Micro-welding demands new laser tools

Green wavelength laser ideal for high volume non-contact welding in automated environment

By Geoff Shannon

The growing medical device industry, a rapid increase in automotive sensors, and the rebound of the telecommunications industry, has driven a need for joining conductive materials such as copper, silver, and gold. As guest author Geoff Shannon from Amada Miyachi America (Monrovia, CA) explains, welding these materials is problematic for any technology and has even proved extremely difficult or impossible with traditional 1064 nanometer (nm) pulsed Nd:YAG technology. But a recent innovation – a frequency doubled 532 nm pulsed Nd:YAG laser capable of 4 J pulse energies – offers nearly an order of magnitude increase in absorption over the 1064 nm wavelength, expanding and legitimizing the use of lasers in conductive micro-welding applications.

PART MINIATURIZATION DRIVES THE NEED FOR NEW MICRO WELDING TECHNIQUES

As part miniaturization continues, and connector sizes decrease below 0.004-inches thick for flat ribbons and wire diameters, such traditional processes as crimping, soldering and brazing techniques become less viable due to high joint resistance, questionable joint reliability and longevity. By contrast, welding, which provides excellent joint integrity, longevity and conduction performance, is quickly becoming the required standard. For joining two materials where at least one is less than 0.02-inch in thickness, the technology required is called “micro welding.”

Copper is typically the material of choice for connecting conductive parts using micro welding, because of its superior ability to efficiently conduct electrical energy and transmit signals. In addition, silver and gold can be used either as a plating or for the conductor itself. However, the very high thermal conductivity that makes copper, gold and silver such good choices as conductors rapidly pulls heat away from the weld joint, making it difficult to maintain heat balance and weld reliably. This difficulty is further exacerbated by trends toward increased production rates, reduced part size, and welding of dissimilar materials and dissimilar conductor cross sections. The challenge of micro welding these materials is how to control the heat balance in these small and highly conductive parts to enable welding while ensuring no over- or under-heating. One way of meeting this significant challenge is by using a 532 nm, or green wavelength.

PLUSES AND MINUSES OF TRADITIONAL MICRO WELDING TECHNIQUES

There are a number of micro welding technologies, including ultrasonic bonding, resistance welding, and laser welding. Each has its advantages and disadvantages and each meets micro welding requirements somewhat differently.

Ultrasonic welding is particularly well suited to sheet and foils welding of conductive parts, including aluminum and copper. However, the ultrasonic process has some drawbacks for micro welding. Since force is imparted onto the parts, mechanical contact is required on either side of the joint. Also, the horn is a consumable that requires inspection and replacement. Joint geometry is somewhat limited to lap welding only and accessibility of the horn design. Also plated materials are sometimes problematic. Finally, the speed of the welding cycle that involves actuation of the horn can slow production rates.

Resistance welding uses the weld interface's high resistance to create heat as current is passed through the parts. The circuit is created by electrodes that contact the part either from the same side or opposite sides of the workpieces. Electrical contact is assured by exerting some force on the parts.

Resistance welding works well for a wide variety of joining applications and materials. However, since the resistance welding process relies on mechanical contact and the need to create an electrical circuit between two electrodes, it may not work properly in all circumstances, especially if the parts are mechanically delicate and themselves highly conductive. In addition, the minimum electrode size is around 0.04-inch in diameter, so this may limit joint accessibility.

Laser welding is a non-contact process, requiring only single-sided access. The technology is useful for working on extremely small joint areas, and can be used to weld different shaped parts, different joint geometries, and dissimilar materials. It uses no consumables that need to be maintained or replaced and the weld cycle is milliseconds. On the face of it, laser welding appears to be an excellent solution for copper micro welding – but there is a problem. The pulsed Nd:YAG (neodymium-doped yttrium aluminum garnet) used for the majority of micro welding applications has a wavelength of 1064 nm, which is more than 90 percent reflected by copper.

Extremely high power is required to overcome the reflectivity and to ensure that sufficient light energy is delivered to the copper to initiate the weld. However, once some laser power is delivered to the copper and raises its temperature, the reflectivity decreases. As the absorption of laser power occurs in time scales of less than a millionth of a second, there is a rapid change in how much power is absorbed. The high power that was initially required now far exceeds what is required to form the weld. As a result, the material rapidly overheats and vaporizes, leaving a large porosity or a hole.

A number of techniques have been used in an attempt to overcome this reflectivity, including pulse shaping, oxygen assist, and the use of less reflective platings. However, few have been successfully used in production due to practical implementation and process reliability.

PULSED GREEN LASERS ADDRESS MATERIAL REFLECTIVITY ISSUES TO FACILITATE LASER MICRO WELDING

As discussed, material reflectivity must be addressed to achieve a good, strong laser micro weld on copper. As shown on **Table 1**, reducing the wavelength from 1064 nm to 532 nm significantly reduces the reflectivity of copper and other conductive materials. The 532 nm (green) wavelength enables consistent coupling into the copper and stabilizes welding. **Figure 1** shows the comparison of 1064 nm and 532 nm wavelength welding of uncoated copper. At 532 nm, the laser couples into copper as 1064 nm couples into steel. Therefore, successful micro welding of copper can be achieved if a 532 nm laser is used.

Producing 532 nm from a solid state laser is known as second harmonic generation (SHG). The principal uses a frequency doubling crystal that operates as a non linear optic. Simply put, the incident laser frequency induces an electric field within the crystal that is out of sync with the incident field. The crystal then re-radiates at a different frequency and therefore a different wavelength to the laser that initiated the effect. The frequency doubling crystal, which can be either LBO (lithium triborate) or KTP (potassium titanyl phosphate), can be located either inside or outside the laser cavity.

Traditionally, 532 nm or SHG solid state laser were q-switched marking or micro machining lasers. The high peak power of the q-switch offers efficient conversion in the crystal, where typically a 50 percent loss in power is standard. Therefore, 10 W in provides 5 W out. However these q-switched lasers have a pulse width of 50-100 nanoseconds (ns) and pulse energies that are typically less than 1 millijoule (mJ). This is adequate for marking and micromachining, but way below what is needed for welding, where even the smallest micro weld is around 100 mJ, and can be up to 1 joule (J). The 532 nm welder is capable of up to 4 J pulses, which covers the majority of micro welding applications. The challenge for a SHG welding laser was to achieve efficient conversion with two orders of magnitude less peak power. Such a laser was developed by placing the crystal within the cavity and with careful control of polarization and beam power density on the crystal.

In the final version, the 532 nm pulsed Nd:YAG welding laser is capable of 1.5 kilowatt (kW) peak power with up to a 5 milliseconds (ms) pulse width. This provides enough weld energy to penetrate approximately 350 microns thick oxygen free copper, which is sufficient for many micro conductor welding applications. All the benefits of a regular pulsed YAG laser are maintained, including real time power feedback, flat top modes, fiber delivery and time and energy shared outputs.

REAL WORLD EXAMPLES OF GREEN LASER MICRO WELDING APPLICATIONS

Electrical connections come in many different sizes, shapes, and materials. The requirement for high quality, reliable terminal connections occur in many industries. The welding of electrical contacts needs to create a conduction path that is seamless to the operation of the part, such that the joint performs as a single solid continuous component. Laser welding offers this potential.

For example, the automotive industry has seen a significant increase in sensor technology to monitor car performance, functionality and environment. Each sensor has many terminal connections that must survive for the lifetime of the car. In this arena, laser micro welding provides a viable option, and the laser provides a great tool for high speed high quality welding.

Connection requirements are also important in the medical industry, for example in implantable devices, sensing and monitoring instruments, where each connection is essential to maintaining part functionality and performance, and thus requires a highly stable joining technology.

Similarly, in the communications industry, signal strength and integrity are crucial to maximize part performance and ensure that the joint is not a limiting factor to the part's design.

There are a number of electrical contact configurations that are needed across all industries chosen according to specific part and component design. A few of these connection options that can be accomplished using the pulsed green laser are shown here.

Wire and ribbon to metalized pad

A common connection in the electronics industry is shown in **Figure 2**, where a 0.0015-inch thick gold coated copper flat wire is bonded to metallized pads. Ideally the pad thickness is at least 1.5 times the thickness of the ribbon, because this creates a good thermal balance between the wire and the pad preventing the pad from overheating.

Side by side square terminal to round wire

The flexibility of the laser is extremely valuable in welding different joint geometries and terminal shapes. **Figure 3** shows a weld between a gold-plated copper connector of rectangular cross section to a silver-plated copper wire. The weld is made in a butt configuration, with the position of the wire in relation to the terminal showing some variation plus the gap between the wire round and the square edge of the terminal. The controlled and consistent absorption of the laser power to both parts enables the weld to be made reliably.

Flat to flat lead frame connections

For high volume production, welding multiple joints on lead frames is all about quality and speed. Being a non-contact process, laser welding lends itself to volume manufacturing. It can execute many welds per second, according to the motion integration. **Figure 4** shows a flat wire welding to a copper lead frame.

LASER WELDING – VIABLE METHOD FOR HIGH VOLUME MICRO WELDING OF COPPER

Micro welding of such conductive materials as copper is a difficult proposition, but laser welding offers a useful non-contact joining method, well geared for automation. In the past, copper's reflectivity at the 1064 nm wavelength has always been the barrier to implementing laser welding. By using a 532 nm green Nd:YAG laser welder, this barrier has been removed, offering a viable method for micro welding copper and other conductive materials in high volume.

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