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Laser Diodes System for Flexible Manufacturing

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Introduction

Industrial laser systems based on high power laser diodes are now available with output power levels as high as 4,000 Watts CW. These lasers are being used in applications such as welding, heat-treating, surface cladding, brazing and paint stripping. This paper will review the recent results of tests performed with the ***ISL-4000L*** (Figure 1) which is manufactured by Nuvonyx Incorporated.

Figure 1 Nuvonyx ISL-4000L Laser System

Industrial Semiconductor Laser (ISL)

The technology basis for the ***ISL*** family of laser systems is a unique lenslet array close coupled to a two dimensional array of laser diodes. The advantages of the laser diodes are their high electrical to optical conversion efficiency. The laser diodes used by Nuvonyx have demonstrated electrical to optical conversion efficiencies as high as 60%. The net result is a laser system with a wall plug electrical to optical power conversion efficiency of >20%. Consequently, a 4,000 Watt CW laser diode system consumes less than 20,000 Watts of electrical power, including the laser water-cooling system. This efficiency translates into a lower cost of operation for the user.

The laser diodes are packaged in individual heatsink assemblies at Nuvonyx (Figure 2) to form a linear array of laser diodes. These linear arrays are then stacked to form a two dimensional array of laser diodes (Figure 3) that is capable of 1.2 kWatts CW. The output from the laser diodes is collimated by a custom set of micro-optics to the high-power laser-diode beam. A lens system it then used to either focus the power from the laser diode arrays or re-image the arrays to a spot smaller than what can be achieved with a simple focussing optic.

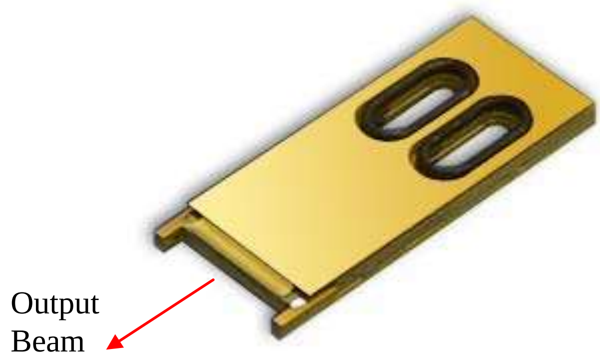

Figure 2 65 Watt CW High Power Laser Diode Package

Figure 3 1.2 kWatt CW High Power Laser Diode Array Package

The ISL-4000L is a complete, turnkey laser system with a laser head that weighs less than 14 pounds and is designed for use on a 6-axis robot. Figure 1 shows the laser head mounted to the end of the robot arm. The robot in this photo is a Panasonic VR-016, which is capable of carrying a 32-pound load. The applications outlined in this paper were performed with up to 3,150 Watts of direct diode laser power.

Welding

Nuvonyx has experimented with a variety of materials and welding techniques. The best results have been obtained with low thermal conductivity materials such as stainless steel, carbon steel, zinc plated steels, titanium, and plastics.

The welding of stainless steel 304 was tested with ISL-4000L laser using the six-axis robot. Complete penetration of the test samples was achieved with little distortion, and good weld quality. The stainless steel coupons that were tested were 2” x 4” in size and

0.020” and 0.035” thick. The coupons were welded along the 4” dimension using an Argon shielding gas.

The coupons were clamped in a fixture and blanketed by Argon using a large area sparger. The argon flow rates was as high as 47 liters per minute which provided complete coverage of the coupons over their entire length. The laser power was varied from 1200 watts to 3,150 Watts and the optimum welding speeds was recorded Figure 4. All of the welds exhibited exceptionally smooth surfaces, very low distortion of the plates which is consistent with the small heat affected zone, and very little oxidation on the surface as a result of the good coverage by the shielding gas. A micrograph of the welds is shown in Figure 5. Similarly, the micrograph for a lap weld is shown in figure 6.

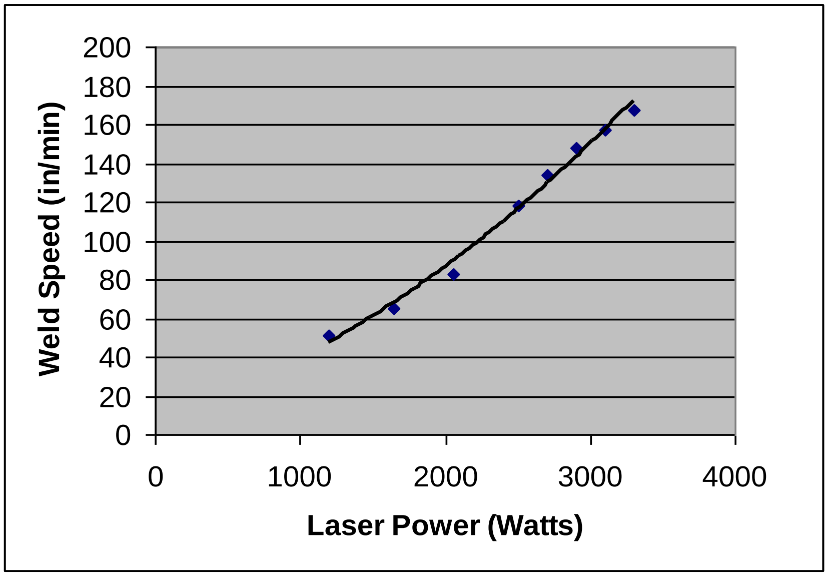

Figure 4 Welding speed vs. laser power for stainless steel.

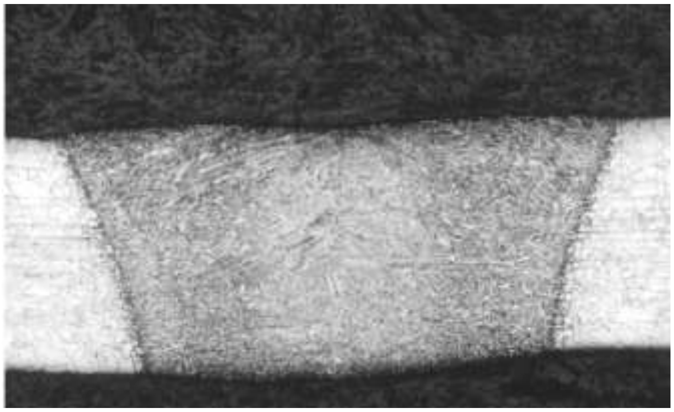

Figure 5 Micrograph of SS weld showing excellent penetration and grain structure.

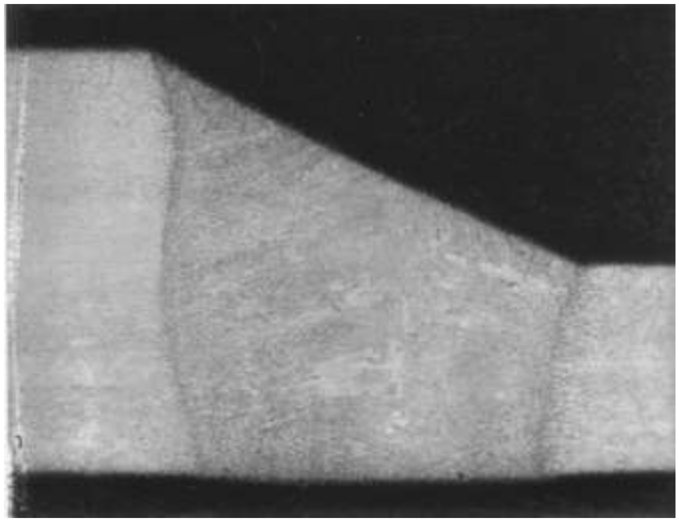

Figure 6 Micrograph of SS lap weld showing excellent penetration and grain structure.

Tests with carbon steel coupons produced similar results, although somewhat slower speeds. The carbon steel coupons that were tested were 2” x 4” in size and 0.06” in thickness. Using 1.5 kWatts of laser power and the same Argon shielding technique, these samples were welded at speeds up to 12”/minute. At higher power levels, speeds in excess of 20”/minute were achieved. The welds were again exceptionally smooth and exhibited low distortion but the heat affected zone was somewhat larger than for the stainless steel materials.

Tests on zinc coated steel revealed the importance of the Argon shielding gas. In several instances where the argon did not adequately shield the parts, the zinc caused an exothermic reaction resulting in significant spatter from the weld pool. However, with the 2” x 4” coupons and 0.02” thick parts excellent welds were obtained at speeds in excess of 20”/minute. These parts were welded with both a tight fit up and a loose fitup of nearly 0.02” gap between the parts. Distortion was minimal on the panels due to the small heat affected zone and penetration was excellent.

The ISL-4000L laser has successfully welded plastics, both opaque to opaque and translucent to opaque. The best results to date have been recorded with the welding of a translucent plastic part to an opaque piece. Speeds in excess of 250 inches per minute have been demonstrated with than 1000 Watts of laser power. Higher speeds are feasible, but the application under study did not require it.

Surface Transformation Hardening

A key application for this laser is surface transformation hardening. This laser was designed with this application in mind. The laser provides a broad area beam that can be swept over the surface to produce the desired hardening. Because of the large area covered directly by the beam, this laser can quickly treat large parts.

Laser surface transformation hardening is the heating of a surface by use of a laser followed by the rapid quenching of the surface by heat conduction into the part. This provides a hardening on the surface of the material through a solid-state transformation that results in the formation of a high-hardness microstructure, i.e. martensite. Varying the amount of heat input provided to the work-piece may alter the depth of the hardened zone. In this evaluation, varying travel speed altered heat input. During these evaluations, the length dimension of the spot of focus, which was approximately 0.47" to 0.55" (12 to14 mm), was directed perpendicular to the direction of processing. This allows very large surface areas to be hardened in a single pass. Laser surface transformation hardening is often used to harden localized areas of machine components such as gears and bearings. A flat-topped shaped hardened zone is obtained through a laser beam surface treatment, as seen in Figure 7.

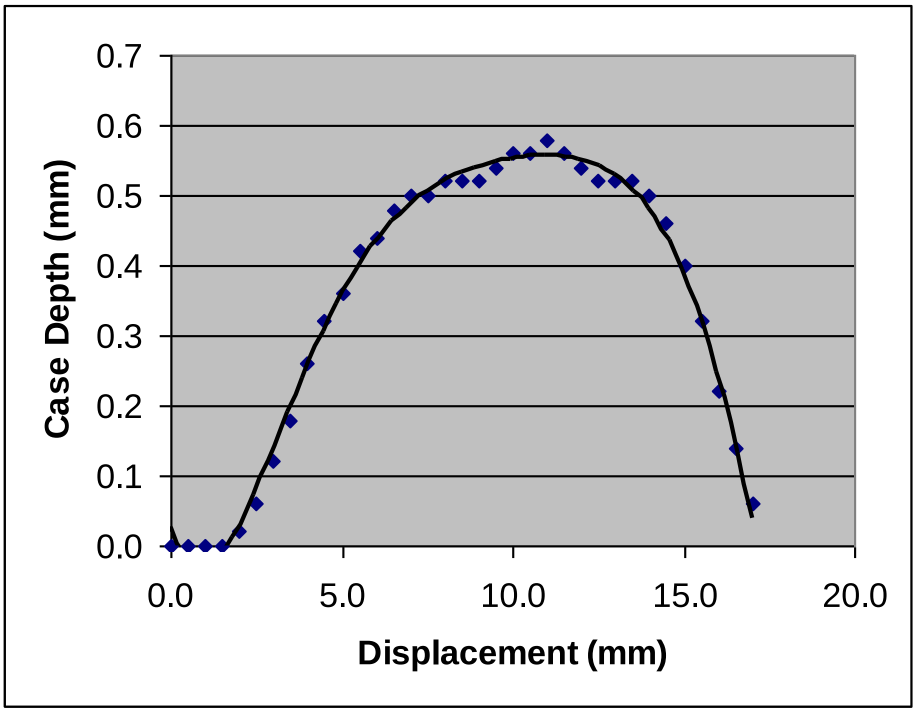

Figure 7 Flat top shaped hardened zone reflects the beam profile of the laser.

Since the diode laser is modular in design, many stacks may be placed side by side to create an unlimited laser heat-treated width. Also, the phenomenon of superhardening occurs when multiple, overlapping passes are conducted with the diode laser. During superhardening, the formation of austenite from martensite is extremely rapid, thus, inducing imperfections that subsequently affect the strength of the martensite. Therefore, the interpass region hardness values ranging from 59 to 65 Rockwell C are obtained as seen in Figure 8.

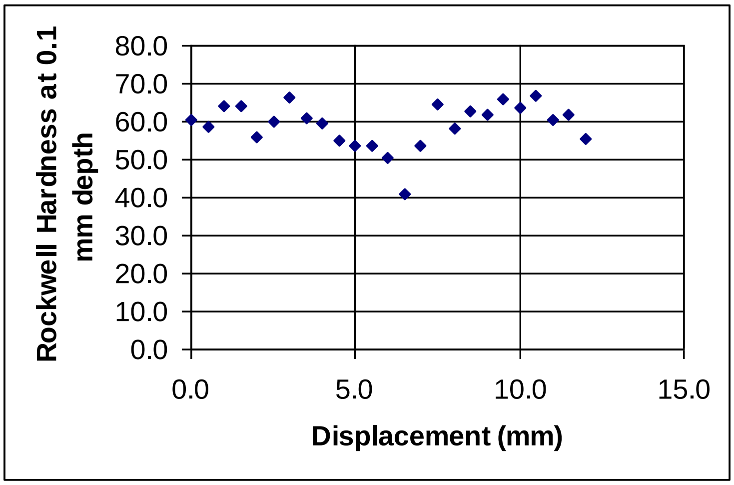

Figure 8 Superhardening has occurred in this sample as seen in the high hardness values obtained 0.1 mm below the surface.

However, in the interpass zone, backtempering can also occur because the heat generated in the second pass causes a portion of the initial pass to be raised to a temperature at which tempering occurs. Thus, the supersaturation of the quenched martensite is relieved and equilibrium mixtures of phases are approached. Tempering results in a decrease in the strength and hardness and a microstructure of tempered martensite. The back tempered region is generally 0.04" to 0.112" (1 to 3 mm) wide with a 40 to 50 Rockwell C hardness range. The effect of backtempering on the case depth of 4140 steel can be seen in Figure 9.

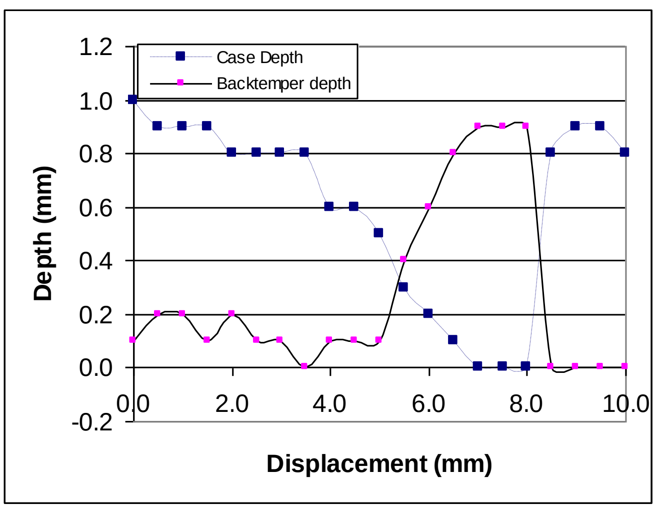

Figure 9 Narrow backtempered region achieved over a 28 mm hardened region after the second pass of the laser.

Surface Transformation Hardening of 4140 Steel

Alloy 4140 steel was evaluated for surface hardening. In this case, the 4140 steel was 1" thick and 2" by 4" in size. The parameters that were used were a constant power of 3,150 W, a focused beam, a constant argon shield of 33 liters per minute, and speeds varying from 5" to 200" per minute. Figure 10 displays the Vickers hardness numbers at different depths from the top surface. The data of Figure 10 represents processing at a speed of 5" per minute, which was the slowest speed that was obtained before melting. Evaluation of Figure 10 reveals that the direct diode laser was able to impart surface hardening to a depth of approximately 0.02". This hardened zone was found to exhibit a hardness of over 200% greater than that of the base metal. A profile of the hardened zone in 4140 steel can be seen in Figure 11.

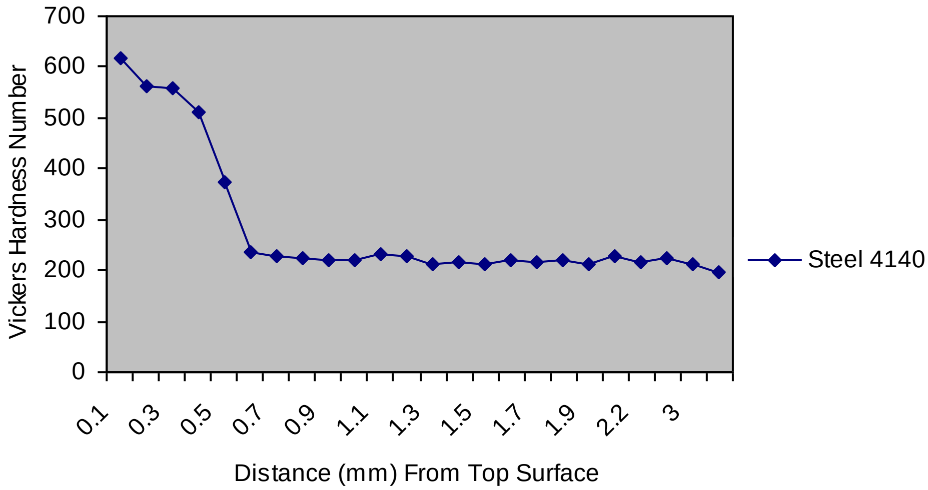

Figure 10 Vickers Hardness Number Versus Distance From Top Surface of 4140 Steel.

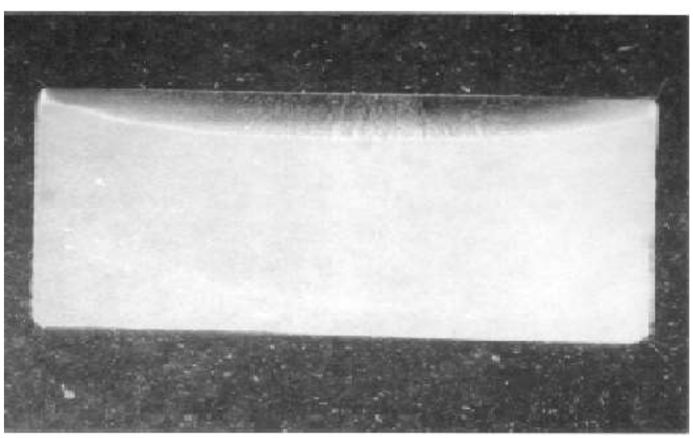

Figure 11 Micrograph of hardening in 4140 steel for a single pass of the laser.

Surface Cladding

Laser cladding was investigated for its applicability with the direct diode laser. Loose powder of Inconel™ 625, Stellite™ 6, or stainless steel 420 was pre-placed onto a 4140 steel substrate and melted with the laser. Complete fusion of the clad material with the base material was desired. For each material, the loose powder was placed 0.04" thick and 0.55" wide. During each of the laser cladding evaluations, the length dimension of the spot at focus, which was approximately 0.47" to 0.55", was directed perpendicular to the direction of processing. This resulted in a larger area of powder being melted. Also, for these investigations, the laser beam was at focus on the top surface of the work piece. The cladding materials were chosen based on their application in industry to provide hard, corrosion resistant, and wear-resistant surfaces. No cover gas was used during the laser cladding operation. Dilution into the substrate, which is the ratio of the intermixed zone and the clad thickness is only 0.02% when using the direct diode laser. Laser cladding done with the CO_2 or Nd: YAG lasers generally yields a dilution of 1 to 10%. Note also that the deposit efficiency of laser cladding with the direct diode laser is in the range of 85 to 95%.

Inconel™ 625 Cladding

Inconel™ 625 was initially investigated. The parameters used were a constant power of 3150 Watts, no cover gas, and the speeds were varied from 7 to 19 inches per minute. The optimal speed was 7 inches per minute. This produced clads with good edge detail and a uniform surface. Photomicrograph of the structure of the clad is shown in Figure 12. Multiple pass samples were prepared which demonstrated uniform cladding thickness.

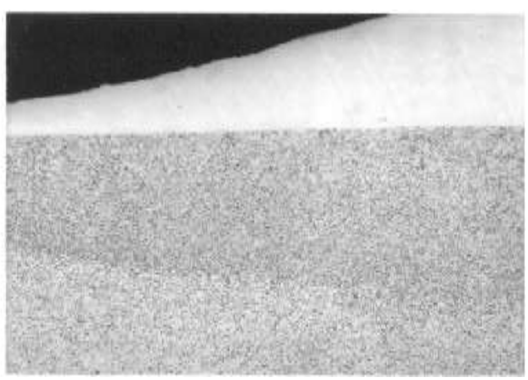

Figure 12 Edge of cladding showing low dilution in the base metal.

Brazing

Brazing of zinc coated steels is an important application for the automobile industry. Nuvonyx has integrated a wire feeder, robot and laser together to demonstrate brazing with direct diode lasers. The wire feeder delivers the copper-silicon wire directly into the molten pool of material formed by the laser. Speeds in excess of 30"/minute have been demonstrated with excellent repeatability on 0.020" zinc coated steel. Since the surface of the steel is never brought to the melting point, the problems observed with the direct welding of zinc are avoided.

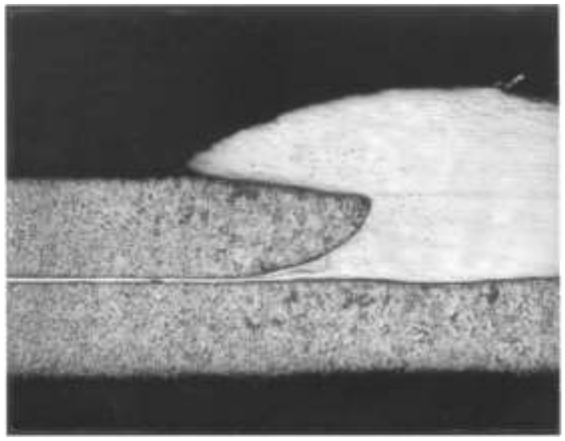

Figure 13 Micrograph of two zinc coated steel panels that have been brazed.

Paint Stripping

The ISL-4000L has the ability to operate in a pulsed mode which is idea of ablating paint from surfaces. At a repetition rate of 20 kHz, the ISL-4000L can rapidly strip the paint from most materials. While the process speed is somewhat dependent on the color of the paint, with white paint being the slowest and black the fastest. Since the ISL-4000L ablates the paint, the dust emanating from the process point can be collected by a vacuum system for disposal. Because there are no chemicals used in this process, the removal of paint from any surface can be done in an environmentally friendly way.

Summary

The ISL4000-L system is a versatile laser system capable of meeting the needs of many industrial applications. The best applications for this system are continuous welding of low conductivity materials such as stainless steel, carbon steel and titanium, heat treating surfaces, cladding of surfaces, brazing and paint stripping. It is clear that this laser system is capable of meeting the needs of many applications.