THREE APPROACHES IN UTILIZING HIGH POWER DIODE LASER TO JOIN THERMOPLASTICS

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Abstract

As we enter the micro age, the new challenge in the plastics industry is to manufacture and assemble smaller and smaller parts. Standard joining methods, such as adhesives, fasteners, ultrasonic or vibration welding may no longer suffice.

Conventional lasers, such as the CO_2 and Nd:YAG, have developed into important tools for the metals industry but their use to the plastics industry is limited to the cutting and scribing of plastics. Diode lasers have a shorter wavelength and have now reached output powers that allow them to be used to produce a controlled melt, or welding, of thermoplastics. Weld lines as narrow 0.1 mm (0.004 in.) have been achieved using diode laser welding systems.

This paper reviews the capabilities of the diode laser welding process, and expands on three methods of delivering the diode laser energy to the work piece.

Background

In 1962 Robert N. Hall, while working for General Electric, invented the first semi-conductor (diode) laser [1]. His laser had an output wavelength of 840 nm, and required a large current density (10,000 amperes/cm^2). As such, the laser generated a tremendous amount of heat, and therefore could only be operated in the pulsed mode at -196º C. (-321º F) [2]. It wasn't until 1970 that a diode laser was developed that could operate continuously at room temperature. In 1982 the diode laser used in CD players was developed. This device has an output of 5 mW with a wavelength of 780 nm. In 1995 DVD's entered the market place using a diode laser, which emit a light with a wavelength of 635 nm.

Today the materials that generally compose High Power Diode Lasers (HPDL) are a mixture of Gallium (Ga), Indium (In), and Aluminum (Al) on one side and Phosphorus (P), Arsenic (As), and Antimony (Sb) on the other side [3]. Driven by a DC current, the HPDL emits a laser light with a wavelength in the range of 600 to 1600 nm, depending on the crystal structure of the diode. HPDL's are composed of diode bars, which are 10 mm wide and 0.1 mm high. Each diode has a power output of 40 to 60 W when operated in the continuous wave mode. Several bars can be stacked to provide greater combined powers (See Figure 1).

Laser diodes are similar to light-emitting diodes (LEDs) in the way that they function. Operating in the forward bias mode (+ on the p-side), electrons are infused across the P-N junction and into the semiconductor to create photons. These photons are then emitted in all directions from the plane on the P-N junction. The cleaved surfaces of the laser diode act as mirrors, and form the diode laser's resonant cavity [4,5]. As the laser light emerges from the diode it diverges in both the perpendicular and parallel direction, with more divergence in the perpendicular (30°-60°) then the parallel (25°-35°) direction. (See Figure 2). This diverging light is generally unusable as emitted from the diode, and therefore needs to be shaped and collimated according to the needs of the application (i.e. spot or line focus) [6].

Transmission Welding

Transmission welding of thermoplastics is accomplished by passing laser light through a top (laser transparent) part and onto a bottom (laser absorbent) part. (See Figure 3). The laser light is absorbed by the bottom part where it is transformed into heat. This heat is conducted into both the top and bottom parts, where it softens and melts both parts. Through the application of a clamping pressure the melted region of both parts are brought into intimate contact with each other. The forces created by the thermal expansion of the materials, and the externally applied clamping pressure, compel a mixing of the melted areas to occur. Upon rapid cooling the weld is formed.

To achieve transmission welding of thermoplastics, the two parts to be welded are chosen so as to have considerably different optical absorption properties at a particular wavelength. The optical characteristics of the top part should be as transmissible to the wavelength as possible. Specially pigmented products are available that allow for tinting of the top piece so as to be translucent. The optical characteristics of the bottom part should tend toward high absorption of the wavelength in a thin layer. Combining these two characteristics results in a high amount of energy being absorbed at the interface between the two parts, and a more efficient use of the energy in producing a weld. Reflectivity of both parts should be kept to a minimum. As the amount reflectivity increases, higher energy will be required to generate the heat necessary for welding. Laser absorption of the top part should also be kept to a minimum, as the amount of energy necessary to penetrate through to the bottom level and elevate the temperature at the weld interface will also need to increase. If absorption is too great, the top part may start to degrade before the bottom part begins to soften.

A typical joint design for laser transmission welding is simply a flat surface to another flat surface. Unlike vibration or ultrasonic welding, no energy directors are required and no collapse of the weld joint is recommended. Collapse of the weld joint causes new material to be introduced into the weld zone. This new material may not be heated to the required temperature needed for welding, resulting in a cold joint. Additionally, with the collapse of material, consideration for the displacement of material would also be required.

The laser energy necessary for welding can be presented to the parts in the form of either a spot or a line. Each form offers its own advantages, and selection should be based upon the application.

Three methods of utilizing laser

Spot (Contour) Welding

Spot or contour welding refers to the use a circular spot of laser energy to traverse a preprogrammed contour path, and create a weld or bond.

As mentioned earlier, as the laser light is emitted from the diode it begins to diverge. Through the use of mirrors and lenses the emitted light can be collimated, shaped and focused to a circular spot. The focused light can then be transmitted into a fiber optic, which has a diameter as small as a few 100 µm. The fiber optic can then convey the light to a work area. As the light exits from the fiber optic it again begins to diverge, and is once again refocused through a lens and delivered to the area to be welded. (See Figure 4).

The amount of energy delivered to the work area is governed by the amount of energy supplied by the diode laser module (minus losses for coupling efficiency of the optics), the size of the laser spot at the weld interface, and the travel speed of the laser.

The input amperage supplied to the diode laser control determines the amount of energy delivered by the diode laser module. A correlation of supplied current to delivered power can be determined for each laser module. The operator predetermines what power will be needed for welding and inputs the corresponding amperage into the controller. Most thermoplastics can be welded at energy levels of less then 60 Watts.

The size of the laser spot is set by the distance between the focus lens and the laser absorbing part, and is determined by the focal distance of the lens. (See Figure 5). The working distance can be set so that the interface for welding can lie above or below the focal point of the lens, depending on the application. Spot sizes of 1 – 2 mm are recommended for welding, but the spot size can be varied from as small as 0.6 mm upto several mm.

The main advantage of spot or contour welding is the flexibility that the process offers with virtually any welding path able to be programmed. In addition to the flexibility that contour welding affords, it also offers the options of varying weld size through an adjustment of the focal distance, and temperature feedback control of the weld via closed-loop control of the power.

Simultaneous Line Welding

Line welding refers to the use of a laser line for welding. Instead of focusing the light emitted from the diode module to a spot, the light is collimated and shaped into a line. (See Figure 6). Typical weld line dimensions are 1 – 2 mm wide and 15 mm in length and the typical weld cycle times 1 to 4 seconds. This line can then be used to weld as a stationary line (simultaneous) or as a moving line (mask). Line welding uses the same transmission welding principles of spot welding.

Simultaneous welding utilizes one or more laser lines to produce a weld along a part's contour. Each laser diode is turned on at precisely the same time to allow an entire contour to be welded simultaneously. (See Figure 7).
Part geometries, for simultaneous welding, have been traditionally restricted to square or rectangular shapes. It is now possible, however, to produce circular lines by utilizing special optic lenses. Again, the typical line widths are 1 - 2 mm. The optic lens can be changed to vary the diameter of the circle pattern from 2 – 3 mm to close to 50 mm. Of course, the intensity of the laser will weaken as it is dispersed to the larger diameters so the weld cycle time will most likely increase.

An advantage of simultaneous welding lies in the short cycle time required for completing a weld. The part is positioned beneath the laser diode modules, and an external clamping pressure is applied. The diodes are turned on, and the weld is achieved. No movement of the laser light or the parts is required during the weld cycle.
Initial set-up required for welding, on average takes longer then the set-up of a contour path, and energy densities tend to be less then that of contour welding.

Mask Welding

Mask welding utilizes the same transmission welding principles as the contour and simultaneous methods. It also requires the same externally applied clamping pressure. Like simultaneous welding, mask welding also uses a laser line to produce a weld. Mask welding differs from the simultaneous process in that it incorporates the use of a mask to block the transmission of the laser line as the line is scanned over a part. The mask shape determines the pattern of weld produced, and its precision is significant in determining the accuracy of the final weld. A precise mask is produced via photolithographic removal of predetermined portions of a metallic coated glass, producing a finite pattern. The pattern can be as varied as required by the application.

The mask is accurately positioned over the parts to be welded and the clamping fixture. The laser line is then scanned over the mask. The mask acts to selectively block the laser light from entering into the part. Where the laser light is allowed to enter, welding is achieved (See Figure 8). Using the mask welding process it is possible produce an area of weld instead of just a line of weld.

The main advantage of this process is that it allows for very precise and very fine weld lines. Weld lines as narrow as 100μm have been successfully made with the mask welding process. In addition, this process allows the possibility of producing welds with elaborate structures or contours. During one weld sequence, it is plausible to weld lines with different widths and shapes, as well as whole areas of weld [7].

The mask process has found a strong foothold in the medical and micro-fluidic markets because of its ability to produce very precise weld lines. In addition, mask welding has also found a market where large areas need to be welded quickly.

When welding micro-fluidic channels, alignment of the mask with the channel is critical to ensure proper location of the weld. If precise location of weld is not required, very quick cycle times are possible as the alignment can be performed mechanically with a fixture. An automated system called the Novolas™ μ has been developed to automatically perform this function and thus, dramatically reduce the cycle time of a manual alignment of critical assemblies.

Conclusion

Diode laser welding is proving to be another viable alternative for joining plastics. The diode laser uses a semiconductor to generate the laser light. The parts to be welded absorb the laser light and convert it into heat for welding. The laser light may be delivered to the part in one of two ways, either in spot or line form. When the laser light is delivered in spot form (Contour Method), it may be moved around the part using flexible preprogrammed paths. When the line form is used it may be stationary (Simultaneous Method) or scanned across the part to be welded. When the laser line is scanned across the part and used in conjunction with a mask (Mask Method), very fine, precise welds can be achieved. No matter which way the laser light is delivered to the parts, the end result is a vibration-free, particle-free, hermetically sealed, gas-tight weld.

References

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[6]Hessler, Thomas. Promising Technology: Laser Welding of Plastics. Euroforum 26, 27 October 1999.

[7]Hessler, Thomas. Promising Technology: Laser Welding of Plastics. Euroforum 26, 27 October 1999.

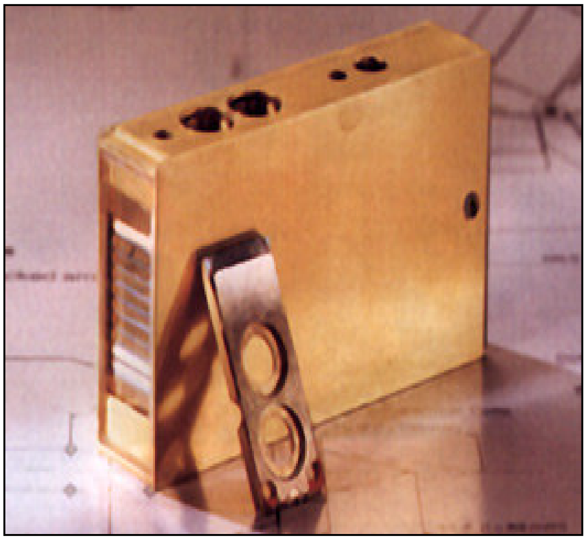

Figure 1 – High Power Diode Laser Stack (Photo courtesy of Dilas)

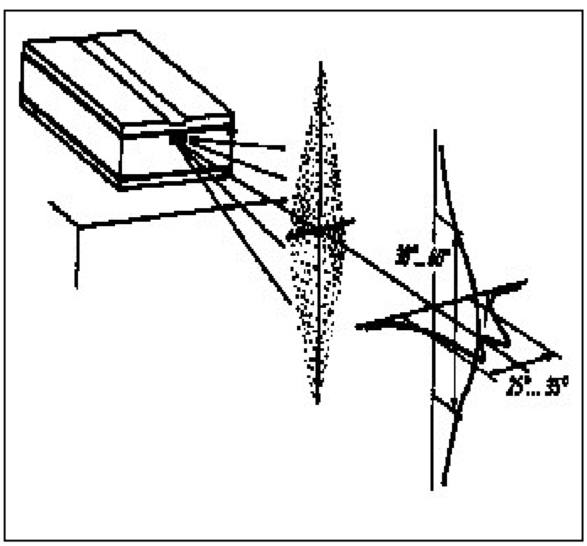

Figure 2 – Divergence of Laser Light from Diode. 30° to 60° in the perpendicular direction and 25° to 35° in the parallel direction.

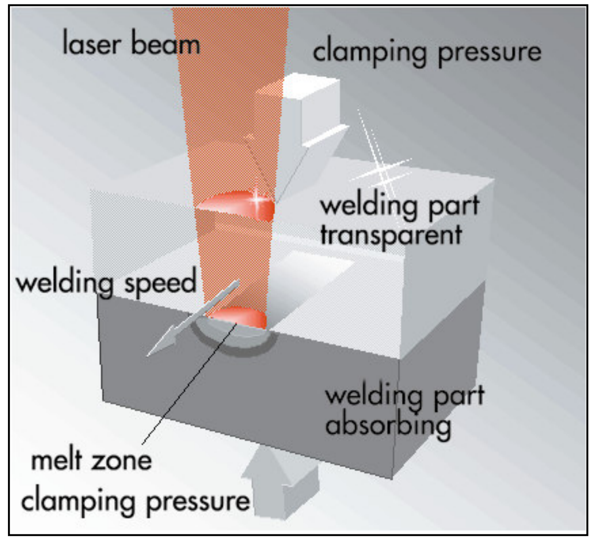

Figure 3 – Transmission Welding Design

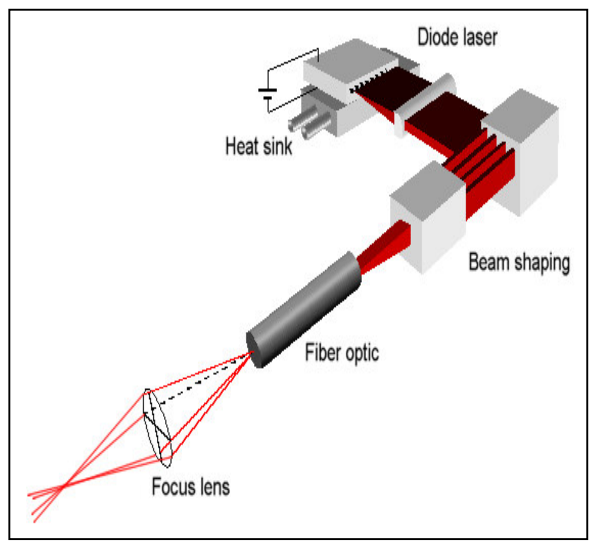

Figure 4 – Fiber Optic Laser Light Delivery

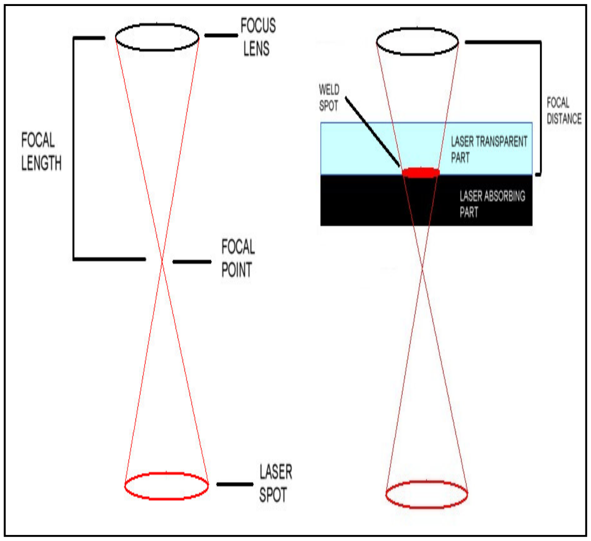

Figure 5 – Determining Weld Spot Size

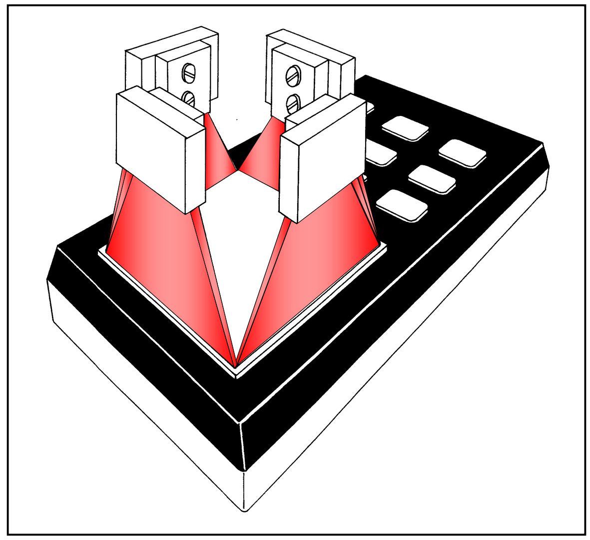

Figure 7 – Typical Simultaneous Welding Application

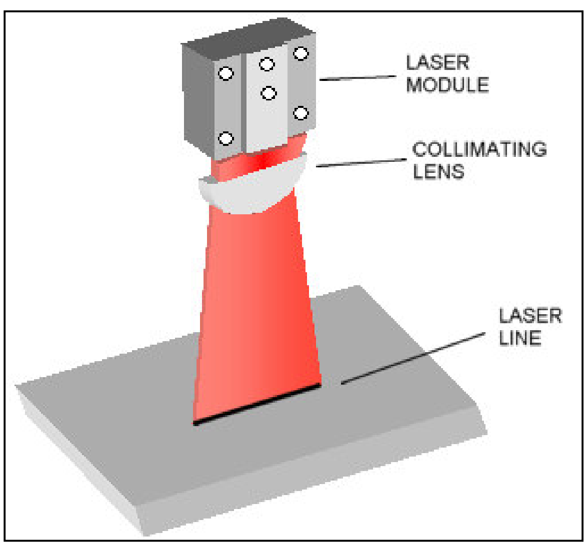

Figure 6 – Production of Laser Line

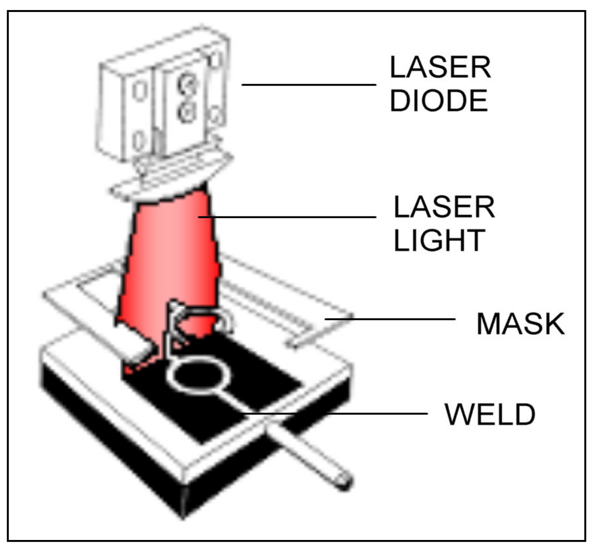

Figure 8 – Typical Mask Welding Application