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Final CRADA Report
for
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DEVELOPMENT OF ADVANCED PHOTOLYTIC IODINE LASER (PIL) CUTTING AND JOINING TECHNOLOGIES FOR MANUFACTURING

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Development of Advanced Photolytic Iodine Laser (PIL) Cutting and Joining Technologies for Manufacturing

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Abstract

An evaluation was made of the Photolytic Iodine Laser (PIL) being developed by Advanced Optical Equipment and Services Corporation for metalworking applications. This laser operates in the infrared region of the spectrum and was anticipated to have a very small focal spot size and very low divergence. With these properties, it would be very effective at making small welds and narrow slots in metals.

The program was of limited success due to low power output from the laser as well as power and positional instability. Some narrow slots were made and evaluated.

The PIL may have applications in the electronics industry, even at low power, if the instability in the beam power and position can be solved.

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Development of Advanced Photolytic Iodine Laser (PIL) Cutting and Joining Technologies for Manufacturing

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Introduction

The purpose of this work was to develop the cutting and welding capabilities of a new metal processing laser, the photolytic iodine laser (PIL). The PIL is a high brightness, microwave-pumped closed-cycle gas laser originally developed for the Department of Defense. Advanced Optical Equipment and Systems Corporation (AOESC) is working to commercialize this new laser for manufacturing applications. The stability and beam quality of the PIL are superior to existing industrial lasers [carbon dioxide (CO_2) and neodymium: yttrium aluminum garnet (Nd:YAG)]. Focal spots to 0.00028-in. (7 μm) and cutting rates up to 200 in./min may be possible. The PIL promised increased precision, better performance and lower cost than CO_2 and Nd:YAG systems.

PIL drill and cutting technologies could potentially replace some of the techniques presently employed in Defense Programs disassembly and quality activities. The PIL is also a potential replacement for electron discharge machining. Because of its almost perfect beam quality and short wavelength, this process offers great potential for material processing of composites, ceramics, and plastics, and can be useful for very high precision applications in the electronics fabrication industry.

Scope of Work

In this work, the original plan for this project involved a parametric study using the PIL for cutting and welding of aerospace and automotive materials. ORCMT Material s Joining Center personnel using AOESC's laser equipment in New Mexico would undertake this study. This work was to demonstrate the utility of the PIL process for manufacturing and speed its acceptance and utilization.

Cutting and welding quality were to be determined, and the repeatability and precision of the process demonstrated. The results of the work were to be compared with other manufacturing process.

The original planned work involved the following tasks:

1) Parametric study design.

2) Parametric study campaign.

3) Analysis of parametric studies data.

4) Compilation of final report.

These objectives were not fully met during this program. The initial work planned for this project was based on a laser output power of at least 50 Watts. The laser system never achieved power at this level. It was, therefore, necessary to adapt any test performed to the power available at the time of the tests. There was also some degradation of the available power during any testing period due to the build-up of free iodine in the lasing medium during the tests. Some welding and cutting tests were performed, and system performance at these low power levels indicated that the anticipated benefits could be achieved if the laser were to reach the design power level of 150 Watts.

We were also able to provide some additional assistance in the development of the laser system. We were able to refer AOESC to information on a sieve material for removing iodine from the system. We were also able to refer them to sources that could provide support on the operation of the machining center base that had been given to them. Yet another source was able to provide some laser beam diagnostic support which was able to confirm the small beam size, as well as confirming a beam jitter problem.

While the system in its current condition is not able to provide the level of material processing for which it was considered, it is closer to achieving this level that it would have been without our involvement. The process has also demonstrated that it has many of the characteristics that produced our initial interest. Additionally, when the beam jitter problem has been corrected, this laser system should be useful for the scribing and cutting of electronic components.

Technical Discussion

The technical effort dealing directly with materials processing was limited. As noted previously, much of the technical effort was directed toward improving the system usability. This included providing support on the optical system, as well as finding additional support in the areas of iodine removal, machine center operation and beam quality measurements.

There were several early evaluations of the materials processing capabilities of the PIL. These were unstructured scoping tests used to determine if there was a sufficient laser power density for material processing. These tests were bead-on-sheet and lap weld samples on stainless steel. Some of these early evaluations indicated that the laser beam was focusing to a spot of less that 0.001 inch. When it was determined that there was a sufficient power density, a series of cutting test were performed. These tests involved repeated passes of the laser beam over a short section of thin (0.0095 and 0.0040 inch) stainless steel sheet. The travel speed and laser assist gases were varied to characterize their effects on material removal. All tests resulted in a grooving or cutting of the stainless steel sheet.

Table 1 gives the details and results of four of the test series. All of these tests were made using oxygen at 35 psig as the assist gas. Other tests were attempted using nitrogen as the assist gas, but no melting or vaporization of the material was achieved when nitrogen was used. This is unusual since nitrogen is typically used as an assist gas on stainless steel. It is theorized that the particular wavelength produced by the PIL interacts with the nitrogen, causing the laser energy to be absorbed in the plume above the surface of the stainless steel sheet.

All of the welds listed in Table 1 were cross-sectioned and examined. This examination provided the penetration and width data that is given. Prior to cross-sectioning the samples, tests that exhibited full penetration were studied on the top and bottom surfaces using scanning electron microscopy (SEM). This provided a second measure of the bottom width of each cut. The top width could not be determined using SEM due to the oxide layer on the top surface. After the parts were sectioned, the full penetration samples were cut so that one cut surface could be studied by SEM.

The cross-sections of the cuts made during Test Series #2 is show in Figure 1 a-d. This is typical of all of the test series. In most cases, the melt pattern had a deep region, with shallow melting and surface dross off to one side. This was probably the result of the beam jitter, but may also have been influenced by the assist gas. The depth of metal removal was not uniform for each beam pass. It would appear that this was the result of the varying beam power during the course of each individual test, and throughout each test series.

Top and bottom views of Test 2-12 as seen with SEM are shown in Figure 2a & b. In order to record the entire weld surface at this magnification, it was necessary to record the surface in thirds (with one photograph of each third). These are from the left third of the cut. This view was chosen so that the regularity of the cut to the end of the travel is apparent. A constant width was noted on this sample along the entire length of the cut.

In Figure 3a, the cut surface from this same sample (Test 2-12) can be seen. It should be noted that there are no horizontal striations denoting the individual passes across this sample, and no vertical striations from the cutting action. This surface was typical of most cuts except for the absence of dross at the root. Dross was found on the root of some samples that had been fully penetrated on a pass just prior to the end of the test. Full penetration was achieved on the fifth of twelve passes on this test.

As can be seen from the table and figures, narrow cuts can be made using the PIL, even at very low beam power. The beam positional instability, jitter, and the inconsistent beam power output limited the laser's usefulness. Testing using a Promotec beam analyzer, and several extremely low energy tests indicated that the actual beam diameter is probably less than one thousandth of an inch. The beam analysis also showed that the beam had very little divergence. If the beam power and positional stability can be improved, this laser would be useful for cutting very thin metals, and could also be very useful for scribing in electronic applications.

Inventions

There were no invention disclosures resulting from the work on this project, and none are anticipated.

Commercialization Possibilities

At the conclusion of this project, AOESC was seeking venture capital to continue development of the PIL. Primary interest was coming from the electronic manufacturers. If the PIL is commercialized in the immediate future, it is probable that it will be used in this area. This will require resolving the beam power and positional stability problems. As the technical hurdles related to increasing the beam power are solved, the PIL may be suitable for commercialization for metalworking applications.

Future Collaboration

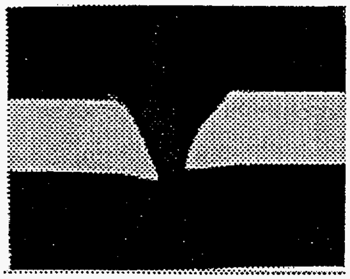
There are no plans for future collaboration with AOESC. If the problems related to stability and power were resolved, collaboration on a future project would be considered.

Conclusions

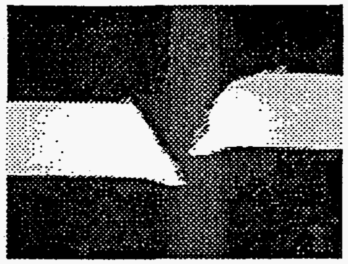
The photolytic iodine laser has the beam qualities of interest for metalworking applications. While progress was made during the course of this work toward solving problems related to power output, the laser is not yet at the point were it would be useful for our anticipated Defense Program applications.

Test No.	Thickness (in.)	Number of Passes	Travel Speed (IPM)	Power Range (W)	Top Width (in.)	Bot. Width (in.)	Penetration (in)	Penetration Pass No.
2	0.0095	12	1.2	17.6	0.0160	0.0005	Full	5
	0.0095	8	1.2	16.4-15.0	0.0210	0.0026	Full	7
	0.0095	4	1.2	16.0-13.9	0.0210		0.0025	
	0.0095	2	1.2	15.6	0.0200		0.0020	
4	0.0095	12	2.4	16.7-14.5	0.0170		0.0070	
	0.0095	8	2.4	15.3-14.1	0.0170		0.0060	
	0.0095	4	2.4	14.7-15.5	0.0190		0.0025	
	0.0095	2	2.4		0.0135		0.0015	
5	0.0040	12	2.4	13.6-12.7	0.0180	0.0110	Full	3
	0.0040	8	2.4	13.3-12.5	0.0155	0.0010	Full	2
	0.0040	4	2.4	13.0	0.0160	0.0095	Full	2
	0.0040	2	2.4	12.4	0.0150		Intermittent	2
6	0.0040	12	4.8	12.8-11.8	0.0180	0.0040	Full	7
	0.0040	8	4.8	13.2	0.0160	0.0018	Intermittent	6
	0.0040	4	4.8	12.4	0.0140		0.0010	
	0.0040	2	4.8	11.6	0.0170		0.0020	

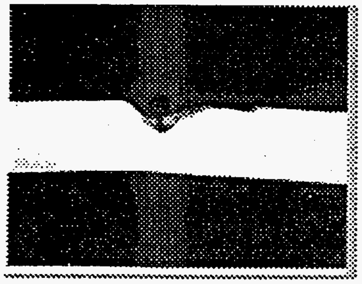
Table 1: Summary of Tests Made Using the Photolytic Iodine Laser at Advanced Optical Equipment and Services Corportation.



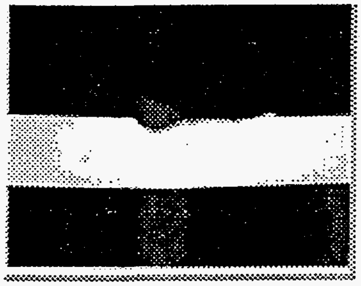
1a) Test 2-12: Twelve Passes



1b) Test 2-8: Eight Passes

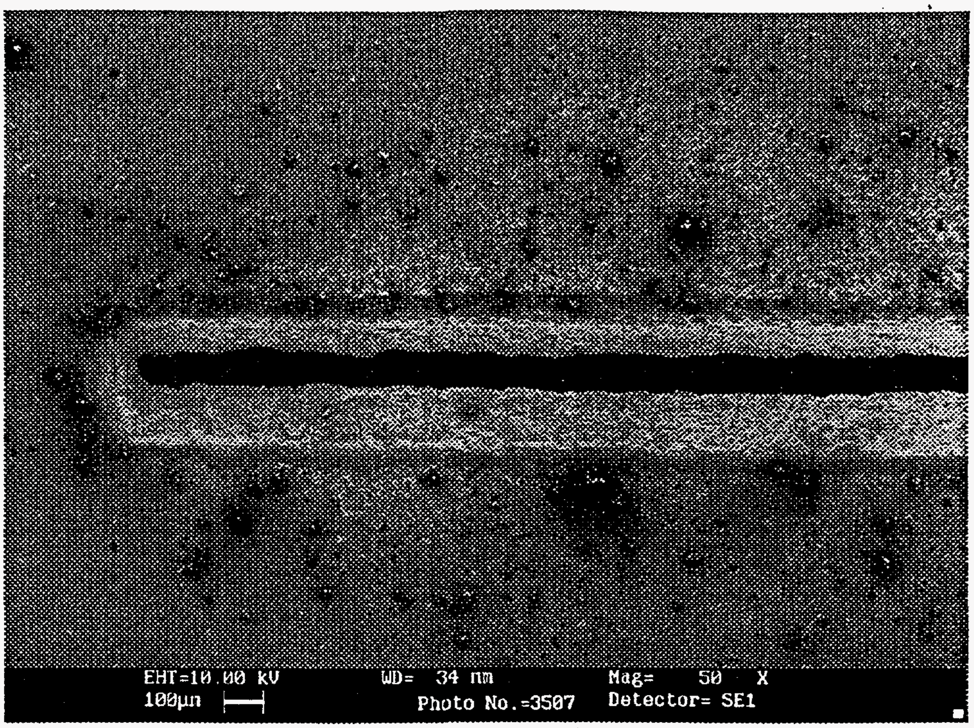


1c) Test 2-4: Four Passes

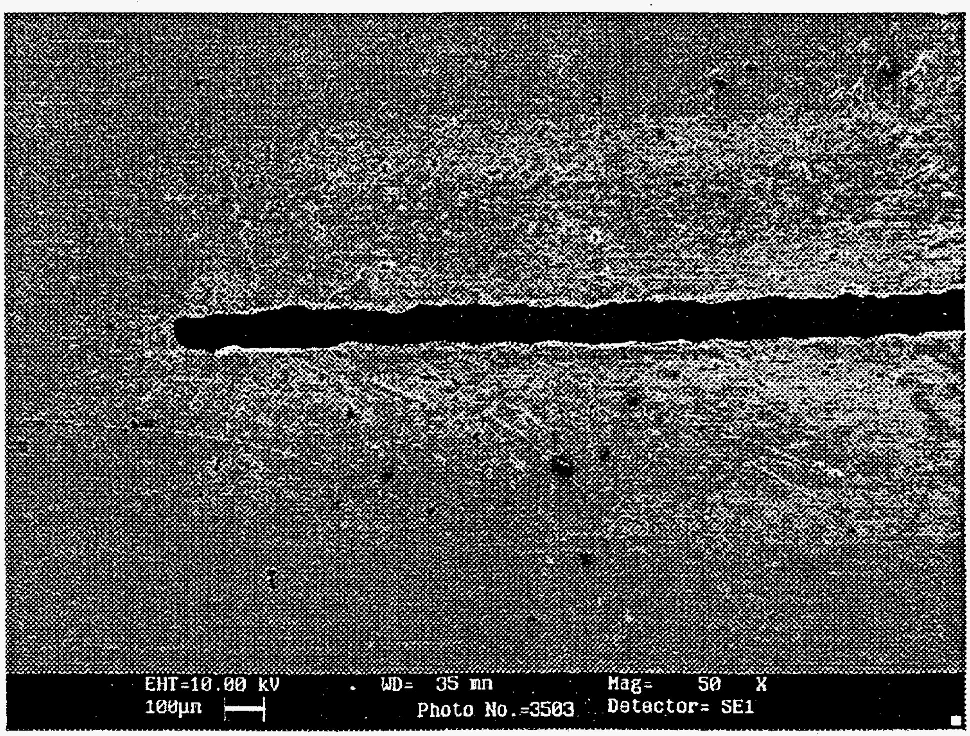


1d) Test 2-2: Two Passes

Figure 1: Cross-sections of cuts made during Test 2 (~17.6W @ 2.4 ipm) in 0.0095 inch thick stainless steel using the Photolytic Iodine Laser at Advanced Optical Equipment and Services Corportion. (Original Magnigication – 100x)



2a) Test 2-12, Top Surface.



2b) Test 2-12, Bottom Surface

Figure 2: Scanning Electron Micrographs of the Surfaces from Test 2-12 (Twelve Passes, ~17.6W @ 2.4 ipm). This is the left end of the cut (as viewed from the top).

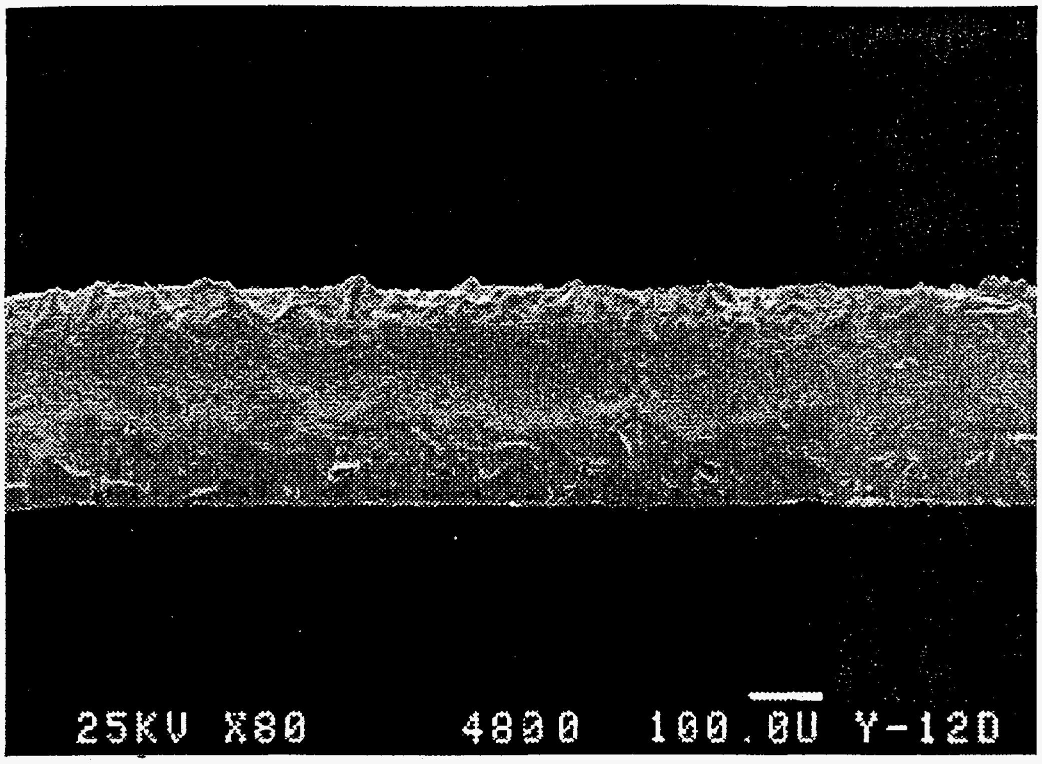


Figure 3: View of one face of the cut resulting from Test 2-12. (Twelve passes, ~17.6W @ 2.4 ipm)

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