfaces make them easily adaptable to automation in manufacturing environments.

Widely used fiber-coupled units provide up to 30 watts of average output power via an 800-micron-diameter fiber. The laser/control unit provides diode laser temperature and current control, and output can be pulsed using internal and external system interfaces, including RS232 and IEEE-488. These systems may have up to four laser diodes and four fiber outputs. The fiber outputs can be used separately for simultaneous top and bottom soldering applications or combined to provide up to 80 watts of average output power.

Today's systems are easily customized to fit specific industrial applications. For example, to solder smaller leads, smaller laser spots are essential; hence, changing a lens to give a different laser spot size may be required. Similarly, direct on-axis real-time viewing of the laser spot is often necessary, and camera accessories can be configured to provide this capability.

Too often in the past, the laser has been seen as an easy answer to manufacturing problems, and the complex issues associated with introducing a new technology such as this should not be underestimated. A number of key system requirements must be considered for successful industrial implementation of diode lasers, including reliability, wavelength and ease of integration. However, many advantages to employing lasers for manufacturing also exist, and, as the industry turns the corner in 2004, laser soldering appears at last to be in a good position to benefit from investment in new technology. ■

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## Laser Soldering Parameters

The main objective of laser soldering is to achieve high-integrity joints. Following is a list of parameters to consider while developing a soldering process. It is applicable to every solder joint configuration.

- **Laser average power (in watts):** Average power controls the rate of heat delivered to the joint. High average power is preferred to minimize soldering time, but excess power causes vaporization and reduces joint quality.
- **Laser pulse time/length (in ms):** Along with average power, pulse time/length controls the amount of energy delivered by a laser to the joint.
- **Laser pulse duty cycle (% on/off):** Pulse duty cycle modifies the rate at which heat is delivered to the joint, giving increased control of the process. A high duty cycle, which allows minimum soldering times, is preferred.
- **Laser power density (intensity, watts/cm$^2$):** Power density (intensity) controls the response of the material to the laser beam and, in conjunction with average power, generally determines the rate of the soldering process.
- **Laser focus position:** Accurate positioning of the laser focus spot is critical to ensure good joint quality and is best achieved using precision x-y positioning tables and/or robotic arms coupled with a CCD camera and an imaging accessory that allows coaxial viewing of the laser beam in real time.

## Reference

1. Tim Skidmore and Karen Walters. "Optimizing Solder Joint Quality—Lead Free." *Circuits Assembly*, April 2000.

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