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DABbling

A blog by DAVID A. BELFORTE

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www.industrial-lasers.com/blogs/dabbling/index.html

update

Running shoes use the best materials

The shoe uppers are cut accurately with the laser system.

DÜSSIN, GERMANY – Under the motto, "Running shoes made in Germany," the brothers Ulf and Lars Lunge decided to start up a running shoe factory in Germany. The Lunge Laufschuhmanufaktur develops and produces technical running shoes for both hobby joggers and professional runners alike. The aim of the Lunge brothers is to manufacture comfortable, extremely high-quality running shoes from the best materials for every kind of runner. In addition, they believe in responsible and sustainable production, so particular consideration is given to ecological and social issues in the manufacturing process.

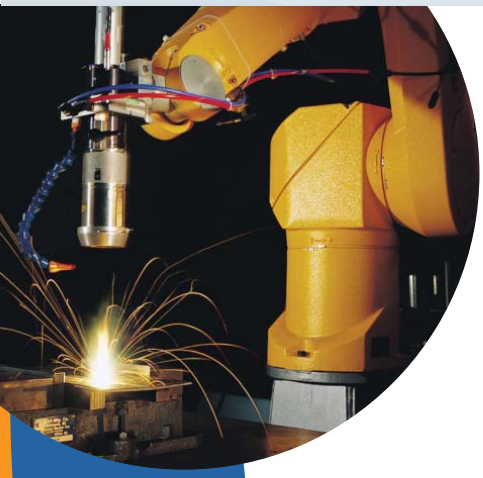
The success story of the Lunge (www.lunge.com) started with a specialist shop for sports shoes in Hamburg. Now the company has six run shops in Hamburg and Berlin. Since 2008, Lunge has been producing running shoes in its own factory.

Great importance is placed on the selection of the materials and optimum workmanship. On principle, the materials used are all free of pollutants and have often been used successfully on the market for decades. The selected materials are ideally processed thanks to the state-of-the-art production facilities. The material for the shoe uppers are cut on a system by eurolaser (Lüneburg, Germany; www.eurolaser.com) that has been part of the production operation from the beginning. A big advantage of this technology is the thermal process that welds the cutting edges, thus preventing any subsequent fraying and eliminating any preparatory or finishing work.

"Flexible shoe parts that need no die-cutting and that can be flawlessly reproduced from different materials make our eurolaser system the very centerpiece of the Lunge production," says Ulf Lunge.

Many years of experience in the market and sophisticated, state-of-the-art technical equipment ensures that the Lunge Laufschuhmanufakur is well positioned for achieving its aims for the future. The owners feel there is nothing standing in the way of the planned expansion of the range. Even the purchase of another eurolaser system is in the pipeline.

(Adapted from *The Laser Magazine*, 10th Edition, by eurolaser)



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2010 Annual Economic
A surpris

DAVID A. BELFORTE

In 2009, the industrial laser market was in disarray. It was still feeling the impact of the 2008/2009 global economic recession that had hit this market fast and hard with few, if any, products and services suppliers spared. Horror stories of sales telephones that never rang and e-mail messages that went unopened were common. And as the months passed, these stories only worsened as the major markets in North America, Europe, and Asia remained dried up, especially in the capital goods sectors.

By mid-year 2009, as governmental agencies around the world gambled their economic futures on massive stimulus actions, it became clear that any financial turnaround was not in the cards. Drastic actions by laser and systems suppliers to stem off complete shut-downs of the companies became a common occurrence. Even the very strongest of the global companies were forced into shorter hours and for some, for the first time ever, employee reductions.

Some good news in 2010

Then, in 2010, hardly noticed at first, good news began to drift out at shows and conferences. Here and there, small, narrowly focused product suppliers began to receive orders from the semiconductor, alternate energy, aerospace, automotive, and medical devices markets. And stories began to be heard about a hyper-active market — China — placing quantities of orders as that government's stimulus package seemed to activate quickly to produce positive results long before the others. Score one point for a non-capitalist government.

At *ILS*, we too began to hear about buyers placing significant orders, and the first half reports of several pubic companies turned positive as revenues turned upward. As the third quarter closed, it was common to hear about record sales being made, many of them attributed to the activity in Asia, specifically China, and others from the aforementioned industry sectors that seemed to be defying recessionary pressures.

The laser industry waited for the other shoe to drop as the dreaded phrase, double-dip recession, took hold. Month-by-month, suppliers waited for the news to turn bad, which it did not. Business news was positive across the board in all the producing nations. Oh, there was still hurt in certain markets; in the U.S., the job shop industry continued to suffer, and quarter by quarter news of bankruptcies grew. The market for big ticket items such as laser sheet metal cutting systems dragged as a large inventory of quality and like-new machines attracted the buyers.

As the last months of 2010 passed, good news appeared in most every company's stockholder reports. Except for the nagging problem in fabricated sheet metal, business was not only good; in some companies, it was great. Quarterly increases in the strong double digits were common, and some companies even reported sales increases up to 40% and more.

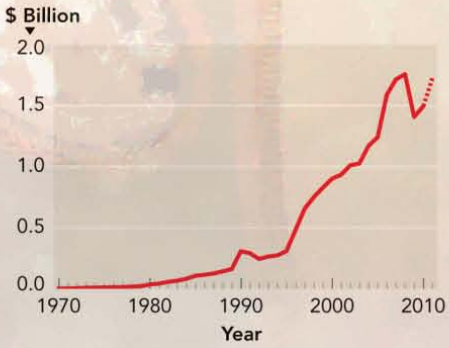


FIGURE 1. Industrial laser revenues, 1970-2010, with 2011 forecast.

It was time to bury the threat of a double-dip recession and to get back to normal by rehiring staff and extending work hours. Low inventories were hampering some markets, but otherwise the companies that *ILS* tracks were all in the black. At the end of the last reporting period before the end of the calendar year, we could only find red figures for six of the 35 companies we track, and all but one of these was in the red because of the quarter they reported. In these companies, the guidance for the coming quarter was a return to the black. At one company, Trumpf, double-digit growth was expected.

As we commenced our company-by-company analysis for this report, it quickly became clear that a stronger than expected market for solid state and fiber lasers was going to boost estimated numbers by more than 20%. This was enough to offset a lethargic high-power CO_2 market to the point where

Review and Forecast

e recovery

projections for 2011 have the industry fully recovered to 2008 levels, about a year ahead of our prediction at the start of 2010.

Fish hook recovery

In 2010, first and foremost, let's look at the curve that, to this writer, was almost like Hawthorne's *Scarlet Letter* "A". After 40 years of continuous growth, save for one minor dip in the early 1990s, the 2009 number drop of more than 30% produced the beginning of a crevice that suggested that recovery to the 2008 edge was many years away. For a year that infamous curve has appeared globally, precipitating wide discussions with this writer about the magnitude of the drop and queries as to the long term health of the industrial laser market — hence the Letter A reference. However, led by solid-state and fiber laser sales, the curve in **FIGURE 1** now looks more like a fish hook, and recovery to the norm seems only a year away. Surprisingly, the CAGR at the end of 2008 was 19.63%, and after the drastic recession, it only dropped to 17.99% at the end of 2010.

TABLE 1, a four year summary, puts into perspective the rapid recovery the industry is making from the record-setting recession. This very positive table is not meant to diminish the pain and suffering the recession brought to most of the companies that make up the industrial laser community, but it does suggest that industrial laser markets are diverse, diverse enough to withstand the second most serious recession in US history. It is safe to say that if company forecasts hold, the rise to pre-recession revenue levels will be a year earlier than expected.

Table 1. Four year summary industrial laser revenues ($ million)

YEAR/GROWTH	2008	%	2009	%	2010	%	2011	%
Laser Revenues	1758	2	1231	-30	1495	21	1727	16
System Revenues	6075	-1	4865	-20	5838	20	6656	14

Table 2. Global industrial laser revenues ($ million)

TYPE/YEAR	2009 REV.	2010 EST.	%	2011 PROJ.	%
CO_2	669	789	18	907	15
Solid State	340	397	17	450	13
Fiber	169	239	41	290	21
Other	53	70	32	80	14
Total	1231	1495	21	1727	16

Revenues by laser type

Now digging into the numbers that make up the *2010 Annual Economic Review and Forecast*, **TABLE 2** details the current situation for industrial

THE STORY BEHIND EXCIMER LASERS

The question occasionally asked is why *ILS* does not account for the sales of excimer laser-based systems used in photolithography applications. This billion dollar market is indeed an industrial laser market, and an important one. We actually do track one of the two major suppliers to this market, Cymer, using its quarterly reports to measure overall market conditions.

Several years ago, we decided that laser lithography, unlike laser graphics (printing), another large market we do not follow, is indeed a laser material processing application but, in our view, a very special one that does not easily fit into comparisons of the other material processing applications.

Lasers for lithography is a billion dollar market, dominated by two suppliers: Cymer from the US and Gigaphotonics from Japan. Together they sell about 250 multi-million dollar systems annually. Thus, we wouldn't be disturbed to add another billion dollars to industrial laser system sales except we still see this sector as "different" than those markets we cover. Consequently, we still follow this market as it is a key part of the semiconductor industry, but we cannot build a convincing argument to count it in the markets we cover.

laser revenues by laser type. *ILS* tracks these lasers and correlates data in our database with published reports from the 35 public companies we follow. As is our practice, we first revisit 2009 data because when reported in January we are missing some final quarter reports, relying on guidance numbers to get a yearly value. When those last quarter reports appear early in the new year, we adjust the published ILS data accordingly. Generally, these adjustments are minor. The 2010 revenue numbers are, for the preceding reason, an estimate, and the 2011 values are also all backed by company guidance statements.

Table 3. Global industrial laser systems revenues ($ million)

TYPE/YEAR	2009 REV.	2010 EST.	%	2011 PROJ.	%
CO_2	3022	3560	18	4050	14
Solid State	1276	1490	17	1680	13
Fiber	430	608	41	720	18
Other	137	180	31	206	14
Total	4865	5838	20	6656	14

After a disastrous 2009, the industry rebounded dramatically, led by solid-state and fiber lasers sales into the semiconductor, solar power, medical device, display, LED, aerospace, and automotive industries. Strong double-digit growth — with these lasers accounting for 41% of the increase — served to offset a slow recovery in the high-power CO_2 sector. Even though CO_2 lasers show a 18% increase in revenues, it comes after a 40% decline in 2009 revenues, so this sector has more catching up to do to reach pre-recession levels. The "Other" category composed of diode and excimer lasers returned to the solid growth numbers experienced before the recession.

An overall 21% growth in industrial laser revenues coming on the heels of a 30% loss in 2009 revenues is gratifying especially as the 2011 forecast also projects good double-digit growth. If there is one overarching message as a takeaway from **TABLE 2**, it is the strong role that solid-state and fiber laser played in setting the table for an industry recovery to pre-recession levels.

TABLE 3 is an extension of **TABLE 2** and shows the integration of these lasers into material processing systems. As has been our practice for years, we use a set of formulas to calculate system sales based on laser selling price numbers because the systems are sold by a group of companies that do not break out laser system sales for reporting purposes. For that reason, we tend to be conservative with our estimates, preferring to uses trend line data rather than hard numbers.

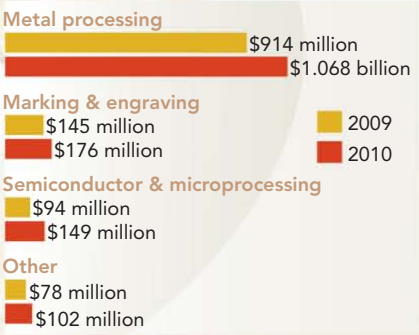
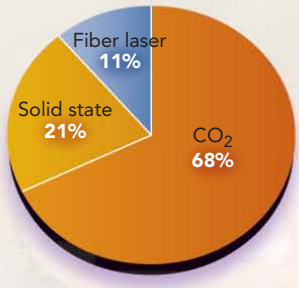


FIGURE 2. Laser revenues by application.



2010 Total: $1.068 billion

FIGURE 3. Lasers for metal processing.

After the shambles of the 2009 markets, which showed a 20% decrease, it was with great relief that the industry rebounded 20% in industrial laser revenues in 2010. Fiber laser powered sheet metal cutters perked up sales in a market sector that had been lethargic most of the year, however, not enough to make up for the loss of revenues from metal cutting lasers, which previously were the major contributor to total system revenues (over 40%). In 2010, the strength of solid-state and fiber laser powered systems perked up the market by 43%. Projections for 2011 show a repeat of the 2010 numbers.

FIGURE 2, laser revenues by application, compares 2010 results to those of 2009. In 2010, 54% of all lasers sold were used for metal processing and of these 65% were employed in metal cutting, another reason why metal cutting is such an important market sector. **TABLE 4** shows that **revenues for metal processing lasers** totaled over $1 billion in 2010, with CO_2 laser representing about 68% of this (**FIGURE 3**). Fiber lasers continue to show the highest growth rate in revenues at 35%.

Microprocessing markets

Commencing in early 2009, in response to pent-up buying demands by the semiconductor industry, sales of lasers into this market sector began to rise, leading to the beginnings of what turned out to be a rousing market expansion in 2010 when total revenues grew by 59%. As shown in **TABLE 5**, all laser segments experienced extremely strong growth, even though this growth came after these same segments experienced a 32% decline in 2009.

Table 4. Lasers for metal processing ($ million)

TYPE/YEAR	2009 REV.	2010 EST.	%	2011 PROJ.	%
CO_2	621	729	17	839	15
Solid State	208	224	8	244	9
Fiber	85	115	35	138	20
Total	914	1068	17	1221	14

Table 5. Lasers for semiconductor and microprocessing ($ million)

TYPE/YEAR	2009 REV.	2010 EST.	%	2011 PROJ.	%
CO_2	10	18	80	20	11
Solid State	36	67	86	86	28
Fiber	10	18	80	22	20
Other	38	46	21	55	20
Total	94	149	59	183	23

In this market sector, China, Korea, and Taiwan, and to some degree others in the Aslan markets, were the drivers in a buying frenzy for lasers used in microprocessing that included laser scribing, cutting, and drilling. The insatiable demands for hand-held communications equipment with their increasingly more complex displays drove up orders

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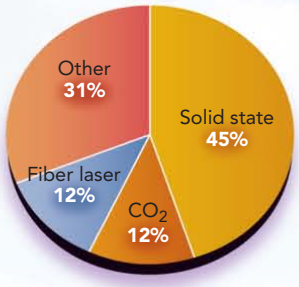
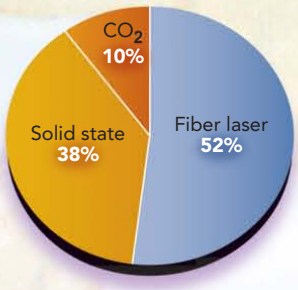


2010 Total: $14 million

FIGURE 4. Lasers for semiconductor and microprocessing.



2010 Total: $176 million

FIGURE 5. Lasers for marking and engraving.

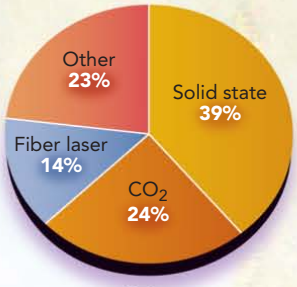


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FIGURE 6. Lasers for "other" applications.

for lasers that perform these tasks. Continuing demands from manufacturers of flat panel displays, LED/OLED processing, microvia drilling, and other micro applications kept system builders running at full output.

An example of the microprocessing market sector strength is printed circuit board (PCB) microvia drilling. In 2010, PCB suppliers in Taiwan, Japan, and other producing regions expected to install more than 600 laser drilling systems in response to a more than 40% increase in shipments of mobile telephones. And in 2011, with smartphone growth expected to more than double, these same producers were expecting to install another 700 laser microvia drillers.

Continuing strength in this and other semiconductor and microprocessing sectors such as solar power and medical device manufacturing leads us to believe that a 23% increase in revenues can occur in 2011, led by solid-state and fiber laser sales, which can represent 60% of the revenues in the market sector (**FIGURE 4**).

Table 6. Lasers for marking/engraving ($ million)

TYPE/YEAR	2009 REV.	2010 EST.	%	2011 PROJ.	%
CO_2	16	18	13	20	11
Solid State	62	66	6	71	15
Fiber	67	92	37	114	24
Total	145	176	21	205	16

Marking and engraving

For the first time in a decade, revenues for lasers used in marking and engraving declined in 2009 by 12%. As shown in **TABLE 6**, recovery in 2010 was rapid as sales rebounded by 21% with a return to the solid double-digit growth that this market sector has experienced for years. The major contributor to this growth at 37%, fiber lasers, showed the continued penetration of this technology into the solid-state marking market (**FIGURE 5**).

Other applications

The ubiquitous "Other" category includes all those applications that don't fit those above such as laser assist manufacturing (rapid manufacturing), heat treating, desktop manufacturing, and lasers used for photolithography. This Other market sector experienced a 20% decline in 2009, and in 2010, as shown in **TABLE 7**, grew 30% as fiber lasers expanded their application base, growing 100%. This industrial laser market sector is home to many of the "developing" applications that are expected to form the basis for sustained technology growth in the coming years. For 2011, the Other laser revenue category is forecast to grow 21% (**FIGURE 6**).

Installation locations

In **FIGURE 7**, we show where all the industrial laser systems are installed. For the past few years, Asia has been growing in importance, thanks mainly to activity in China. In 2010, the market in China, abetted by activity in Taiwan and Korea, was the prime force in growing the total market for industrial lasers. As a result, the Asian market represented 47% of the total, and East Asia (China, Taiwan, and Korea) at 32% equaled the European market share, a reversal of past numbers, made ironic as the shipments to China are credited with turning around a lethargic recession recovery in Germany. This situation did not appeal to some German government officials, one of whom suggested at the LASYS meeting in June that German manufacturers should perhaps concentrate on making the goods that Chinese companies were buying lasers to make, instead of exporting these lasers. One can only assume that he was making an attempt at some humor.

Table 7. Lasers for other applications ($ million)

TYPE/YEAR	2009 REV.	2010 EST.	%	2011 PROJ.	%
CO_2	22	24	9	28	17
Solid State	34	40	18	49	23
Fiber	7	14	100	17	21
Other	15	24	60	29	21
Total	78	102	30	123	21

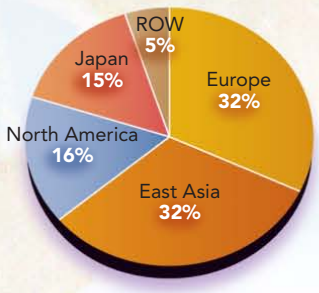

FIGURE 7. Global installations of industrial laser systems, 2010.

Meanwhile, there are concerns that the Chinese government might rein in some of the funds that are stimulating the overheated economic growth. Recalling how quickly this government's stimulus money flowed in late 2009 and early 2010, we think exporters of the lasers needed could experience a downturn in 2011.

The two markets that together make up about a third of the total market, the US and Japan, are currently mired in extremely slow economic growth. The US is beginning to mirror the stagnant economy in Japan, so prospects for a more important contribution to growth in 2011 seem ephemeral. In Europe, where Central and Eastern European markets were in the past three years a counter to slower growth in Western Europe, continuation of this is not assured.

As a consequence, *ILS* has modified its growth projections for 2011, and we are looking to modest low double-digit growth, below the 40-year CAGR level of 18%.

Laser sheet metal cutting

Laser sheet metal cutting is the single largest system revenue producer and as such vagaries in the market always produce rapid repercussions. Not to lay the blame for the recession on this market sector, but the sudden and precipitous decline in 2009 unit sales produced 73% of the revenue lost from 2008 sales, so it is easy to see why *ILS* tracks this market sector. **FIGURE 8** — a 20-year history of industrial laser systems sales compared to unit sales of laser sheet metal cutters — shows how closely the latter tracks the former.

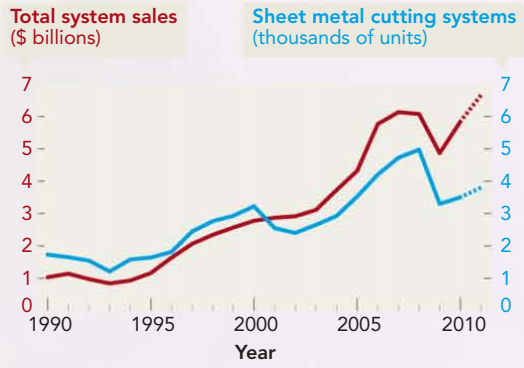

FIGURE 8. Impact of laser sheet metal cutting.

The market for these laser cutters in North America (**FIGURE 9**) is not a good gauge of global sales as this market has been on a downward trend since 2006, and the recession seems to have expedited the trend change. Even so, laser cutter sales in North America still represent about a third of industrial laser system revenues in this market.

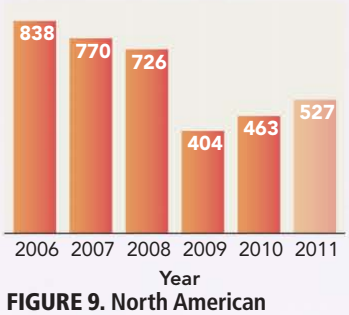

FIGURE 9. North American installations of laser cutters.

The new year

Looking ahead to 2011, we continue to be impressed by the strength of the solid-state and fiber laser segments, which are expected to be 43% of the total industrial laser revenues and 36% of the systems revenues. In 2011, solid-state lasers at $450 million will come close to the $480-million high water mark of 2004, a period when fiber laser sales ate into the solid-state markets, namely for laser marking. In that same period, solid-state lasers lost 6% of their market while fiber lasers grew more than 400% to $290 million.

We conservatively expect CO_2 revenues to be in the $900 million range and possibly higher. The selling price for high power lasers will stabilize after several years of deep discounts when suppliers coped with the recession and the competition of the recovery period. A factor that we identified in the September/October 2010 issue, the impact of high-power fiber lasers on this market sector, remains to be seen. Proponents of fiber laser metal cutting are comfortable with sales doubling in 2011 and perhaps 2012. Most of this growth will come from new installations, where the product is thin gauge stainless steel. At the 4 mm thickness level where CO_2 lasers regain the edge with jobshops wanting to serve a wide range of cutting requests, these lasers hold market share.

By our count there are now at least 25 companies offering fiber laser sheet metal cutters. Many of these also offer CO_2 laser cutters as their main product, so any loss of business to fiber lasers may be negated by keeping the sale in-house.

As shown in **TABLES 2-7**, for 2011 we project lasers to grow at 16% and systems by 14%. Fiber and CO_2 laser will enjoy double-digit growth in metal processing, and all lasers except CO_2 will see strong double-digit growth in semiconductor and microprocessing applications. Solid-state and fiber lasers will gain at double-digit levels for marking/engraving, and all lasers will experience good double-digit growth in the Other category.

By the end of 2011, the industrial laser sector will be back to 2008 levels, a year ahead of the forecast we made at this time last year. The market sectors driving the growth are those that are expected to remain strong except for a predicted slowing in the semiconductor sector, which should be offset by growth in the fabricated metal products area.

DAVID A. BELFORTE *is the editor-in-chief of* Industrial Laser Solutions for Manufacturing. *He can be reached at belforte@pennwell.com*

technology report

HYBRID LASER ARC WELDING: Has its time arrived?

PAUL DENNEY

OBSTACLES REMAIN, BUT THE "HYBRID AGE" IS COMING, DUE ESPECIALLY TO HIGH BRIGHTNESS LASERS

During this year's FABTECH show, two related events occurred that address the status of laser hybrid welding. First, ESAB (www.esabna.com) added a new section to its corporate web site related to its hybrid laser arc welding (HLAW) systems (**FIGURE 1**). The same week, Lincoln Electric (www.lincolnelectric.com) announced a strategic partnering with IPG Photonics (www.ipgphotonics.com) for the development of HLAW welding systems. To have two of the world's largest arc welding companies promoting HLAW says something about how the process is being viewed by industries.

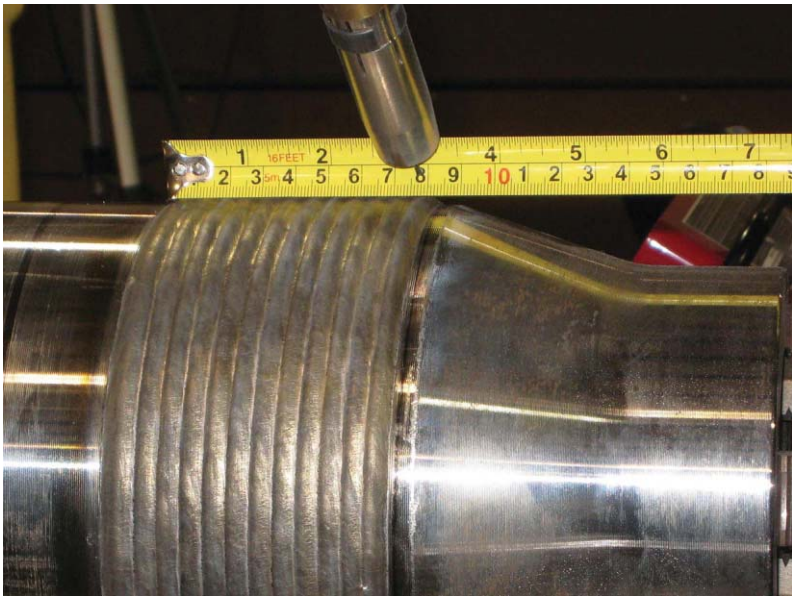

Figure 1: Typical robotic hybrid laser arc welding (HLAW) process. Courtesy: Alabama Laser.

History of HLAW

Having traditional welding companies embrace a laser-based technology did not occur overnight. The combination of a laser with an arc process to address some of the shortcomings of the technology is almost as old as laser processing itself. In fact, Bill Steen published a paper titled "Arc Augmented Laser Processing of Materials" in the *Journal of Applied Physics* in 1980. In most cases, the combination of the laser with an arc process was to address the fit up, chemistry, or power limitation of the laser. And while most hybrid processing has been centered on gas metal arc welding (GMAW) (**FIGURE 2**), there have been others who have investigated combining lasers with gas tungsten arc welding (GTAW) (Diebold and Albright, *Welding Journal*, 1984) and plasma (Walduck and Biffin, *Welding Research Abroad*, 1995).

While HLAW has been investigated for a number of years, there were a lot of reasons for its limited utilization. "I felt that a big disadvantage of the work that we were doing was that we were using a big clunky old laser that didn't focus all that tightly," says Vivian Merchant, an independent consultant, of his research efforts in the early 1990s at the Canadian Defence Research Establishment. He went on to say that their interest in using HLAW was to achieve higher production rates for military applications such as welding HY-80 material for submarine fabrication as well as for the welding of high strength materials for cross country pipelines. Vivian goes on to say that they recognized that "without the laser, it will take 10 passes to weld this one-inch-thick steel. With the laser, we can narrow the groove, and weld this one-inch-thick steel with only two passes!"

Even with "clunky" lasers, some applications did transition from the laboratory to the factory floor. Efforts in Germany

with HLAW continued to be very active in the 1990s. Researchers such as The ISF - Welding and Joining Institute of RWTH Aachen University worked with companies such as Meyer Werft Shipbuilding, Papenburg, Germany, to develop and assist in the implementation of the technology. The result was the opening of a new panel line at Meyer Werft in 2000 for the welding of deck and bulkhead panels with stiffeners using HLAW with CO_2 lasers. Not only did this represent a major acceptance of the technology, but it required the development and acceptance of new specifications for shipbuilding by organizations such as DNV and Lloyds.

A major change

The late 1990s and early 2000s saw a major change in laser technologies that would greatly impact the HLAW process. With advances in diode technology, greater power, better beam quality, and lower cost allowed these lasers to be used alone or as pumping sources for advanced laser systems. You no longer had to choose CO_2 lasers (with hard optics) for high power or Nd:YAG for the flexibility of fiber delivery (but limited to 4 kW). Diode lasers were being used to produce fiber and disk lasers that were not only fiber deliverable and equal to or higher power than CO_2 lasers, but which were easier to operate and maintain.

"The recent appearance of the new high-brightness laser technologies has by far had the greatest impact," said Brian Victor of the EWI, Columbus, Ohio. "These new lasers are much less intimidating for potential HLAW users. They're easier to operate/maintain, more robust than previous laser technologies, fiber-delivered for flexible manufacturing, capable of higher powers than possible with previous industrial fiber-delivered lasers, and all at a relatively low cost per kW."

Dr. Simon Olschok, chief engineer at ISF - Welding and Joining Institute, RWTH Aachen University, states that he is aware that hybrid is used in "…ship building (in use), automotive (in use), vessel fabrication, pipe welding orbital up to 6 mm, and pipe welding J-Lay up to 15 mm." He states that since efforts at Meyer Werft Shipbuilding, he is aware of a number of companies that have or are considering hybrid welding. These efforts are being fueled because of "new laser sources which allow robot usages and that there are now many institutes around the world that do hybrid welding (that can assist in development and implementation)."

While hybrid processing has occurred in European shipyards since 2000, efforts have also been ongoing in the United States. Applied Thermal Sciences (ATS), Sanford, Maine, has worked with the US Navy to qualify the welding of structural HSLA 65 components as well as lightweight sandwich panels (know as LASCOR) out of duplex stainless steel. The LASCOR panels are targeted for applications on the new DDG 1000 ship. To echo Dr. Olschok's earlier comments, ATS's original efforts in hybrid welding were with high power CO_2, while recent efforts have been accomplished with high power fiber and disk lasers.

Hybrid welding is not only for shipyard applications. In Sweden, the first industrial application of HLAW was initiated in spring 2005 at Duroc Rail AB in Luleå. This application consisted of using a 20 kW CO_2 laser at Duroc combined with a GMAW source for welding together large, thick, high strength steel sheets for rail car applications. This application was developed from the Nordic Network on Hybrid Welding (NORHYB) that had the goal of disseminating this technology to the Nordic industries.

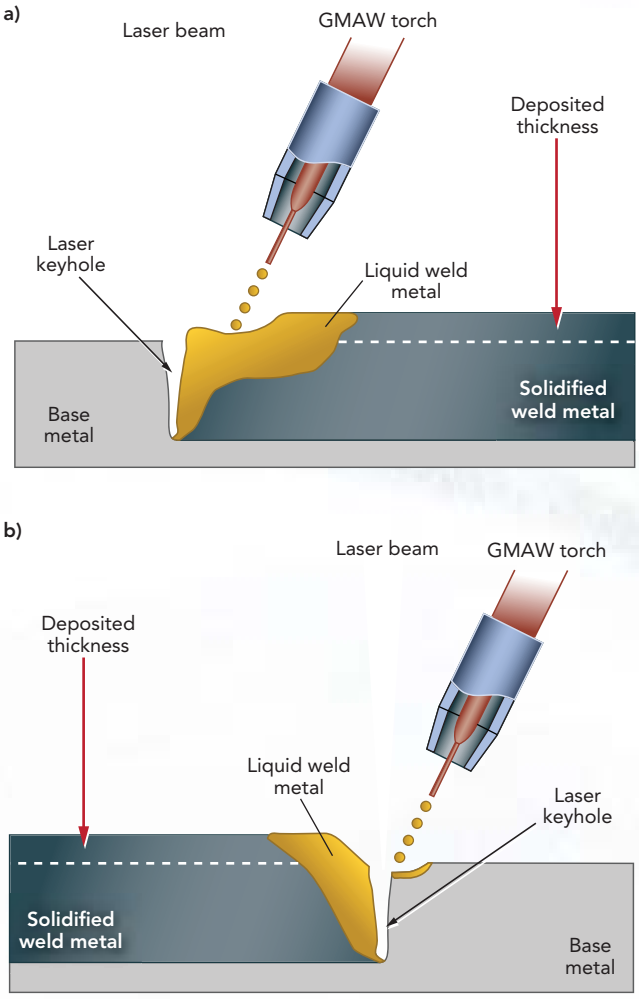

Figure 2. The two primary approaches to HLAW: a) laser leading or b) arc leading. Either approach has proven to work with the selection depending on the application. Courtesy: EWI.

"Non-arc" hybrid processes

While HLAW implies an "arc," there are many other "hybrid" processes that are being developed and implemented that combine laser with other "electrical" processes. In these other cases, the laser is being used as a precision heating source and/or the electrical process is supplying an inexpensive heat source to the application.

An example of one of these "non-arc" hybrid processes is hybrid laser brazing. This process uses resistance heating between the part and the tip of the wire feeding system to increase the temperature of the wire. The laser then is used to take the brazing alloy, usually a bronze alloy, to a melting temperature while at the same time heating the substrate to a high enough temperature to allow for wetting without

flux. This can occur at very high speeds (> 5 meters/minute) and result in joint quality that can be painted over. A number of car companies have implemented this process, including VW, Mercedes Benz, and Chrysler. Examples of some of the uses include truck lids and roof ditch welds.

Another "borderline" HLAW process is laser cladding. This can be accomplished like laser brazing without an arc and using simply resistance heating in conjunction with laser. Or the laser can be combined with the GMAW process for the deposition of a consumable wire. Usually these processes are used to repair a worn or damaged surface and match the chemistry of the substrate or the material being deposited to tailor the surface of the part for improved corrosion and/or wear resistance.

Wayne Penn of Alabama Laser, Munford, Alabama, reported on their efforts with resistance heated wire-laser "hybrid" process at last year's Laser Additive Manufacturing (LAM 2010) workshop. An example of HLAW cladding can be seen in **FIGURE 3**. Alabama Laser uses the process to clad large surfaces with corrosion and wear resistant material with less dilution and better surface conditions than can be achieved by conventional GMAW processes. Also at LAM 2010, Joel DeKock of Preco Inc., Somerset, Wisconsin, (www.procoinc.com) reported on the company's "true" hybrid welding process for depositing wear resistant materials at very high rates with very low dilution.

For most "hybrid" applications, the GMAW is assisting the laser process by:

- Adding filler material at an elevated temperature with little or no additional energy from the laser,
- Permitting welds to be made in joints with greater fit-up issues and gaps than can be normally welded by autogenous laser welding, and
- Altering the chemistry of the weld metal.

However, in some cases, the laser assists the GMAW process. As reported by Brandon Shinn at FABTECH 2005 under the AWS Technical Sessions, combining a laser with pulsed GMAW welding of titanium resulted in a higher quality weld. Normally, welding titanium by the GMAW process is difficult because the arc cathode is not "stable" and drifts around on the weld bead. The result is an irregular weld bead and spatter. However, Shinn found that focusing as little as 200 W of laser power on the weld puddle "locked" the cathode location, resulting in a very regular weld bead. This "laser-assisted GMAW" hybrid process could achieve very high welding speeds and small weld beads for use in welding of thin titanium structures such as those used in aerospace applications.

These increases in applications are also driving examination of what is an acceptable hybrid weld. As stated earlier, DNV and Lloyds have already developed standards for hybrid welding for shipbuilding applications. But with the recent activities for HLAW in other industries, there have been additional interest/needs for the development of other standards/specifications by other organizations. The American Society of Mechanical Engineers (ASME) and the American Welding Society (AWS), both of which have had laser specifications for years, are active in the development of standards and/or recommended practices for hybrid processing. Both organizations are reacting to requests for specifications by companies that are using their specifications to develop their procedure qualification records (PQRs) and their welding procedure specifications (WPS). These standards will address what parameters need to be documented and how much variations or changes will be allowed before a process must be partially or fully re-qualified.

Figure 3. Image of HLAW-deposited clad material. Courtesy: Alabama Laser.

Obstacles to greater utilization

While there seems to be an increase in the implementation of hybrid processes, there still remain obstacles to greater utilization. When asked what "obstacles" for implementation they see, Stan Ream and Brian Victor of EWI responded, "The main limitation is equipment cost. Most of the key HLAW markets are going to be in industries that currently

use conventional arc welding. Buying a laser and the associated equipment will be a significant cost increase. To make a large capital investment of a HLAW system, the productivity and other ROI benefits of the HLAW process have to be well understood upfront."

While cost is a factor, others believe there are physical limitations to the process. Dr. Olschok said he thought that as the weld thickness increases, a point will be reached where the ability to produce a "free-formed root bead" will be reached. He said that today this limit is between 12 mm and 15 mm, depending on the laser used. Physical limitations were also voiced by EWI representatives, who commented that while the HLAW process does allow for greater fit-up variation than normally possible for autogenous laser welding for thinner material, as the thickness increases, the limitation of the HLAW process will require industries to improve their fit-up tolerances over what is presently achieved for the arc process. The cost for this improvement will have to be factored against the other benefits of the HLAW process.

Further R&D

While implementation of the HLAW process is occurring, further research and development is being accomplished for other applications. While it may not be practical to achieve 25 mm thick welds in a single pass with an HLAW process today, it may be possible to achieve this with multiple pass welds. Researchers are investigating this approach for pipeline and other thick section applications by using HLAW for the root pass and HLAW or conventional arc welding for the subsequent pass. There is also work being accomplished in the use of multiple wires for greater fill or cladding applications and also efforts to have the laser and the GMAW power suppliers working in "concert" together to achieve even greater performance and control.

As has been seen, the "hybrid age" may have been slow in coming, but has accelerated in the last few years. This acceleration in implementation has been driven by improvements in lasers, especially high brightness lasers. These new lasers have allowed for easier integration into systems and lower ownership cost, which have improved the ROI of the process. In addition, as new standards become available, there is a potential for the technology to be accepted and implemented. Further implementation will be driven by additional advances in the lasers and processes.

Acknowledgments

The author would like to thank Stan Ream and Brian Victor of EWI, Dr. Simon Olschok of Aachen University, and Vivian Merchant for their extensive comments and input that made this article possible.

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application report

Laser drilling aids cool running for gas turbines

ROBB HUDSON AND RICHARD BAXTER

LASER ABLATION CAN REMOVE TBC AND BOND COAT BEFORE DRILLING

Both aero engine and industrial gas turbine manufacturers have battled a process chain for many decades in the efficient production of cooling holes in various turbine components. Typically, producers of these parts must drill the cooling holes in these components prior to the application of thermal barrier coatings (TBCs), which are highly advanced material systems applied to the metallic surfaces of gas turbine or aero-engine parts operating at elevated temperatures. These coatings serve to insulate components from large and prolonged heat loads by utilizing thermally insulating materials which can sustain a predictable temperature difference between the base metal alloys and the coating surface. By so doing, these coatings allow for higher operating temperatures while limiting the thermal exposure of structural components, extending part life by reducing oxidation and thermal fatigue. In conjunction with the advancement of active film cooling hole design, TBCs permit working temperatures higher than the melting point of the metal airfoil in some turbine applications.

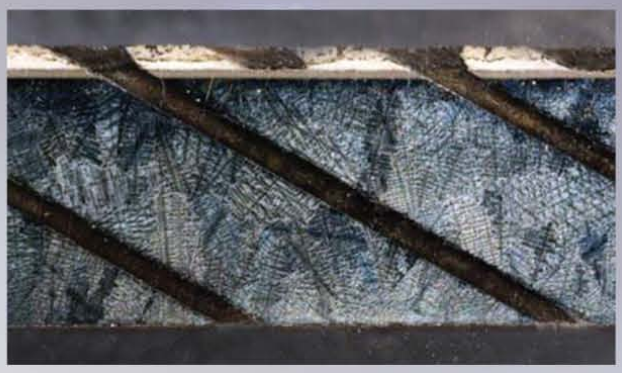

FIGURE 2. Cross section of laser ablation of TBC and high speed EDM meter hole.

FIGURE 1. TBC removed by laser ablation.

TBC composition

Generally, TBCs consist of four layers: the metal substrate, a metallic bond coat, a thermally grown oxide, and a ceramic topcoat. The ceramic topcoat is typically composed of an yttrium-stabilized zirconium (YSZ), which is desirable for having very low conductivity while remaining stable at nominal operating temperatures typically seen in these applications.

In the past, it is the low conductivity of the ceramic top coat in TBCs that have presented challenges to manufacturers of certain turbine components, i.e., turbine blades and turbine vane segments. The classical process sequence of drilling the various turbine components prior to the coating process has often created a time consuming and costly manual process of clearing the ceramic top coat from previously drilled holes.

Coating before drilling

Manufacturers can now coat these critical life-limited components prior to the drilling process thanks largely to the advancement of laser technology. By employing laser ablation techniques, these turbine companies are now able to gently create a "patch" by clearing the ceramic coating from the surface of the part, exposing the parent material and allowing for conventional drilling methods by way of high powered laser sources or electrical discharge machining (EDM) (**FIGURES 1** and **2**).

The laser ablation process is usually carried out via a Q-switched Nd:YAG laser or a pulsed diode pumped solid state laser. These ablation lasers are usually 100 W of maximum average power with either laser source. However, the methods of operating the two lasers vary a bit as the diode pumped solid state laser usually has a fixed pulse width and one must manage parameters via diode current. Whereas with a Q-switched Nd:YAG laser, the pulse width is widely variable in the nanosecond range and allows the achievement of a much higher peak energy and power. Regardless of the laser source, the beam delivery is carried out via a 2-axis or 3-axis scanning head also known as a galvanometer. The 3-axis version is used where ablation depths require a focus shift of the laser in order to properly maintain control on material removal and surface quality.

FIGURE 3. Laser ablated diffuser shape.

Shaped hole openings

The ablation cycle can be used as well to create very complex shaped diffusion hole openings, allowing for more advanced forms of film cooling to be used on the airfoils in commercial and military jet engines as well as industrial gas turbines. This advanced film cooling design allows for higher firing temperatures of the engines, thereby making them more efficient while simultaneously reducing their emissions into the environment. Processing these unique shapes presents ever-changing challenges to the laser ablation process as diffusion-shaped holes have grown in complexity in recent years. Processing time and volumetric material removal rates are highly variable depending on the shape of the diffuser. These variables relate to verticality of the diffuser walls to overall depth of the shape. Because of the complexity of the shapes, it is imperative to have 3D solid models of these shapes where the models can be imported into a CAM or post processor to more quickly calculate the most concise tool path. Material removal rates slow as the diffusion shape gets deeper and, as material evacuation slows, the cavity grows in size, particularly depth.

Laser ablation provides the perfect solution to machining operations on today's high pressure turbine blades and vanes. The complex and intricate pattern of cooling holes required on these parts are fundamental in satisfying the demands for reduced noise emissions and increased fuel efficiency on the latest generation of engines, such as those used to power the Boeing 787 Dreamliner and the Airbus A350. As the turbine blades and vanes on these engines run at high temperatures that often exceed the melting point of their base metal alloys, they not only require round and shaped cooling holes, but the surface is protected by the TBC.

TBC challenges

The TBC is non-conductive and not conducive to the widely accepted EDM process. It is extremely costly for the manufacturers of all TBC coated turbine components to drill prior to the application of the TBC. The process in which the coating is applied, while controlled better than in the past, still has a tendency to clog the holes as in industrial gas turbine components or to cover over portions of the hole openings as on aero-engine parts. In either case, the air flow for each part is greatly compromised due to the coating. It is an expensive and laborious process to clear the TBC from the holes. Typically the clearing has to be done by hand utilizing high RPM air tools and diamond tipped burrs. This operation is time consuming; the perishable tooling cost of the diamond burrs is high; and the chance of damaging an otherwise finished part is great.

The preference would be to drill cooling holes after the TBC coating has been applied to the part. In some instances, it is possible to use high peak power pulsed lasers to generate the cooling hole. This option can have an impact on hole quality in terms of heat affected zone (HAZ), recast layer, micro-cracking and de-lamination in the interface between the bond coat and TBC. Any one of these scenarios could result in the failure to meet the stringent criteria laid down for components of this type.

The laser ablation process allows the manufacturer to remove the TBC and bond coat, exposing the parent material. For the case of diffusion shaped holes, the ablation process can also be used simultaneously to create the complex diffuser. Afterward, the manufacturer can drill the metering section of the hole using the conventional

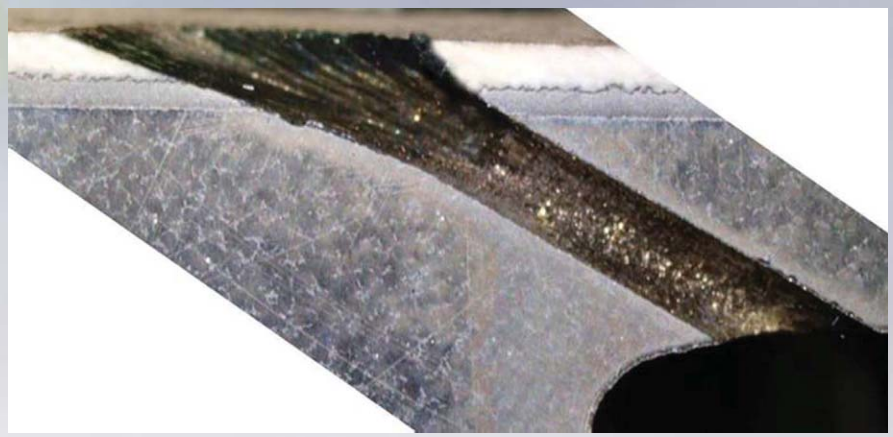

FIGURE 4. Cross section of laser ablation diffuser and high speed EDM meter hole.

methods via EDM or the high peak power pulsed laser (**FIGURES 3** and **4**).

Combination systems

Combination machining systems are now available in the marketplace from companies such as Winbro that offer laser ablation and EDM drilling or laser ablation and high peak power pulsed laser drilling in the same platform. Now manufacturers are able to take a coated part to a machine and completely drill the component (including diffusion shapes) in a single operation and single workholding while meeting and/or exceeding the stringent quality standards that have been established for these hot section engine components.

For those engine components that have been in production and already have a documented and certified manufacturing process, whereby all drilling must be done prior to the TBC process, laser ablation is still a viable option in replacing the costly, laborious process of clearing the TBC from the previous drilled holes. Salvaging components in this manner has proven to be effective for both IGT and aero engine components and can be performed with high reliability and repeatability.

Each laser source for ablation has unique benefits and drawbacks. Different types of laser sources are appearing as candidates to carry out the ablation process in turbine components as well. It is suggested that if considering this process, one should test both laser sources to determine which is the best fit for the overall application requirements.

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application report

Laser assisted machining

YUNG C. SHIN

LAM BENEFITS A WIDE RANGE OF DIFFICULT-TO-MACHINE MATERIALS

Recent years have seen a substantial growth in the use of advanced materials to obtain improved properties such as high hardness, thermal stability, and wear resistance, which are required to meet the stringent specifications of modern products. Such materials include ceramics, high temperature alloys, and composites. Currently, these advanced materials are fabricated into products by a broad range of manufacturing processes. While forming processes can produce various shapes with a high production rate, the attendant dimensional accuracy and surface finish are often lacking and a finishing operation is usually performed to achieve a high dimensional tolerance and/or a very fine surface finish. Due to the expanding use of such materials in automotive, aerospace, biomedical. and other engineering applications, there is an increasing need for cost-effective finishing processes. Machining processes have been most commonly used as finishing processes when high accuracy or flexibility is required. However, many advanced materials are known to be very difficult-to-machine and in some cases are considered unmachinable by conventional techniques.

With the rapid advancement of laser technologies in recent years, laser assisted machining (LAM) has begun to emerge as a viable industrial option for machining of difficult-to-machine materials. Over the last decade, the author's group systematically demonstrated the capabilities and advantages of LAM for a wide range of advanced materials through a scientific study.

Concept and setup

The capabilities of LAM have been developed and applied to various materials including ceramics, high temperature alloys, composites and other difficult-to-machine materials. In LAM a laser provides intense localized heating to the workpiece in front of the cutting region (**FIGURE 1**). Fine control of the local temperature is possible by adjusting various parameters such as rotational (lathe) or translational (mill) speed, spot size, and laser power. The higher temperatures created by the laser lead to a reduction in strength in the heated regions and an increased machinability, thus leading to higher material removal rate, an ability

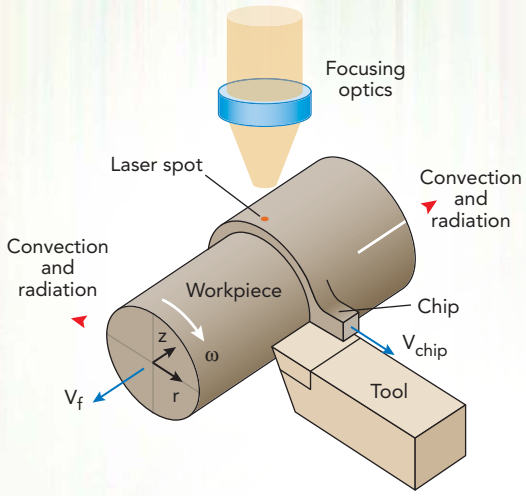


FIGURE 1. Schematic diagram of LAM.

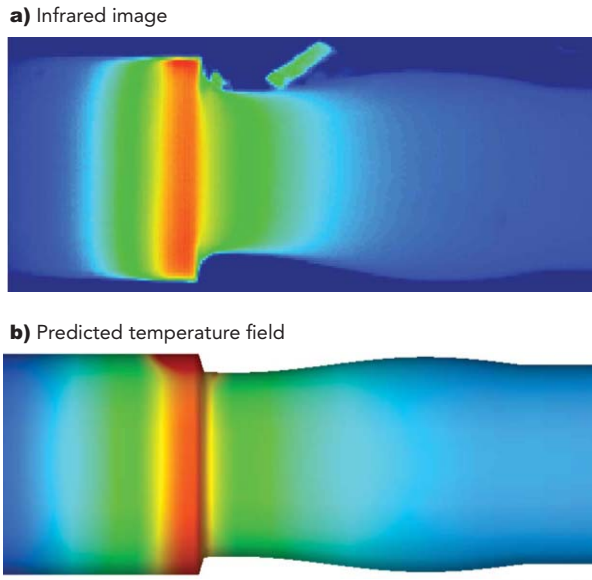


FIGURE 2. Comparison of the infrared image with the prediction after 56 seconds of LAM: a) infrared image and b) predicted temperature field.

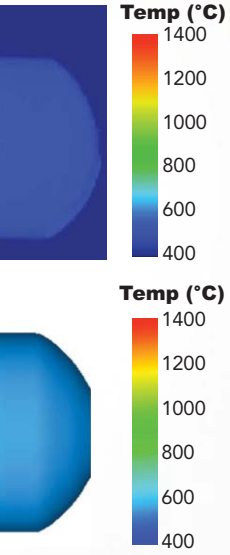
to machine complex shapes, and a high quality surface finish with little or no thermal related damage.

A key to the success of LAM is its ability to control the temperature field of the workpiece during operation. This can be achieved by two methods. First, use of an accurate thermal model assists in selection of optimal operating parameters. The thermal models developed at Purdue provide the capabilities of simulating the three-dimensional temperature profiles with material removal for both turning and milling in terms of operating parameters.[1,2] **FIGURE 2** illustrates the capabilities of the thermal model in accurately predicting the temperature distribution within a workpiece during LAM. Second, it will require in-process temperature measurement using a pyrometer as illustrated in **FIGURE 3**, which ensures maintaining the desired temperature during LAM.

Laser assisted machining of ceramics

Three types of structural ceramics have been used for LAM: silicon nitride (Si_3N_4), partially stabilized zirconia (ZrO_2), and mullite (65% alumina and 35% SiO_2). Representative machining conditions are 0.1~0.2 mm/rev in feed, 0.5~1 mm in depth of cut, and 1~2 m/s in cutting speed. Usually 300 to 600 W in laser power is sufficient in achieving successful conditions of LAM. Under acceptable machining conditions, segmented chips were generated as opposed to power type chips generated by grinding processes. Inspection under a scanning electron microscope (SEM) revealed that the chips are relatively congruent and long, thus indicating plastic deformation.[3,5] In general, the chips became more continuous with increasing temperature and became larger with increasing feed.[4,5] Specific cutting energy decreased with temperature and was about 3–6 J/mm^3 compared with 40~100 J/mm^3 typical in grinding. Therefore, much lower mechanical energy is used to remove the material, thus it is less likely to induce the sub-surface damage.

The analysis of surface damage provides answers to the following questions. Does thermal enhancement cause increased plastic deformation and reduced cracking compared to conventional machining and grinding? What is the effect of thermal enhancement on the magnitude and distribution of the residual stresses resulting from machining? Can strength degradation be reduced by LAM? Answers to all of these questions were positive, contrary to some earlier findings and skeptics. Inadequate heating sources and methods used in earlier investigations appeared to be the reasons for earlier negative results. Inspection under a SEM after LAM with suitable conditions reveals little or virtually no cracks in the sub-surface of the parts produced by LAM, and the residual stresses measured by x-ray diffraction were all compressive with the magnitude equivalent to those produced by successful diamond grinding processes. In addition, XRD measurement confirms that the machined parts exhibit no phase or compositional changes.[6] This clearly indicates that no



adverse results are generated by laser-assisted machining despite the elevated temperature of the material prior to cutting. Precise control of laser heating and temperature gradient is the primary reason why these successful results are obtained.

The last remaining question is whether the elevated temperature due to heating will shorten the tool life. Several earlier investigators concluded that LAM would not be economically justifiable due to shortened tool life at an elevated temperature. However, the cubic boron nitride inserts used in LAM revealed slow development of flank wear. In fact, it was possible to achieve up to 40 minutes of tool life for LAM of silicon nitride under nominal operating conditions.[4] This can be regarded as acceptable even for machining of metals and hence is excellent for ceramics. Under the nominal condition, the tool wear was mostly flank wear without any sign of crater wear. In the case of partially stabilized zirconia, a tool life approaching nearly 2 hours was achieved. In the case of mullite, the tool life of about 20 minutes was achieved with an uncoated carbide tool. It would be much longer if CBN tools were used. All these results clearly indicate that LAM can yield very long tool life for machining of ceramics. The economic study conducted also reveals that LAM can reduce the cost of ceramic machining significantly. Despite the added cost of a laser for LAM, the machining cost in LAM is reduced by over 70% over diamond grinding.[4]

Laser machining of metals and composites

Extensive studies have been carried out on LAM of various metals, including Inconel 718, Ti_6Al_4V, Waspaloy, hardened steel, compacted graphite iron, high chromium steels and metal matrix composites. Unlike ceramics, these materials are machinable by conventional single point cutting tools. However, their poor machinability usually brings a difficulty in machining and results in high machining cost. LAM brings many beneficial aspects such as reduced cutting force, prolonged tool life, and improved surface finish.

Metals and metal matrix composites exhibit a rapid reduction of hardness above 400~600°C. Therefore, the workpiece temperature doesn't need to be elevated to such a high temperature as in LAM of ceramics. In general, cutting forces decreased with increasing temperature as expected. In the case of Inconel 718, with increasing material removal temperature from room temperature to 620°C, the benefit of LAM is demonstrated by a 25% decrease in specific cutting energy, a 2 to 3 fold improvement in surface roughness and a 200-300% increase in ceramic tool life over conventional machining.[7] Moreover, an economic analysis shows significant benefits of LAM over conventional machining with carbide and ceramic inserts.

The cost associated with titanium (Ti_6Al_4V) machining is high due to lower cutting speeds (<60 m/min) and shorter tool life. LAM was utilized to improve the tool life and the material removal rate.[8] LAM with the use of simultaneous cryogenic cooling of the cutting tool, i.e., hybrid machining, improved the machinability from low to high (150–200 m/min) cutting speeds. Two- to three-fold tool life improvement over conventional machining was achieved by hybrid machining up to cutting speeds of 200 m/min with a TiAlN coated carbide cutting tool. Post machining microstructure and micro-hardness profiles showed no change from pre-machining conditions. An economic analysis shows that LAM and the hybrid machining process with a TiAlN coated tool can yield an overall cost savings of ~30% and ~40%, respectively.

Very similar benefits have been also demonstrated for hardened steel, stainless steel, CGI, Waspaloy and high chromium steels. While the properties of these difficult-to-machine materials are all different, very similar benefits in terms of improving tool life, reducing cutting force, and improving surface finish could be achieved without any adverse effects on the microstructure and hardness of the finished parts. All these findings are summarized in **TABLE 1**.

Metal matrix composites also present a difficulty in machining. Excessive tool wear and high tooling costs of diamond tools make the cost associated with machining of these composites very high. LAM also has been applied to metal matrix composites: Aluminum-matrix MMC reinforced with Al_2O_3 particulates and Al-2%Cu aluminum matrix composite reinforced with 62% by volume fraction alumina fibers (Al-2%Cu/Al_2O_3). LAM was able to improve the tool life and the material removal rate while minimizing the sub-surface damage. LAM significantly reduced the specific cutting energy, surface roughness, tool wear and fiber pull-out as compared to conventional machining (see **TABLE 1**). In conclusion, LAM shows considerable improvement in enhancing the machinability of the high volume fraction, long-fiber MMC through increased MRR, better surface finish, increased tool life, and reduced damage.[9]

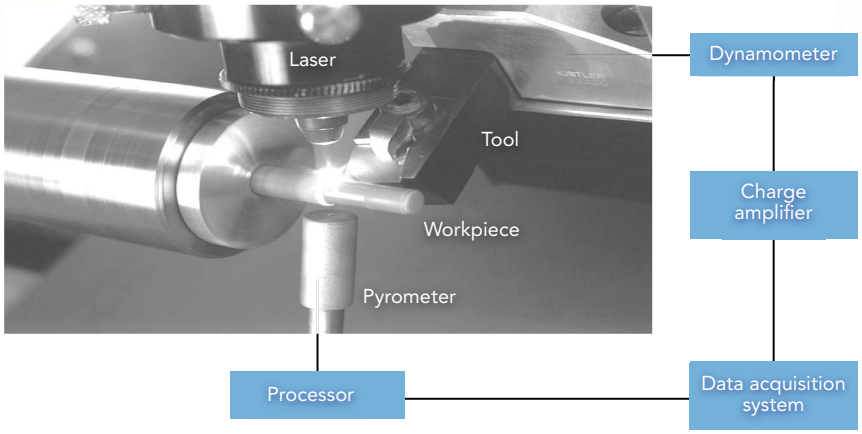


FIGURE 3. Laser-assisted machining set-up with in-process temperature monitoring.

Laser-assisted micro-milling and macro-milling

Laser-assisted machining has also been successfully applied to milling. Unlike in turning, the rotating tool makes the

Table 1. Key results achieved from LAM of various materials

	CUTTING FORCE REDUCTION	SURFACE ROUGHNESS IMPROVEMENT	TOOL LIFE INCREASE	COST REDUCTION	MICROSTRUCTURE
Inconel 718 (%)	25	200-300	200-300	50-66	Compressive residual stresses in axial direction
Titanium (%)	20	30.00	170-200	40-42	No change in hardness and phase
Waspaloy (%)	20	600	40-60	N/A	No change in hardness or microstructure
Hardened steel (%)	20	5-60	N/A	N/A	No noticeable change in hardness and peak compressive residual stress
High Cr. steel (%)	30-36	240-300	30-100	30-90	No change in hardness and phase
P550 (%)	25	30-40	200	20-50	No change in hardness and phase
CGI (%)	15	5	160	20.00	No phase change (graphite intact)
MMC (Al-2% Cu/Al_2O_3, fiber, 65% volume fraction) (%)	65	280	160-280	N/A	Damage depth reduction by 17-20%
MMC (A359/SiC/20p particulate) (%)	12	58	170-235	N/A	Damage depth reduction by 45%

application of laser-assisted machining more problematic. Despite that, a carefully designed beam path and focus pattern could produce very promising results.

In laser-assisted micro-milling, the typical setup includes at a minimum: one or more precise (and rigid) CNC stages, a high speed spindle, a laser and miniature endmills. Generally stages with a positional accuracy of a few micron or less, spindles with speeds greater than 100 kRPM, and tools with diameters less than 500 µm are required for successful laser-assisted micro-end-milling. Unlike in macromachining, a low power laser, typically in the range of 20–50 W, is sufficient to provide the requisite heating due to the small spot size used. Laser assisted micro-milling has been successfully implemented in a slotting configuration[10,11] and side cutting configuration.[12] Improvements have been shown in terms of cutting forces, tool life, and machined surface quality for a range of materials, including aluminum, steel, stainless steel, Inconel 718, and Ti_6Al_4V. In micro-milling processes, cutting speeds are limited by maximum possible spindle speed and small tool diameters, leading to lower than optimum shear plane temperatures. Laser assisted micro-milling offers the ability to somewhat overcome the size-effect and often eliminates the burr formations, which are known to be a significant problem in mechanical micro-milling.

Macro scale laser-assisted milling has also been successful in machining of ceramics and some high temperature alloys.[13,14] Laser-assisted milling of silicon nitride was successfully conducted using

TiAlN coated carbide tools by elevating the material removal zone temperature to 1200~1300°C. Laser assisted milling of silicon nitride yielded good surface finish, repeatable performance and acceptable tool wear.[14] Laser-assisted milling of Inconel 718 also yielded a substantial improvement of machinability. LAM with the material temperature elevated to 520°C resulted in 40–50% reduction in cutting force, over 50% reduction in tool chipping and two fold improvement in surface roughness.

Potential and future

In this article, successful application results of LAM for various difficult-to-machine materials have been shown. Many benefits could be established by LAM. At this point in time, evidence is mounting that LAM processes have the potential to provide commercially viable means of improving manufacturing capabilities for difficult-to-machine materials such as super alloys, ceramics, and composites. The higher material removal rates that LAM offers present an opportunity to significantly reduce the manufacturing cost of fabricating products made of these materials. Development of a scientific basis of laser assisted machining and an ability to fabricate complex parts with monitoring and control has taken LAM from laboratory-based experiments to manufacturing processes that can be implemented and precisely controlled in industry, with several successful industrial implementations reported.

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showcase

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12 Measurements for Laser Safety, Cincinnati, OH, www.rli.com

3-14 6th Symposium on Advanced Laser Application (SALA), Hartford, CT, www.ccat.us

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MAY

9-13 Symposium on Laser Materials Processing for Micro and Nano Applications, Nice France, www.emrs-strasbourg.com/

23-26 Russia Essen Welding & Cutting 2011, Moscow, Russia, www.russia-essen-welding-cutting.com/

23-26 Laser World of Photonics, Munich, Germany, world-of-photonics.net/en/laser/start

23-26 LiM 2011 - Lasers in Manufacturing, Munich, Germany, www.blz.org/index.php?id=lim

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my view

Welcoming a new decade

SEVERAL YEARS OF GOOD BUSINESS AHEAD

Turning the page of my new calendar, I realized that it's a new decade. At least I think so, as I'm never quite sure when a decade starts and ends. For this commentary, I am assuming that 2011 is the start of a new decade. If it isn't, and 2010 was, I guess I should have written something about a new decade in January 2010.

In any case, I'm glad it's no longer January 2010, as we were then just beginning a recovery from the most severe recession in laser history. As last year progressed, things began to look much brighter, and as I sit in front of the keyboard preparing this editorial, 2011 looks like it can be a real winner for industrial lasers. (I'm told that many readers turn to "My View" first when they get the latest issue, so for them my editorial is a little like first reading the last page of a mystery novel where the culprit is identified. I'm sorry if I ruined the surprise of my Annual Economic Review in this issue starting on p. 4.)

As I've said and showed in my Economic Review, the strength and timing of the recovery in the industrial laser market took most companies by surprise; at least, that's what they said as the year ended. However, some of them knew that the recovery was underway, but chose not to publicly recognize their improved numbers throughout the year. Fortunately, I now track three dozen laser oriented public companies who are obligated to report their financials quarterly, giving me an early look at their current and future numbers. As a consequence, I picked up signs of optimism early in the year, and since I am not obligated to comply with SEC reporting rules, I began to advise that good things were happening at the mid-year point, when I reported the positive news at two conferences: AKL in Aachen and SLT in Stuttgart.

However, it wasn't until I finished compiling the backup data for my report that I realized the industry, led by the solid-state and fiber laser suppliers, was having a remarkable year growing their business sector by 25%. And in so doing, many of the companies that make up these two industry sectors set records for revenue, bookings, and profitability.

Last year, I visited an international solid-state laser systems supplier that, along with its peers, had experienced an almost devastating 2009. As the company president and I were walking the floor of an assembly hall, which was jammed with new systems being readied for international shipment, the president told me that the company was on a record run, so strong that he was moving up the date of a proposed IPO. This is one example of how strongly the solid-state and fiber laser suppliers grew in 2010, and this scenario is expected to repeat this year.

Admittedly, the semiconductor markets, a hot laser market since mid-2009, are predicted to cool off this year, and I planned accordingly by moderating my projections for this laser sector. The potentially very active market for high-power CO_2 and fiber laser fabricated metal products is projected, at the very least, to return to normalcy, and, if true, this will offset any softening in the total laser revenue numbers caused by the semiconductor markets.

But back to this decade thing — according to my data, the industrial laser market has experienced only two severe downturns in 40 years, the first one 20 years ago. So the odds are the industry should experience at least a good decade of growth.

Even with the specter of potential international financial difficulties that could precipitate another downturn, an occurrence that is difficult to factor into my projections, I see several years of good business for the industrial laser community.

So a very happy new year to you all and here's to the start of a great decade.

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