

# LIA

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# TODAY

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THE FIRST LAYER  
OF ADDITIVE  
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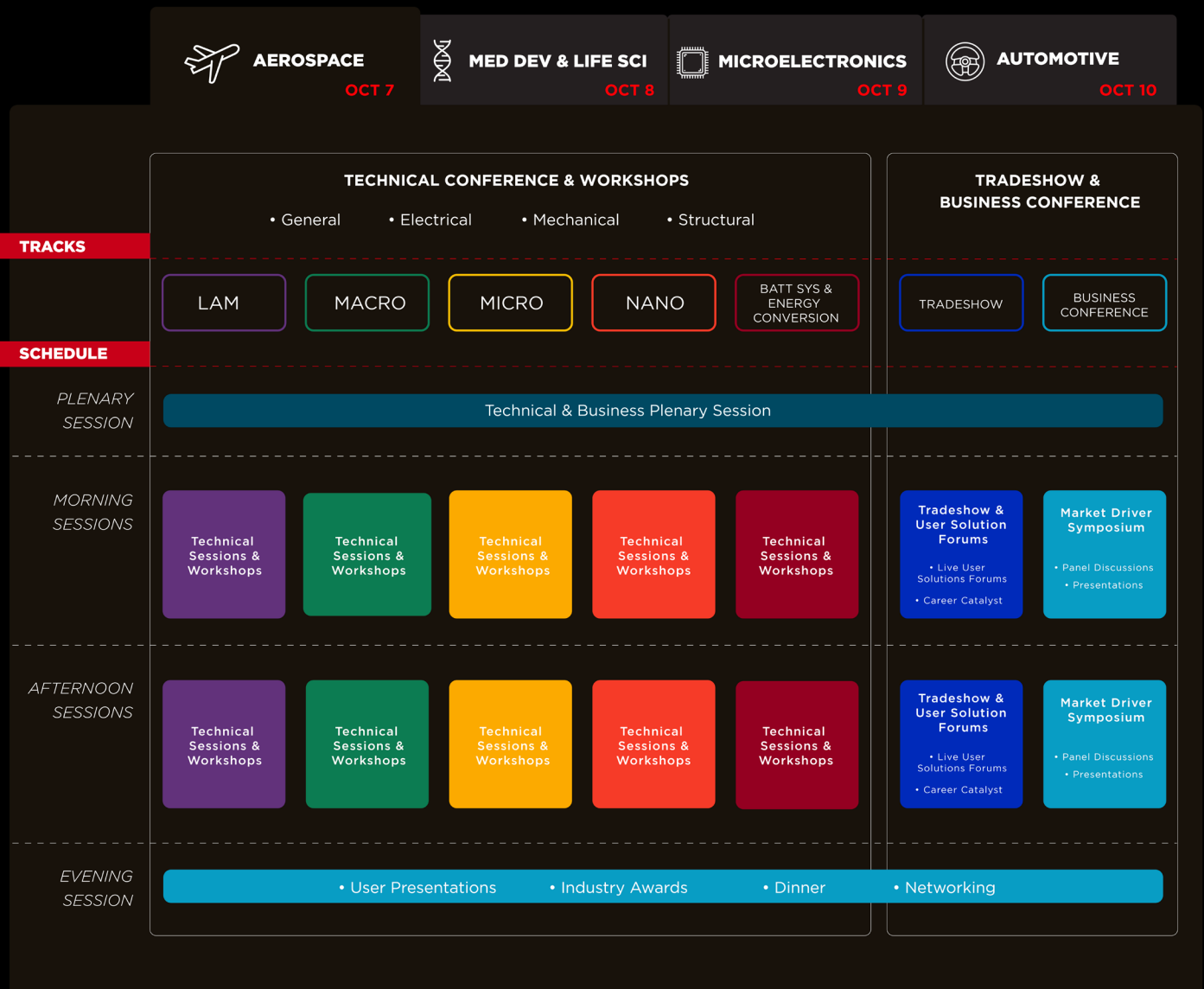
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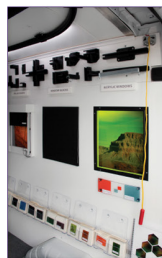
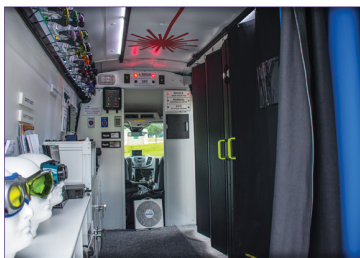
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# LIA TODAY

THE OFFICIAL NEWSLETTER OF LIA

*LIA TODAY* is published bimonthly to educate and inform students and professionals of challenges and innovations in the field of photonic materials processing.

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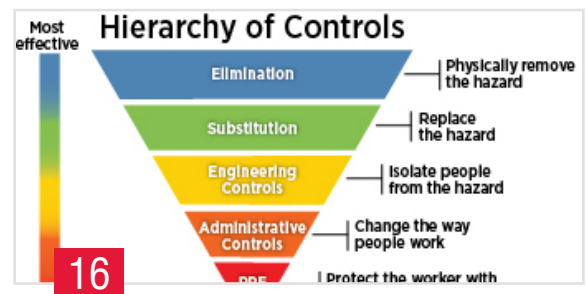
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## LASER CLADDING: THE FIRST LAYER OF ADDITIVE MANUFACTURING

By Wayne Penn

Understanding the strengths and weaknesses of any process is important for good application results. Laser cladding is a welding process producing metallurgical bonds between the base material and the deposited clad surface. In this article, Wayne Penn of Alabama Laser explains the fundamentals of Laser Cladding.



## NON-BEAM TO THE EXTREME!

By Wesley Chase

Although laser beam hazards are better known, non-beam hazards (NBHs) pose an equal or possibly greater risk of injury or death. As laser technologies increase and new hazards are discovered, a greater number of ancillary or NBHs will need to be considered for a safe work environment. Wesley Chase of Lawrence Livermore National Laboratory briefly discusses the hazards, findings, and controls for silica, ozone, and nanomaterials in laser operations.

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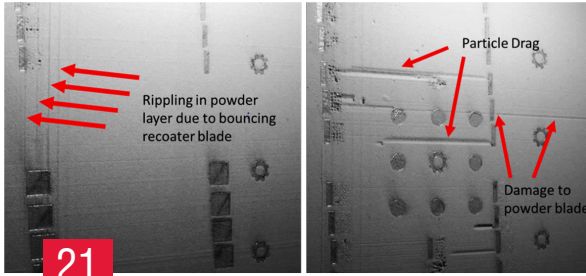
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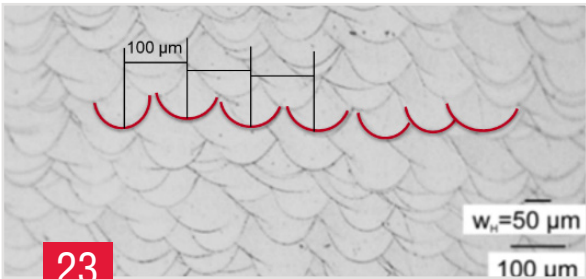




## IN-PROCESS SENSING FOR LASER-POWDER BED FUSION ADDITIVE MANUFACTURING

By E. W. Reutzel

Metal part production by laser powder bed fusion additive manufacturing (AM) is being embraced as a revolutionary technology promising to enable both unprecedented design freedom that enhances performance and rapid part replacement that improves supply chain logistics. In this article, Dr. Reutzel of the Applied Research Laboratory at Pennsylvania State University discusses the potential in using in-process sensors to assess and control build quality



## HIDDEN TRACKS IN SELECTIVE LASER MELTING

By Joerg Volpp

Selective laser melting (SLM) is a process that is widely used for many industrial applications such as the automotive and aerospace sectors, and in the development of medical tools. Despite the many benefits of SLM, the process often suffers from porosity or the creation of inclusions due to a lack of local energy input for the melting and re-melting of adjacent tracks and layers. Joerg Volpp of Lulea University discusses understanding process efficiency by analyzing track geometries.

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## Conference Highlight

# ICALEO

INTERNATIONAL CONGRESS ON  
APPLICATIONS OF LASERS & ELECTRO-OPTICS

OCTOBER 7 - 10, 2019  
ORLANDO, FL

Laser industry professionals from academic and industrial settings will gather to discuss the latest in laser additive manufacturing (LAM), laser materials macroprocessing, laser materials microprocessing and laser nanomanufacturing. Topics range from the interaction between a laser beam and a material to how a process can be integrated and optimized for an application.

ICALEO 2019 will feature presentations that focus on cutting-edge research in these technology areas for high impact applications in the following industry sectors:

•[View Program Information](#)



Oct 7, 2019



Oct 8, 2019



Oct 9, 2019



Oct 10, 2019

## LIA Laser Safety Trainings

### LASER SAFETY OFFICER WITH HAZARD ANALYSIS\*

Orlando, FL \* BLS Certified Laser Safety Officer Exam  
offered after the course.

Aug. 19 - 23, 2019

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Orlando, FL \* BLS Certified Medical Laser Safety Officer  
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Aug. 17 - 18, 2019



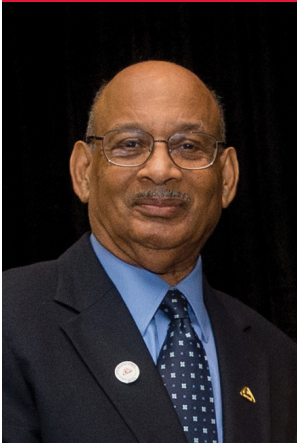
### Featured Course:

**INDUSTRIAL LASER SAFETY OFFICER TRAINING**  
NOVI, MI  
WED, 08/14/2019 TO THU, 08/15/2019  
(8:30 AM – 4:30 PM)

This course is designed to keep LSOs working in manufacturing and industrial facilities on the leading-edge of safety training requirements and program administration. This course teaches a non-mathematical approach to facilitating the duties of a Laser Safety Officer, and is designed to fit the needs of environmental health and safety professionals, engineers, laser operators and laser technicians who are not required to perform hazard analysis calculations. This course is hosted by LIA Corporate Member IPG Photonics Corporation, Midwest Operations. IPG Photonics Corporation is the world's leading provider of high power fiber lasers and fiber amplifiers that are revolutionizing performance and utility in a remarkable array of materials processing, telecommunications, medical and other advanced applications. course meets the training requirement to apply to sit for the official Certified Laser Safety Officer exam offered by the [Board of Laser Safety](#).



# EXECUTIVE DIRECTOR'S MESSAGE



This past week, I had the privilege of traveling to Munich, Germany, the location for Laser World of Photonics, to attend a symposium to honor the retirement of Professor Reinhart Poprawe, Director of Fraunhofer ILT, and his incredible career. In witnessing the impressive presentations and panel discussion, which included four additional renaissance men, (Dr. Reinhard Pfeiffer, Deputy Chairman of the Board Messe Munich, Dr. Alfred Gossner, member BOD of the Fraubhafer-Gesellschaft, Dr. Burkhard Rauhit, former Rector of RWTH Aachen University and Dr. Peter Leibinger, CTO and Vice Chairman of the Group Mgt Board at Trumpf GmbH + Co. KG), I understood the bridging among German academic institutions, industry, government, research and development to synchronize workforce development with digital photonic production and Industry 4.0 demands. It was invigorating to see how Germany is pursuing what I would call Education 4.0, to maximize workforce contributions to Germany's economic growth. Aspects of this plan impact not only Germany, but also the larger global community. It brings to mind what Dr. MJ Soileau has advocated for in his work with UCF's College of Optics and Photonics; in his interview with Dr. Panayiotou he talks about the college's mission to transition knowledge into industry.

In our own way, LIA can contribute to Education 4.0 by providing platforms for members of the LIA community to share knowledge; platforms include publication in LIA TODAY or the Journal of Laser Applications, and sharing research at conferences. This issue of LIA TODAY shares knowledge with industry with additive manufacturing topics covering the fundamentals of laser cladding, the potential uses of in-process sensors to assess build quality in LAM, and the analysis of track geometries to understand process efficiency in Selective Laser Melting. Learning opportunities at the new ICALEO will be more expansive than in previous years, adding LAM to the list of conference tracks and adding expanded networking opportunities and focused industry interactions. There are new registration options now available to match ICALEO 's new architecture. Program information is available at [www.icaleo.org](http://www.icaleo.org) and will be constantly updated.

Before the month passes us by, it's important to recognize that June is National Safety Month and one of the themes this year is Hazard Recognition. Fitting with that theme is the article Non-Beam to the Extreme, by Wesley Chase, originally presented at ILSC 2019, which discusses the lesser-known non-beam hazards of nanomaterials, ozone, and silica. I encourage all to read it. For National Safety Month, LIA is providing discounts on all Z136 laser safety standards until July 19, 2019.

A handwritten signature in black ink, appearing to read 'Nat Quick', with a long, sweeping underline.

**Nat Quick**  
Executive Director

# Laser Cladding:

## The First Layer of Additive Manufacturing



**By: Wayne Penn**  
**Alabama Laser**

Wayne Penn is an applied physics consultant for Alabama Laser with over 45 years of experience with lasers and materials processing.

[www.alabamalaser.com](http://www.alabamalaser.com)

Understanding the strengths and weaknesses of any process is important for good application results. Laser cladding is a welding process producing metallurgical bonds between the base material and the deposited clad surface. With the proper use of optics, one can focus a high power laser beam into a small spot and melt metal at a high speed. The ability to melt the metal at higher speeds lowers the heat input per unit length. For over 45 years I have worked with and built lasers. The first time adding metal to a part created a new level of excitement in working and playing with laser light. Over the past 20 years of my career, I have worked with laser cladding using both wire and powder deposition. In this article, I will elaborate on the laser cladding process, additive filler materials using powder and wire, a few cladding applications, plus some thoughts on cladding and additive manufacturing.



## The Laser Cladding Process

The rapid heating and cool-down or quenching of the weld puddle and area affects the deposition material and the base material properties. Post-weld heat treatment (PWHT) is often needed for conventional welding and may also be necessary with laser cladding. Even though the heat input with laser cladding is less, it is still inducing stress and material property changes at some level. Laser cladding is not a magic wand, but with proper parameter development and application it can be a powerful tool for achieving results that otherwise may be difficult or impossible.

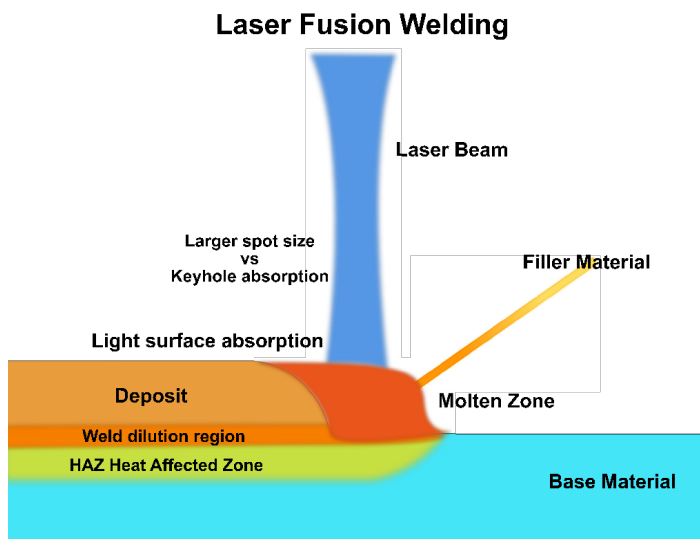
Benefits of Laser Cladding	Challenges of Laser Cladding
Creation of a Small Heat Affected Zone (HAZ) in the base material	High capital equipment cost
Production of a component with improved erosion properties	Many parameters to dial in, control and monitor
Production of a component with improved corrosion properties	High grade and consistent quality required for the incoming materials
Creation of a Metallurgical bond between the additive material and the base	Precise integration of the optical, electronic, mechanical, and software control
Creation of a deposition material chemistry with low dilution of the base material	
Lower heat input improves the ability to deposit matrix materials where one of the materials may otherwise melt and or evaporate into the deposit.	
Ability to iterate and dial in the parameters for targeting material properties	
Tailoring of the material performance properties of components; for example, internal ductility with a tough outer layer.	

Conventional Tungsten Inert Gas (TIG) Gas Tungsten Arc Welding (GTAW) or Metal Inert Gas (MIG) Gas Metal Arc Welding (GMAW) utilizes a plasma created by an electric arc to melt the metal. While the plasma temperature can be considerably higher than the melting point of the metal, it still takes time for the heat of the plasma to transfer and melt the metal. The heat of the plasma is transferred to the metal by some of the following mechanisms:

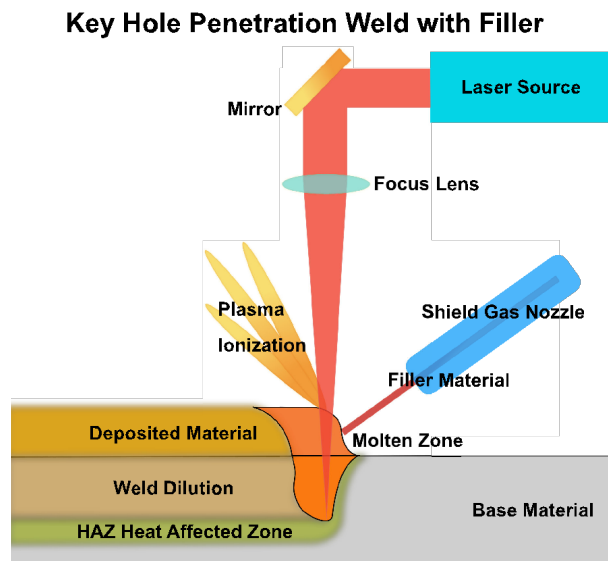
- Plasma surface contact
- Electrical resistance heating
- Convection carried with the shield gas
- Radiative energy from the plasma light

The plasma welding spot size or power density coupled with the heating mechanisms require additional time to melt the metal compared to laser welding. The additional time results in a slower weld speed and heating the base metal to a greater depth and increases the dilution of the additive filler material. While this can produce a good weld, the heat input to the base metal can be higher than a weld with a laser-produced filler.

The laser heating and melting of metal is a different mechanism. A laser beam is simply light. Light contains many packets of energy called photons. The laser beam itself is neither cold nor hot; rather, it is the interaction of the laser beam with a material that produces the heat.



**Fig. 1-** Larger spot size- Laser conduction mode welding with filler or cladding



**Fig. 2-** Laser keyhole mode welding with filler or penetration welding

## Laser Fusion Welding

Laser beam power densities on the order of 10,000 Watts/cm<sup>2</sup> can be absorbed by the surface of a metal; the material quickly melts under the power of the laser beam (see Fig. 1). The key here is surface melting. Melting below the surface is by heat conduction from the laser irradiated surface; hence, the term laser conduction welding or *fusion welding*.

## Key Hole Penetration Weld with Filler

Laser beam power densities above 100,000 Watts/cm<sup>2</sup> result in a different melting mechanism (see Fig. 2). The laser light no longer just interacts with the surface, but now the higher power density results in a propulsion mechanism that drives the laser beam down into the material resulting in even much greater absorption. The laser beam propelling down into the material causes metal vaporization and expansion that creates a keyhole or tunnel; hence, the term laser *keyhole welding* or penetration welding.

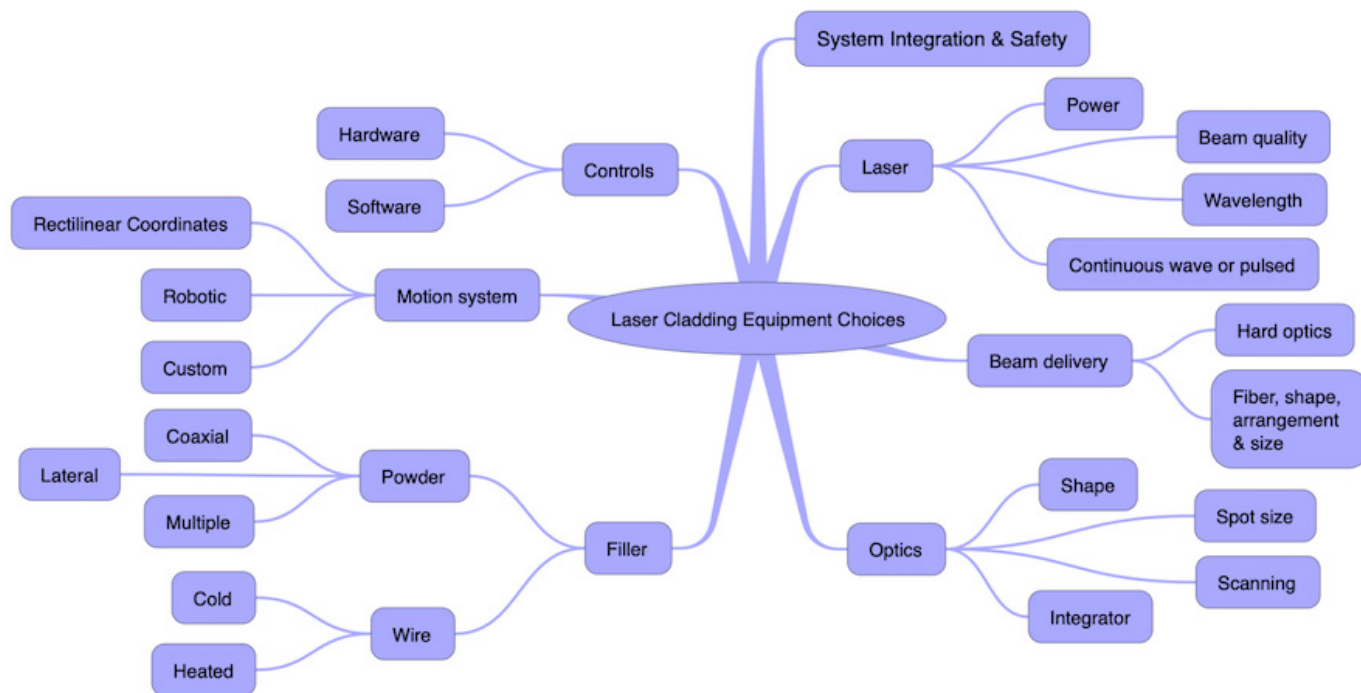
The beginning of my cladding journey started with some of the first industrial power diode lasers. A 1 kW diode laser offered a power density that was enough for welding metal. A high power diode laser wavelength of less than 1 micron offers improved absorption of the laser light for metals over the industrial CO<sub>2</sub> laser with a wavelength of 10.6 microns. Industrial laser power levels are now readily available to well over 10,000 Watts for the 1 micron to near-infrared (NIR) wavelength region.

## Another Tool in the Welding Toolbox

The laser is just another tool in the welding toolbox. It still results in producing heat that can result in material transformations, material stress along with distortion and warping of the laser processed parts. Laser light is not a mystery, nor is it pixie dust; it is just basic welding with a new higher power density source that works with light for the heating mechanism.

Chart 1 on the next page shows many variables that begin to define the capabilities and features of the system. The system hardware I/O capabilities, controller, and software further define the cladding parameter matrix capabilities. For example, the starts and stops of cladding may need precise synchronous controls of laser power, surface speed, and feeder parameters for smooth controlled transitions.





**Chart 1-**  
Some of the laser cladding system configuration choices

The overall laser cladding system design, enclosure, safety interlocks and environmental control for safety and a consistent process are paramount.

Laser cladding needs, functions, and parameter choices include:

#### 1. Laser

- 1.1. Power control including ramping
- 1.2. Spot size
- 1.3. Scanning
- 1.4. Beam pattern
- 1.5. Continuous wave (CW) and or pulsed

#### 2. Optical head

- 2.1. Beam quality design
- 2.2. Optics
- 2.3. Cooling
- 2.4. Beam manipulation functions

#### 3. Filler material delivery

- 3.1. Shield gases
- 3.2. Cooling
- 3.3. Geometrical configuration

#### 4. Motion hardware

- 4.1. Geometry of part and beam motion
- 4.2. Axis of control
- 4.3. Surface speed control

#### 5. Software

- 5.1. Input / Output (I/O) interfaces
- 5.2. Human Machine Interface (HMI)
- 5.3. Machine control algorithm
- 5.4. Ease of use
- 5.5. Compatibility with other software input
- 5.6. Vision
- 5.7. Quality and logging functions

#### 6. System safety, enclosure, integration, HMI and environment

#### 7. Control, interlocks, monitoring, logging, control functions, and I/O

From the list above you can get the idea that there is a wide spectrum of challenges and technologies for controlling and maintaining the process in an industrial environment.

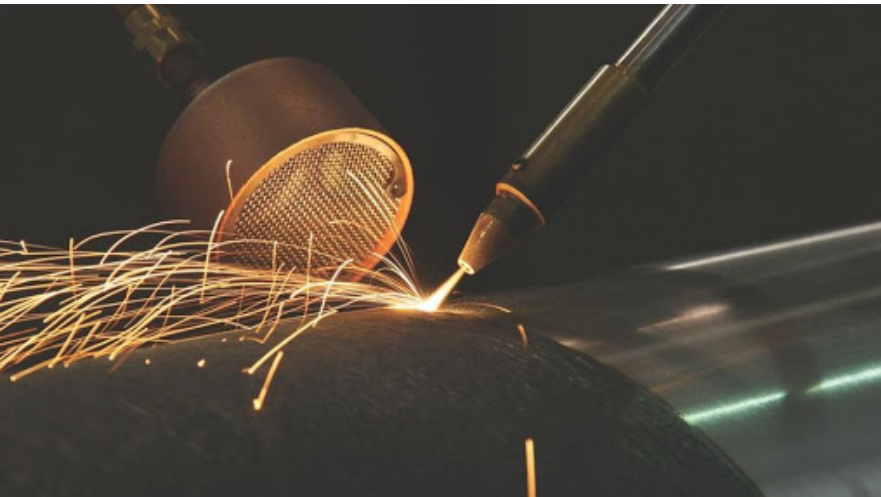
## Additive Filler Material

Additive filler materials are generally metal alloys or pure metals. Powders and cored wires may have mixtures of alloys and elemental metals. Cladding is basic conduction welding with the addition of a filler.

Laser cladding is welding an overlay with less heat input (provided optimal parameters are dialed in). For laser cladding, the filler is added to the laser generated molten puddle, to build up the surface rather than burn the additive material down into the base. A small amount of dilution between the filler and the base is necessary to ensure good weld layer bonding.

Laser cladding and laser processing parameters provide the ability to iterate a matrix of experiments with the goal of improving material properties.

## Powder Filler Material



Laser cladding with coaxially configured powder nozzles enables multi-axis motion systems where the head is steered to follow the contours; for example, cladding for part repair. Worn edges of the part can be built back up and then machined to finish dimensions.

Laser cladding with powder

Laser cladding with powder is also useful for materials that are made up of a mixture of powders. For example, in a wear resistant application, tungsten carbide (WC) particles are mixed with binder metals for fusing the WC particles into place without melting the WC.

Additionally, powders can be configured as mixtures of elements and alloys to achieve desired metallurgical properties. Optimizing particle size and shape distribution is essential for smooth powder flow. The nozzle geometry is important for controlled powder flow. If the nozzle is too close to the welding puddle, spatter can adhere to the nozzle surface and modify the powder spray pattern, thereby changing the cladding results.

### Parameters affecting the cladding properties for powder include:

- Distance from puddle
- Powder flow collimation
- Powder streams and beam orientations
- Keeping the powder evenly mixed and dry
- Weld orientation, vertical down, angled, side or upside down
- Transport gas velocity: quality of shield, cooling effects of the gas
- Powder intersection volume with the laser beam and weld puddle
- Nozzle location and geometry- coaxial, lateral, single nozzle or multiple.

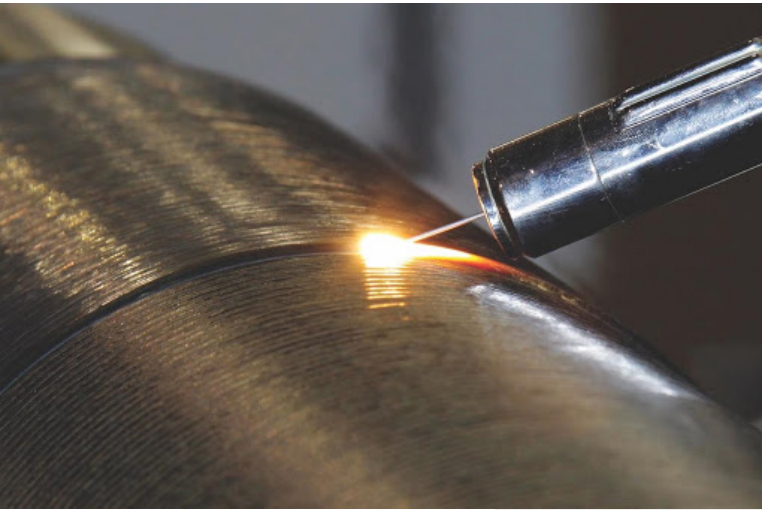
*A proper maintenance schedule for cleaning the nozzle and maintaining the powder feed and lines is important for consistent results.*

### Powder Considerations

- Spatter adhering which changes the spray pattern
- Parameter balance, bond at base not too much powder
- Surface finish powder grain texture
- Coaxial powder feed gives motion system freedom
- Additive material must be available in powder
- Resolution smaller laser spot size possible lending to smaller parts
- Deposition thickness, multiple passes
- Nozzles and pre-placed powder
- Material selection & properties
- Powder deposition efficiency, lost money, clean up



## Wire Filler Material



Wire as the filler material can be advantageous, especially for cylindrical part geometries. Wire feed can also be made into a hybrid process with the integration of a hot wire power supply for pre-heating the wire while being fed into the molten puddle.

Laser cladding with wire -  
part restoration with multiple clad layers  
NIR Laser beam coming in from the top

In general, laser welding with hot wire filler offers higher deposition rates with a smooth deposited finish. System integration plus optical, mechanical, and software control are important for good cladding capabilities. The purpose is to be able to add filler material to the weld puddle with minimal cooling to the molten volume, enabling the opportunity for improved deposition speeds. Iteration of a parameters matrix to optimize for the desired material properties is very important and requires validating with metallurgical analysis to insure base bonding and optimization of the heat input.

### Wire Considerations

- **Clean wire**
- **Consistent processing performance**
- **Smooth surface finish from the melt pool**
- **Deposition speed increase with pre-heated wire**
- **Beam to wire orientation impacts motion direction**
- **Additive material must be available in wire**
- **Higher deposition rates for larger parts and less geometry resolution**
- **Range of deposition thicknesses possible**
- **Material selection & properties of solid wire and cored wire**

It is fundamental in any welding method, including laser welding with powder or wire, that the weldability of the base material with the addition of the filler is verified with welding trials. Typically, welding trials are made on metal coupons made of the same base material and using the same filler materials.

### Considerations for both powder and wire:

- **The part must be clean, free of surface and ground in contamination**
- **Weld bond and satisfactory welding results from the base material and the additive material**
- **Process qualification**
- **Machine qualification**
- **Welding operator qualification**
- **Part qualification: Does the part meet the customers' requirements?**
- **Quality control, incoming material, processing results. Visual finish, special attention to starts, stops. Required testing**
- **Meets welding code standards as required**
- **Pre-machine and or surface finishing**
- **Post weld heat treat**
- **Post-machine**
- **QC and inspection**

## Cladding Applications

The purpose of using lasers for cladding is the ability to produce a high enough power density for melting metal. The welded bond between the clad and the base results in a stronger bond than a mechanical bonding process. The benefits of laser cladding often focus on improving surface wear and corrosion performance. Application industries includes:



Power generation



Oil and gas



Pulp and paper



Mold and die repair



Engine component repair



Electric motor component repair



Turbine component repair



Aerospace component repair



Agriculture components



Earth moving equipment repair

In addition to part-repair and rebuild, cladding can be used in manufacturing new parts for realizing the benefits of the improved surface performance.

The upstream and downstream resources for a laser cladding operation include:

1. **Incoming materials inspection, qualification and metallurgy information.**
2. **Part pre-machining determination and operations.**
3. **Pre-machined part inspection**
4. **Part cleaning**
5. **Defining the laser cladding system need and parameters**
6. **Cladding operation**
7. **Cladding inspection and repair as needed.**
8. **Part post machining and finishing as needed**
9. **QC inspection and documentation as needed**

For new jobs and applications, one must develop the process. The development of the cladding process includes basic testing and parameters for the weldability of the incoming materials. Determining the success of the weld includes performing metallurgical micrographic investigations on the test parts bonding interface, clad chemistry, micro hardness across the bond region, and various bending and elongation tests and measurements.

## Cladding and Additive Manufacturing Going Forward

Laser cladding is the first layer of additive manufacturing. What I am implying is that launching with the achievements of laser cladding can help to enable a larger scale production for direct energy deposition.

Laser cladding is all about welding with a filler material using a process that enables an improved component. By adding more layers, you can build a new component with features tailored for the application along with a potential for cost savings. Net shaping using basic laser cladding metal deposition technology can open the door to large component creation. The money being invested in research and industry with 3D printing bears witness to the growing enthusiasm and potential that laser additive metal deposition can have on our designs, capabilities, and our economy.

# JUNE IS NATIONAL SAFETY MONTH

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# NON-BEAM TO THE EXTREME!

## LAWRENCE LIVERMORE NATIONAL LABORATORY

Although laser beam hazards are more well-known, non-beam hazards (NBHs) pose an equal or possibly greater risk of injury or death. As laser technologies increase and new hazards are discovered, a greater number of ancillary or NBHs will need to be considered for a safe work environment. There are several non-beam-related hazards that can be classified into three categories: chemical, physical, and biological. Expertise in the occupational health area is not required for laser users and Laser Safety Officers (LSOs), but an awareness of such hazards is important. Occupational Hygienists and other safety professionals can perform an evaluation and advise on specific controls to mitigate these hazards.

By Wesley Chase, CIH

**NBHs can have extreme health and safety consequences and have many regulations associated with them. There are a wide variety of health and safety issues related to NBHs when compared to beam hazards. Most of the laser safety concerns have been centred around beam hazards with little attention given to NBHs. The American National Standards Z136.1 and Z136.8 [1 & 2] briefly discuss NBHs; however, with the advent of new laser technologies, the promulgation of new safety regulations, and an understanding of new NBHs, it is important to maintain an awareness and to anticipate, recognize, evaluate, and control NBHs.**

The more well-known NBHs include electrocution, fire, chemical agents (e.g., laser dyes and solvents), biological agents, etc. However, there are a few NBHs such as silica, ozone, and nanomaterials that either have new occupational exposure regulations, are not well understood, or not well characterized. Such circumstances can be extremely harmful to unprotected or unaware individuals. This paper will briefly discuss the hazards, findings, and controls for silica, ozone, and nanomaterials in laser operations.

### Hierarchy of Controls

Occupational Hygienists, LSOs, and other health and safety professionals use the hierarchy of controls (Figure 1) for preventing and controlling hazards in the work place, including laser use. Lasers have their fair share of hazards that are not related to beam hazards, as discussed in this document. Thus, employers and health and safety professionals should select the controls that are the most feasible, effective, and permanent. Controls should be chosen according to a hierarchy which highlights engineering solutions (including elimination or substitution) as a first line of defense. Other controls are administrative in nature and include training, safe work practices, medical surveillance, posting work area signage, etc. The last line of defense would include the use of personal protective equipment (PPE) such as a respirator to prevent exposures. [3]

### Silica

Silica is the second most common mineral in the Earth's crust and is a major component of sand, rock and mineral ores. In addition, laser optics are primarily made from silica-based materials. When high-power (Class 4) lasers such as carbon dioxide (CO<sub>2</sub>) lasers interact (e.g., ablate, drill, etc.) with laser optics, or other materials containing silica, there is a risk of exposure to airborne crystalline silica as a by-product from these operations. The inhalation of respirable crystalline silica dust can lead to silicosis and has been associated with other diseases such as bronchitis, tuberculosis, lung cancer, kidney disease, and chronic obstructive pulmonary disease (COPD). [4]

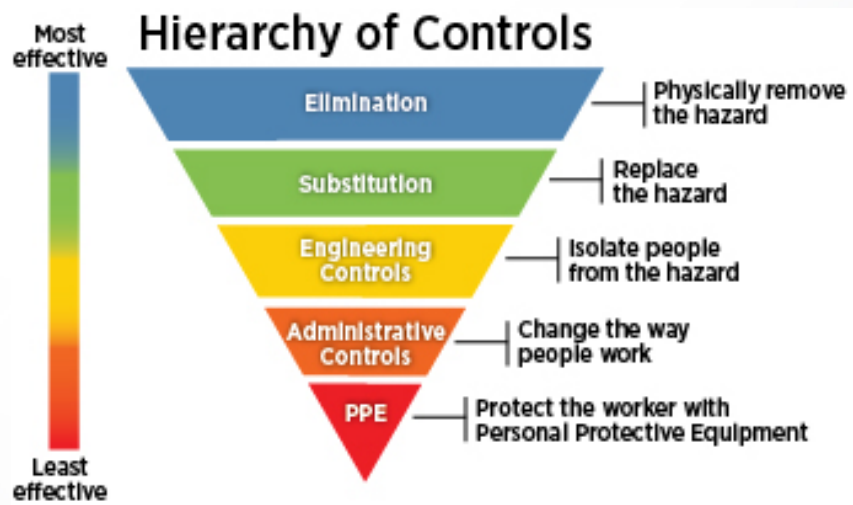


Figure 1. Hierarchy of controls.

As of June 23, 2018, the Occupational Safety and Health Administration (OSHA) has promulgated the silica rule for general industry. This new standard, amongst other requirements, establishes that employers must determine and maintain employee exposures to airborne silica below the Action Level (AL) of 25 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) and the Permissible Exposure Limit (PEL) of 50  $\mu\text{g}/\text{m}^3$  as an 8-hour time-weighted average (TWA) under any foreseeable conditions. [5]

One exposure assessment from the National Institute for Occupational Safety and Health (NIOSH) has found significant amounts of airborne silica concentrations collected from a process involving the use of a  $\text{CO}_2$  laser cutting fused silica. For this evaluation, NIOSH collected personal breathing zone samples from employees, which revealed respirable exposure concentrations to fused silica as high as 2.2 milligrams per cubic meter ( $\text{mg}/\text{m}^3$ ). When extrapolated to an 8-hour TWA basis, these samples yielded fused silica concentrations of 0.5  $\text{mg}/\text{m}^3$ . Results from five area samples indicated extrapolated 8-hour TWA results as high as 0.9  $\text{mg}/\text{m}^3$  (900  $\mu\text{g}/\text{m}^3$ ). [6]

When using high-power lasers such as  $\text{CO}_2$  lasers for cutting, drilling, ablating, or other activities that disturb materials such as quartz, ceramics, masonry, etc. there is a risk of exposure to airborne respirable silica. As such, engineering controls are a great solution and method of control in preventing silica exposures. Examples of engineering controls for silica dust include:

- Local exhaust ventilation (Figure 2) which removes silica dust at or near the point where it is generated.
- Enclosures that isolate the work process or the employee.
- Wet methods that apply water at the point where silica dust is created.

## Ozone

Ozone is another recognized NBH, but it is not well characterized or documented. Acute effects from ozone exposures include fluid in the lungs and haemorrhaging. Very low concentrations (e.g., one part per million) can cause headaches and dryness of the eyes. Chronic effects include significant changes in lung function. Besides the direct hazards with ultraviolet (UV) light, ozone can be produced from short wavelength/"far UV" (typically less than 220 nm), high repetition rate lasers and some flashlamps. Some flashlamps can have output in the UV that can produce significant amounts of ozone. However, the flashlamps at the National Ignition Facility (NIF) have quartz envelopes that are doped with cerium to nearly eliminate output below about 380 nm. As such, they produce very little ozone when operated in air (Figure 3).

When compared to lasers, the production of ozone has been well studied during certain welding activities where ozone is produced by welding arcs due to UV irradiation of the surrounding air. Ozone is formed in the welding arc, especially during plasma-arc, metal inert gas (MIG) and tungsten inert gas (TIG) processes. The effect of the welding process, material, current level on ozone generation, and the resultant ozone levels in the welder's breathing zone have been determined. Due to the high temperature produced by the welding arc plasma, the light generated is very intense and includes radiation in the 130-400 nm UV range. Radiation within the wavelength range of 130-170 nm is extremely effective at splitting the oxygen molecules in the air to produce free "excited" oxygen atoms that readily combine with other oxygen molecules to form ozone. As this wavelength spectrum is very effective at producing ozone, it is completely absorbed by the air within a few centimeters of leaving the arc, and results in very high ozone levels, up to 1,000 ppm in the air layer close to and surrounding the arc. [7 & 8]

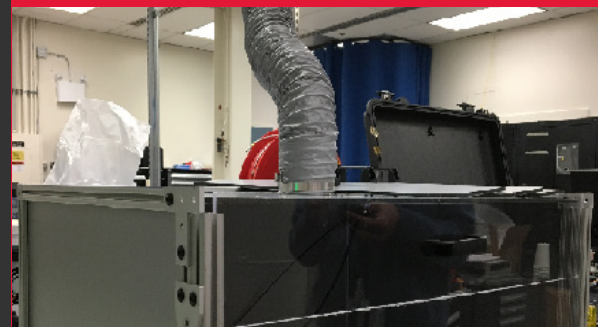


Figure 2. Local exhaust ventilation set up for a Class 4 laser which generates secondary fumes. Photo courtesy of Matthew Legaspi, CIH at the National Ignition Facility, 2018.



Figure 3. Flashlamp display at the National Ignition Facility (NIF), 2018. The 6-foot (180 cm) flashtubes used on the NIF laser were some of the largest in commercial production.

<sup>1</sup> ANSI Z136.1-2007, Safe Use of Lasers, Laser Institute of America, Orlando, FL.

<sup>2</sup> ANSI Z136.8-2012, Safe Use of Lasers in Research, Development, or Testing, Laser Institute of America, Orlando, FL.

<sup>3</sup> OSHA Recommended Practices for Safety and Health Programs, <https://www.osha.gov/shpguidelines/hazard-prevention.html>

<sup>4</sup> OSHA Fact Sheet, <https://www.osha.gov/Publications/OSHA3682.pdf>

<sup>5</sup> OSHA, 1910.1053. Respirable Crystalline Silica.

<sup>6</sup> NIOSH Health Hazard Evaluation report, October 1990, HETA 89-331-2078, <https://www.cdc.gov/niosh/hhe/reports/pdfs/1989-0331-2078.pdf>

<sup>7</sup> The Annals of Occupational Hygiene, Volume 10, Issue 3, 1 July 1967, Pages 175–188, <https://doi.org/10.1093/annhyg/10.3.175>

<sup>8</sup> The Linde Group/BOC Gas, <http://www.boc-gas.com.au/en/sheq/welding-cutting-hazards/ozone/ozone.html>

A recent survey conducted at Lawrence Livermore National Laboratory measured three different lasers with low wavelengths that were not in enclosed systems or under inert gas. Ozone measurements were collected near the output of the lasers using real-time detection equipment; however, ozone was not detected as a by-product from these lasers. Although these lasers have low wavelengths, it is likely that ozone was not produced due to the low repetition rates which did not allow time for a build-up of ozone.

Nevertheless, one study involved the use of enclosed compartments with controlled and monitored exhaust ventilation to evaluate emissions from laser cutting operations. This evaluation conducted by Pilot et al. [9] measured ozone and other emissions from plasma arc and laser (CO<sub>2</sub>) cutting of mild and stainless steel in air. They found that laser cutting produces negligible levels of ozone compared to plasma arc cutting.

In some instances, the risks from exposure to toxic gases, such as ozone, are more substantial than the risks from exposure to the UV radiation itself, due to the incorporation of optical safeguards into the UV generating system, and the absence of adequate ventilation in the area of the UV source. [10]

When working with lasers, flashlamps or other ozone-producing equipment, engineering controls are a great solution to prevent exposures. Examples of engineering controls for ozone are similar to the controls previously mentioned for silica, with the exception of the wet methods.

## Nanomaterials

Engineered nanoparticulate (ENP) have recently garnered attention due to their properties, benefits, and various technological applications. The potential for employee exposures when handling ENP is also very real, as evidenced by worker exposures to polyacrylate nanoparticles [11], silicon dioxide ENP playing a major role in the development

of cardiovascular diseases [12], and nickel ENP causing sensitization [13]. A review of ENP exposure studies from 2000 to 2015 found high-quality evidence of workplace exposures to multi-walled carbon nanotubes (CNTs), single-walled CNTs, carbon nanofibers (CNFs), aluminum oxide, titanium dioxide, and silver ENP; moderate-quality evidence for non-classified CNTs, nanoclays, and iron and silicon dioxide ENP; and low-quality evidence for fullerene C60, double-walled CNTs, and zinc oxide ENP [14]. With studies like these, we are gaining more understanding that the properties which make ENP technologically useful may also make them harmful.

For Occupational Hygienists and other health and safety professionals, assessing potential ENP exposures has its challenges. The challenges stem from an increasing presence in the workplace, including the synthesis of nanomaterials from lasers (Figure 4), and a lack of solid toxicological information for establishing occupational exposure limits (OELs). The deficiency with toxicological information has been extremely limited since nanoparticles can be reactive, can deposit in various regions of the respiratory tract, and have the capability of crossing normally impenetrable barriers (e.g., blood-brain barrier, skin).

Whether nanoparticles are intentionally [15 & 16] or unintentionally produced with lasers, the hazards can still be present, even though they may be invisible to the unaided eye and must be assessed and controlled. However, the traditional Occupational Hygiene methods for assessing exposures do not work for ENP since appropriate health-relevant exposure indices are unknown, analytical methods are not available to quantify this index, and exposure levels at which those particles produce adverse health effects are unknown [17]. To fill this void, control banding (CB) provides an alternative to the traditional Occupational Hygiene methods.

CB is a method used to guide the assessment and management of

workplace risks, at least for the time being. It is a general procedure that determines a control measure (for example dilution ventilation, engineering controls, containment, etc.) based on a range or "band" of hazards (such as skin/eye irritant, very toxic, carcinogenic, etc) and exposures (small, medium, large). It is an approach that is based on two pillars; the fact that there are a limited number of control approaches, and that many problems have been met and solved before. CB uses the solutions that experts have developed previously to control occupational chemical exposures, and apply them to other tasks with similar exposure situations. It is an approach that focuses resources on exposure controls and describes how strictly a risk needs to be managed. [18]

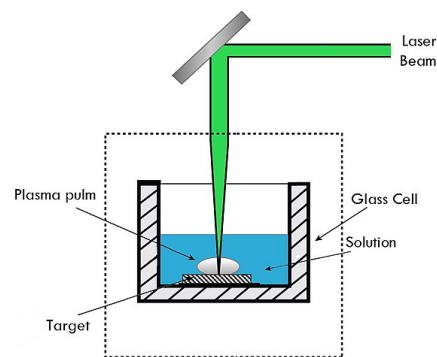


Figure 4. Typical schematic diagram of laser ablation synthesis in solution (LASIS) for nanomaterial preparation.  
Source: Wikipedia.org.

Lawrence Livermore National Laboratory has developed a CB tool (Figure 5) for assessing and controlling ENP. This tool allows for an ease of use with an appropriate level of rigor. The risk level



Mr. Chase is a C Ignition Facility v the University of experience in th and safety plan evaluations, rad gas industry EH



**LAWRENCE LIVERMORE NATIONAL LABORATORY**  
Science and Technology in the National Interest

**CB NanoTool**  
Control Banding Deterministic Model

Scenario Description: Lorem ipsum ddd  
Name or description of nanomaterial: Lorem ipsum ddd  
CAS #: Lorem ipsum  
Current Engineering Control: General ventilation  
Activity classification: Clean-up of spills or waste material

**A) Severity score**

1- Surface reactivity	Medium	5
2- Particle Shape	Tubular or fibrous	10
3- Particle diameter	> 41-100 nm	0
4- Solubility	Soluble	5
5- Cancerogenicity	Unknown	4.5
6- Reproductive toxicity	Yes	6
7- Mutagenicity	Yes	6
8- Dermal toxicity	Yes	6
9- Asthmagen	Yes	6
10- Toxicity of parent material	< 10 µg/m³	10
11- Carcinogenicity of parent material	No	0
12- Reproductive toxicity of parent material	Yes	4
13- Mutagenicity of parent material	Yes	4
14- Dermal toxicity of parent material	No	0
15- Asthmagen of parent material	Yes	4

**B) Probability score**

1- Estimated amount of chemical used during task	11 - 100 mg	12.5
2- Dustiness / mistiness	Unknown	22.5
3- Number of employees with similar exposure	6 - 10	0
4- Frequency of operation	Daily	15
5- Operation duration	1 - 4 hours	20

**Result**

Severity: 70.5  
Probability: 60  
**RL 3**  
RL 3 : Containment  
Upgrade ? Yes

Friday, July 20, 2018

Figure 5. View of the Monte Carlo version of the CB Nanotool with an example task using ENP where the outcome is a risk level 3. Monte Carlo model courtesy of Dr. Drolet. [19] Source: controlbanding.llnl.gov.

outcomes generated by the tool, which are dependent on the inputs, will prescribe the appropriate level of control (e.g., general ventilation, local exhaust ventilation, etc.). In addition, the CB Nanotool has gained international acceptance from the International Organization for Standardization (ISO/TS 12901-2:2014) as a proactive approach, the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) and has been used in many different universities and institutions. This tool is available for public use at [controlbanding.llnl.gov](http://controlbanding.llnl.gov).

## Summary

The consequences of non-beam laser hazards can be extreme, when compared to traditional beam hazards. As laser technologies and applications develop and new hazards are introduced, it is important for laser users and LSOs to maintain at least an awareness of new safety regulations and hazards, even when some hazards may not be visible. Occupational Hygienists and other safety professionals play a valuable role in anticipating, recognizing, evaluating, and controlling NBHs by performing evaluations and recommending specific controls based on the degree of hazard and by utilizing the hierarchy of controls and new approaches to evaluating and controlling hazards when traditional methods are unknown or unavailable.

## Acknowledgements

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ertified Industrial Hygienist with Lawrence Livermore National Laboratory at the National where he also serves as the Nanomaterial subject matter expert. Mr. Chase graduated from f Oklahoma with a B.S. in Environmental Science. With over 13 years of comprehensive he Environmental, Health, and Safety (EHS) field, Mr. Chase has experience in health development and review, noise assessments, laser safety evaluations, nanomaterial ation safety, hazardous drug exposure assessments, chemical hygiene/lab safety, oil/ S, and other similar fields of the industry.

<sup>9</sup> Pilot, G., Noel, J.P., Leautier, R., Steiner, H., Tarroni, G., & Waldie, B., Measurements of secondary emissions from plasma arc and laser cutting in standard experiments, Report EUR-14065, Commission of the European Communities, 1992.

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<sup>16</sup> Habiba K, Makarov VI, Weiner BR, Morell G. Fabrication of Nanomaterials by Pulsed Laser Synthesis. In: Wagar A, Ali N (editors). Manufacturing Nanostructures. UK: one central press (OCN); 2014. 263-92. ISBN: 9781910086070

<sup>17</sup> Paik S, Zalk D, Swuste P (2008). Application of a Pilot Control Banding Tool for Risk Level Assessment and Control of Nanoparticle Exposures. Annals of Occupational Hygiene 52(6):419-428

<sup>18</sup> The National Institute for Occupational Safety and Health (NIOSH), Control Banding, <https://www.cdc.gov/niosh/topics/ctrlbanding/default.html>

<sup>19</sup> OD. Drolet, J. Sahlme, D. Zalk, and P. Dessureault, "Monte Carlo Simulation Implementation in Three Control Banding Tools: Assessment of Dermal Risk, The "CB Nanotool" and Heat Stroke Prevention Guide (CS-108-06)," Presented at American Industrial Hygiene Conference and Exposition, Salt Lake City, 2015.

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Application scenario with hydraulic shear  
(picture: WEBER-HYDRAULIK GmbH).

# DEMONSTRATION OF A MOBILE LASER CUTTING SYSTEM FOR COMPLEX RESCUE OPERATIONS

By: Alexander Brodesser, Christian Hennigs, Alexander Pfaff, Robert Grafe, Michael Hustedt, and Stefan Kaierle

**Abstract:** In the case of serious accidents, severely injured persons may be trapped inside damaged vehicles and thus must be rescued quickly. Typically, structural parts containing high-strength steels or fiber-reinforced plastics must be cut to generate rescue openings. Hence, mechanical rescue systems like hydraulic shears may reach their performance limits. Therefore, a mobile laser cutting device for rescuers has been developed, being suitable for harsh outdoor conditions and providing optimized robustness, handleability, and weight. A crucial aspect is the requirement of laser safety for all persons involved. Here, the description of the

first version of a demonstration system consisting of a mobile laser cutting device for complex rescue operations is presented.

**Journal of Laser Applications 31, 022209 (2019)**

<https://doi.org/10.2351/1.5096128>

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# IN-PROCESS SENSING FOR LASER-POWDER BED FUSION ADDITIVE MANUFACTURING

By E. W. Reutzel, Ph.D.

The Center for Innovative Material Processing through Direct Digital Deposition and  
The Applied Research Laboratory at the Pennsylvania State University

Metal part production by laser - powder bed fusion additive manufacturing (AM) is being embraced as a revolutionary technology promising to enable both unprecedented design freedom that enhances performance and rapid part replacement that improves supply chain logistics. Metal AM production involves costly design expertise, processing systems, and post-processing that drives cost up and limits most applications to critical engineered components, where verifiable high quality is imperative. Commercial systems currently rely on a pre-defined, optimized processing recipe that does not compensate for the systematic process variations or random perturbations that can degrade quality. For cost effective use of AM in critical applications, it is imperative that quality be monitored and/or controlled. In the metal powder bed fusion AM process, powder is spread evenly across a substrate using a recoating mechanism to prepare a thin layer of powder for processing.

A CAD model or STL representing the desired component is virtually “sliced” into individual layers that provide a basis for defining the laser scanning paths. A high speed laser scanner manipulates the laser beam along these paths to melt a thin layer of the powder, and this melt pool ultimately resolidifies into solid material. The substrate is translated downward, another thin layer of powder is spread, and the process repeats until the part—now buried within the bed of powder—is formed. As noted earlier, anything that disturbs the process can influence process physics and increase likelihood of a degradation in quality. Figure 1 shows examples of process defects that reduce part quality. In-process sensors can be employed to identify such process disturbances.

During the recoating operation, accelerometers mounted to the recoating system can detect collisions with so-called “super-elevations” that are indicative of excessive component distortion or undesirable process effects (such as “balling” and other surface characteristics driven by surface tension effects

during solidification). Such collisions can damage the recoater blade, leading to disturbances in the thin powder layer that will influence process physics during the laser-powder-substrate interaction and may degrade build quality. The recoater blade has been observed to bounce along the powder bed surface and drag large particles through the powder bed, serving another source of process perturbations (see below). Researchers have utilized a variety of sensors to characterize these powder perturbations, including high resolution photography with oblique or structured lighting, and scanned laser displacement sensors.

After the powder recoating operation, the laser (~80  $\mu\text{m}$  diameter) is scanned across the powder (~40  $\mu\text{m}$  diameter), providing myriad other opportunities disturb the process. The laser beam heats up and melts the powder to form a melt pool, which exhibits high speed fluid flow due to steep thermal gradients, Marangoni convection, and other forces. In some cases, molten metal ejected from the melt pool combines to form agglomerates up to 500  $\mu\text{m}$  in diameter that can block



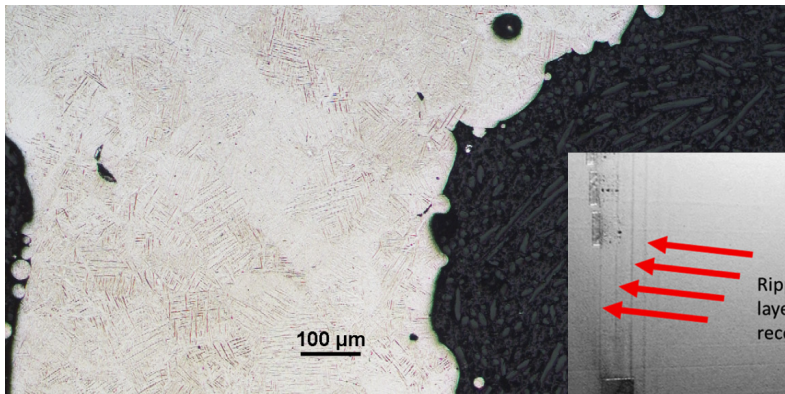


Figure 1. This PBFAM component built in Ti6Al4V reveals both gas porosity and lack-of-fusion defects.

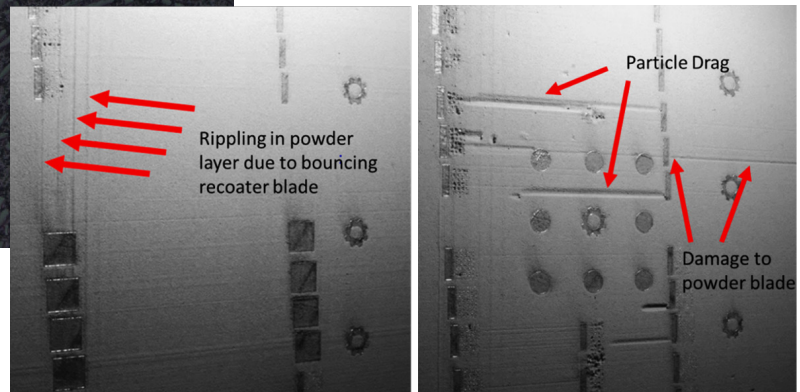


Figure 2. The recoating operation can introduce perturbations that degrade powder layer uniformity. High resolution images of the build plate can reveal such disturbances.

energy from the processing laser from reaching the substrate, with a likely degradation of quality. The laser heats the melt pool until a superheated plume of metal vapor and plasma expands orthogonal to the melt pool surface, exerting a recoil force that depresses the melt pool. These complex interactions, combined with the melt pool momentum during the scan, increase the probability of flaws whenever the laser is turned on or off, as occurs repeatedly in the region of the contour-hatch interface. Interaction between the laser and any contaminants may also degrade the process. Again, in-process sensors can be employed to identify such process disturbances.

Coaxial interferometry-based sensors can measure the melt pool depth at a high rate. Filtered high speed photodiodes can quantify either plume fluctuations or variations in the amount of laser light reflected off the melt pool. Spectroscopic techniques can be applied to the electromagnetic emissions from the plume to detect the presence of contaminants in the powder. Plume fluctuations also disturb the gaseous processing environment, generating pressure waves that are emitted as acoustic energy. There is growing evidence that signals such as these can be used to identify individual flaws in near-real-time, thus opening up the potential for inter-layer repairs, e.g. remelting a region known to contain a lack-of-fusion defect in order to “heal” the flaw. Non-contact pyrometers and high speed thermal imaging are used to collect information related to the thermal characteristics of the melt pool. The thermal characteristics of the melt pool map closely to the presence or absence of powder beneath the interaction region, which is known to significantly influence process characteristics. Researchers have utilized this phenomenon to realize real-time control of laser power to account for such process variations.

The data from in-process sensors that monitor the laser - powder bed fusion AM process provides practitioners critical data related to build quality. As researchers develop improved understanding of the fundamental physics leading to flaw formation, confidence in using in-process sensors to assess and control build quality will grow.



#### About the Author

Dr. E.W. (Ted) Reutzel is acting Head of Penn State's Center for Innovative Material Processing through Direct Digital Deposition (CIMP-3D) and the Applied Research Laboratory's Additive and Laser Manufacturing Division, and serves as graduate faculty in Penn State's Engineering Science & Mechanics Department and Additive Manufacturing & Design Program. Dr. Reutzel has led numerous programs to investigate and implement metal AM, including support for the Navy's first demonstration of a flight-critical part (Ti6Al4V AM link on the MV-22B Osprey). Current interests include process monitoring for AM process understanding, machine learning for quality control of metal-based AM processes, and process implementation.

# HIDDEN TRACKS IN SELECTIVE LASER MELTING

By: Joerg Volpp

Lulea University of  
Technology

Selective laser melting (SLM) is a process that is widely used for many industrial applications such as the automotive and aerospace sectors, and in the development of medical tools. SLM uses a laser beam to melt pre-placed powder material in a container known as a powder bed, building a technical structure by melting layer upon layer of material. This additive process offers high flexibility of part design and opens new possibilities for more efficient and customized part production.

Despite the many benefits of SLM, the process often suffers from porosity or the creation of inclusions due to a lack of local energy input for the melting and re-melting of adjacent tracks and layers. Recently, it was shown that excessive re-melting (up to five times [1]) of previous tracks and layers takes place when building structures at processing parameters provided by the SLM-machine designers. In order to achieve a sufficient overlap and to minimize cavities, conservative parameters that induce a high-energy input and thereby the unnecessary re-melting are often chosen to avoid those defects and guarantee a homogeneous and dense part. Unfortunately, these strategies can lead to powder usage inefficiencies, a higher energy input, a reduction of processing speed, and ultimately higher costs and longer manufacturing time.

For efficient energy usage and high processing speeds, the energy input must be tailored to the actual task; therefore, the basic effects of the process have to be better understood. When building SLM-parts, single tracks are built within one layer of pre-placed powder before adding the following powder layer to build the next section. The track geometry defines the amount of melted powder, the attachment to the previous tracks or layers and the amount of re-melted material. The main constraint is that cross-sectional track

geometries can significantly vary across one layer. In Figure 2a, it can be seen that the track geometry within one layer significantly varies even though each of the tracks were processed with the same processing parameters (316L steel powder, 180 W laser power, and 50 m/min. processing speed). Those variations could be derived from changed absorption effects, laser power variations or also from varying powder availability for the different tracks. Therefore, a simplified mathematical model was developed describing the influence of the amount of the 316L steel powder, which is available for each track within one layer, on the track geometries during laser processing. The model considers the denudation effect to derive the actual amount of powder that is used to build the track and calculates the track geometry and location depending on the laser energy input and amount of available powder. The shrinking of the volume during melting of the powder and the changed absorption on the powder surface are taken into account. This model was used to derive variations of the track geometries within one layer (Fig. 2b). One of the main parameters in SLM is the hatch distance that defines the overlapping of adjacent tracks.

The hatch distance has a significant impact on the processing speed and can impact the occurrence of pores or inclusions if chosen too large. When smaller hatch distances were present, the model helped identify high fluctuations from track to track that were not immediately evident simply from viewing the cross-section (Fig. 3a). Upon first glance, the track geometries look homogeneous, but the model predicted high fluctuations from track to track (Fig. 3b). A closer look reveals that every second layer is not visible in the cross section anymore due to re-melting; essentially, they are 'hidden'.

It can be concluded that the variations of the powder availability can cause the geometric variations of the tracks and can impact the laser energy absorption. It seems that an adaptive energy input that depends on the actual amount of available powder can increase the process

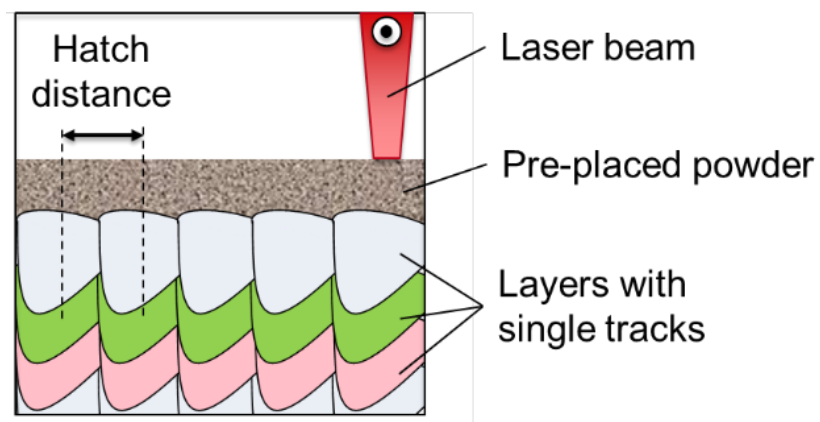
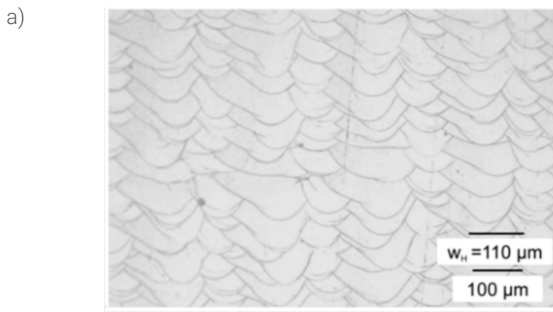
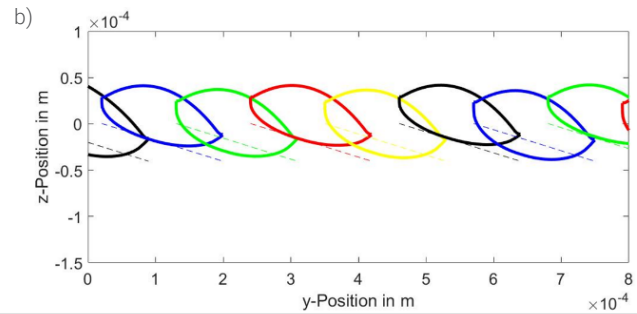


Figure 1. Sketch of the powder bed process including layers and tracks at different hatch distances



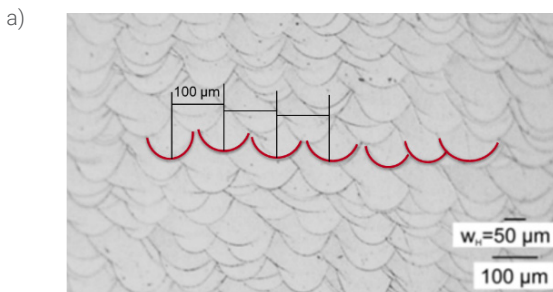
Laser spot size	70 µm	Fiber laser	180 W
Layer depth	40 µm	Powder grain size	10 µm to 45 µm
Hatch distance	110 µm	Processing speed	50 m/min

Figure 2a. Structure built with selective laser melting at 110 µm hatch distance; Excerpt of a cross-section



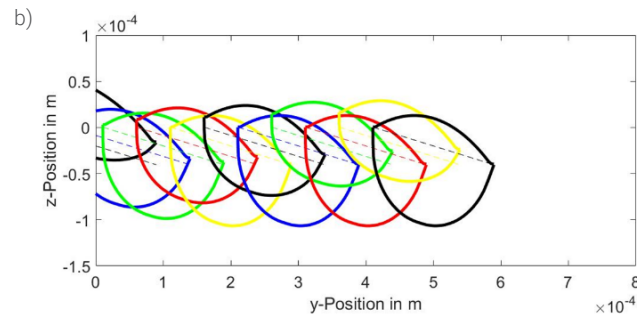
Laser spot size	70 µm	Fiber laser	180 W
Layer depth	40 µm	Powder grain size	10 µm to 45 µm
Hatch distance	110 µm	Processing speed	50 m/min

Figure 2b. Modeled track variations in one layer



Laser spot size	70 µm	Fiber laser	180 W
Layer depth	40 µm	Powder grain size	10 µm to 45 µm
Hatch distance	50 µm	Processing speed	50 m/min

Figure 3a. Structure built with selective laser melting at 50 µm hatch distance; Excerpt of a cross-section



Laser spot size	70 µm	Fiber laser	180 W
Layer depth	40 µm	Powder grain size	10 µm to 45 µm
Hatch distance	50 µm	Processing speed	50 m/min

Figure 3b. Modeled track variations in one layer

The author acknowledges subcontracting from IWS Dresden, Germany in the Agent3D project funded by the Bundesministerium fuer Bildung und Forschung (BMBF), Germany and the funding by VINNOVA - Sweden's innovation agency (project ÖVERLAG, no 2017-03240).

<sup>1</sup> Mishra, P.; Ilar, T.; Brückner, F.; Kaplan, A.F.H. (2018) Energy efficiency contributions and losses during SLM. Proceedings of the 36th international congress on applications of lasers and electro-optics (ICALEO), LIA Congress Proceeding, paper 901.

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Joerg Volpp studied in Stuttgart (Germany). During his studies he worked with IFSW in Stuttgart and as an intern for Bosch mbH in Charleston, SC (USA). He finished his diploma thesis at Bosch GmbH, Schwieberdingen (Germany) in 2011 in the field of laser welding of steels. From 2011 through 2017, he worked for BIAS GmbH in Bremen (Germany) in the field of laser deep penetration welding and received his Ph.D. in 2017. Since June 2017, he works in the Laser group at Lulea University of Technology (Sweden).





# LASER PIONEERS

Interview with M.J. Soileau, Ph.D.

September 14, 2018

By Chrys Panayiotou, Ed.D.  
Executive Director and Principal Investigator of LASER-TEC

Read Part-1 of MJ's story in the  
[January/February](#) issue of  
LIA TODAY



M.J. Soileau received his PhD in Quantum Electronics from the University of Southern California, and is currently a University Distinguished Professor of Optics and photonics, Electrical and Computer Engineering, and Physics at the University of Central Florida. He is known for his pioneering research in nonlinear interaction of laser pulses with optical materials and for leading the development of the internationally recognized Center for Research and Education in Optics and Lasers (CREOL) at UCF. Soileau holds 6 U.S. patents, the applications of which have contributed to the advancement of high energy laser optics used by the United States Department of Defense. His leadership has helped UCF become a catalyst for the region's high-tech development, stimulating the local economy in central Florida. He is a Fellow of IEEE, the SPIE--The International Optical Engineering Society, and the Optical Society of America. M.J. has been honored as a Foreign Member of the Russian Academy of Sciences, inducted to the Florida Inventors Hall of Fame, is a Fellow of the National Academy of Inventors, received the SPIE Gold Medal Award, and the OSA Esther Hoffman Beller Award.

I talked to Dr. Soileau about his personal experiences in the early days of the invention of the laser and his journey through the last 60 years of laser history.

## Part 3

**CP:** You were talking about CREOL and the recipe that you created and started in the mid-80s and its great success and where it is today.

**MJS:** I'm egocentric enough to mark the formal start date as the day I arrived on campus at UCF, which was January 2, 1987. I was given a suite of four offices, a doublewide trailer for laboratories, and 15 faculty. The challenge was to create a third optical center in the academic world in the US. A blank slate more or less, but it was more a blank slate than I thought, because the university was also a blank slate having only one PhD program in engineering and one in computer science.

In the beginning, we had a "dispersed model", meaning the center could not directly hire or tenure track faculty. We had to place our hires in existing departments of existing colleges, and none of these units had a tradition of recruiting top scholars. This was a major obstacle, which took over a decade to clear!

The key in building any large organization, University organization is to hire good faculty. The key in building any organization period is to hire good people. As the first criteria, the politics of the situation cannot get in the way.

A huge problem was research space. There wasn't room for us. A doublewide trailer to build state-of-the-art labs was not going to work. There was some empty space. There was a dead person assigned to the office next to mine and I could not get it released for my first faculty hire (Eric Van Stryland) for CREOL. Therefore, we leased space in the adjacent research park. It was raw space in a "spec" office building. We had it built out to our specifications and we moved in during the 1987 Christmas holidays.

There were advantages and disadvantages to being in rental space, off campus. One of the great advantages was that the university facilities people told us we were on our own, and they could not help us. Therefore, if we needed a plumber, we called a plumber. If we needed a drywall person, we called a drywall person. Just like you do at home. The result was that we got things done fairly cheaply and fairly quickly. We did it all legally of course, just a purchase request, but without having to go through the facilities bureaucracy.

A second advantage was that we were out of sight and out of mind; therefore, we were able to develop our labs and our programs pretty much without interference. Except when we wanted to hire somebody. We had

to get permissions from the departments to hire the person.

That worked most of the time; not all the time. We were trying to hire a guy that was postdoc in engineering at the University of Iowa. He had a PhD in physics from the Imperial College in London, pretty good pedigree. We were going to hire him to be tenure tracked in the physics department. The day before his arrival the physics chair called me and said, well I see he's been doing a postdoc in engineering. Maybe he should be interviewed in engineering instead of physics. What difference does it make? The guy has a PhD in physics, so he's doing physics. The state of the University was such that, this idea that you did physics in physics and engineering in engineering was thought to be something sacrosanct. The net result was that we lost an excellent candidate.

Fast forward after about ten years when we were trying to hire an optics person. We had gotten permission to offer our own graduate program in the College of engineering through the Electrical Engineering Department. But, we needed somebody to teach classical optics and optical design. We had a lot of electrical engineering-like people, a lot of physics-like people, some chemistry-like people, et cetera;



Art Guenther (who has since passed away) was a very forceful individual. He addressed the report to the President of the university. It was ignored. However, Art didn't let the president have any rest! Art kept bugging the president. Finally, the president had the provost convene an internal committee to recommend what to do with the report. This resulted in about a year of sometimes-fierce debate. Finally, I got a call from the provost (the late Gary Whitehouse, a fine gentleman) office saying that he needed to see me. The purpose of the meeting was to tell me that we would form the School

of Optics (not yet the College of Optics and Photonics) with its own tenure and academic programs, as recommended by the External Review Committee. This was a major phase change, and removed the biggest obstacle to achieving our goal of being on a par with the established comprehensive optics programs in the USA.

**CP:** When was that, when did that happen?

**MJS:** That was in 1988.

**CP:** That was pretty quickly after the...

**MJS:** Yeah, I'm sorry not '88, '98. A decade, a decade later.

**CP:** Ten years

**MJS:** Ten years later yeah, ten years later we had a going program. In the middle of that, in the early days of CREOL, we got involved in a major DARPA project, and it was a statewide project. That's a complicated story, that program allowed us to ratchet up very quickly, as a phase change in the organization. You know about phase changes: when you heat ice, it turns to water. That's a phase change, it's not hot or ice, it is something new. Heat the water, you get something new, vapor. That's a phase change. That was one of the phase changes, is this DARPA program. Another phase change was moving back to campus.

The third phase change was the School of Optics. By this time, we had built this building on campus; that was also important because it really put us in the middle of the

University. We were not done yet, but we had our own building and Masters and PhD program in the School of Optics.

Things were going great. Then I get a second call from the provost about six months later, he had to see me. He wanted me to serve as Interim Vice President for Research and Dean of Graduate Studies. I kind of felt like how I imagined Moses felt when he was allowed to see the Promised Land, but not to enter it!

I took the job and went on to be VP for Research and Commercialization for seventeen years. I did so as a matter of self-defense. I thought, maybe it's time for somebody else to lead CREOL anyway. It was important for CREOL to have someone in that office that understood what we were doing, lest it get screwed up. We asked the president to change the name of the office to the VP for Research and Commercialization. But, then he started using the name. After that, I suggested that we should formalize the change since he was using this term. This time he agreed and that he thought it was a good idea. This put emphasis on completing the task: going all the way from discovery to

teaching to transition of new knowledge into the economy.

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I like to call this the Noble Scheme. We get state money for establishing the place. We educate people, we develop new technology, new technology goes into industry, and industry pays taxes that goes

to support the University. It's a great cycle. That's the idea of the Land-Grant University that made this country great. UCF was founded 100 years too late to be a Land-Grant University, but we operated that office like it was a Land-Grant University, meaning that we wouldn't consider the job finished until knowledge was transitioned to industry.

When I went to the VP office, Eric Van Stryland became the Director of the School of Optics, which report to the VP for Research (me). Eric was trying to get a raise for his administrative assistant; and he couldn't because a director could only get administrative assistant paid up to a certain level, but deans could get paid more. Therefore, he asked if he could change the title to Dean of the school instead of director of the school. This seemed okay

but, no real optics person. So, we tried to recruit Jannick Rolland. She is now on the faculty at the University of Rochester. She had done a PhD in optics at Arizona, and it turns out she had done a postdoc in computer science. The engineering people said, you need to tenure track her in computer science. Computer science said, "We would welcome her here, but she has to teach the standard curriculum in computer science." Well, we're hiring her to teach optics. We're paying her all of her salary. We're paying, not you. We eventually got engineering to agree to let us hire her, and let her teach optics. However, we decided we'd have an external committee come in to help us out, to help get CREOL organized into something that was more like Institute of Optics and the Optical Sciences Center.

I formed, without permission, an external commission that had three people on it. Brian Thompson, who had been director of the Institute of Optics at Rochester and had been provost of the University of Rochester, pretty knowledgeable person in the field of optics; and Bob Shannon, who was at the time the Director of Optical Sciences Center, University of Arizona, he knew something about the discipline. Who should chair it? Why not Art Guenther? Art Guenther at the time had retired from the Air Force as Chief Scientist at the Air Force Weapons Lab. At that time, he was on the faculty at the University of New Mexico, was science advisor to the governor of New Mexico, and had received the Presidential Science Metal from President Ronald Reagan. I mean he was a pretty knowledgeable person in the field. He chaired the committee. The committee spent a week here and wrote a great report.



to me so I asked the provost who said he would think about it. I went to the provost and said, "Can we change the title of Eric to be dean of the school instead of a director of the school?" The provost said he would have to think about it. Well, I didn't hear anything more about it until at one Board of Trustees meeting it was announced that we were now going to have the College of Optics and Photonics! The genesis of that change was to give Eric's secretary a raise. As it turned out, the provost at the time, Terry Hickey, wanted to establish another new college, the College of Biomedical Sciences. Because both of those schools, if you like, were headed by very top research people, and he needed to have more top research people in the Deans Council. He thought this was a way to do it. The university was growing by leaps and bounds anyway, and it needed a more complicated structure than we had before. That's how the College of Optics and Photonics came into being. It was the first college in the country devoted to optics. That was a big deal.

It no longer reported directly to me, although the Center, CREOL, still did, and the main budget for the college was the Center budget — I still had my finger on it so I could defend it, shall we say. The place thrived under Eric's leadership. That decade included the time when Jeb Bush was governor of Florida. I'm a bleeding-heart liberal Democrat. But, I have great respect for Jeb Bush because he's a very bright man and very focused on the right things. He established a Centers of Excellence program, and we had an opportunity to bid for a Center of Excellence, a State Center of Excellence, in Optics and Photonics. The basic idea of Jeb's program was the same as original idea of CREOL (some of my colleagues around the state assumed that I had come up with the program, but indeed it was all Jeb's idea.) That is, you build infrastructure in the universities to drive the economy of the state.

I worked behind the scenes to make sure that the competition for those was based on something other than zip code. Because the older more established universities always like the competition to be based on zip code, so they would get 90% of the money, and the rest of us would fight over the 10% left. We ended up with a rigorously reviewed process, and CREOL had the top-ranked proposal in the state. Therefore, we were selected as the first-round Center of Excellence, under that competition, which allowed us then to expand the faculty. We finagled with the economic development people to get some federal

money to expand the CREOL building by including three labs that were for incubation space for new companies. We actually incubate companies here on campus, in our building. We do that because it's the right thing to do, and it allowed us to get some money to expand the building. Three labs were for incubation of optics companies, another dozen labs for ourselves, some new faculty positions, and three endowments for Chairs. Another one of these phase change operations.

When it came time for the second competition, we proposed an addition to the Center of Excellence, which became named the Townes Laser Institute in honor of Charlie Towns, who we had a lot of interaction with through our faculty member Dr. Martin Richardson. Martin wrote that proposal to expand the Center of Excellence to include a focus on lasers of substantial power, shall we say, for whatever the job there was to be done e.g., industrial applications, medical applications, defense applications and so forth. That was another boost to the original CREOL.

So, now we had the Photonics Center of Excellence and the Townes Laser Institute as well as CREOL, three state funded centers inside the College of Optics and Photonics. Eric served wonderfully for a decade in the position of Dean, the Founding Dean. After that, by the way, the University of Arizona changed the Optical Sciences Center to the College of Optical Sciences. So one hand washes the other. We look and see what they do, this is really good, and we try to emulate it. They look to see what we do, and they try to emulate it. Meanwhile, the profession itself grows, which is OK. Nothing makes you better than having a good competitor. We try not to imitate each other but there's a lot of emulation that goes on so, the idea is pretty much the same with mixing these disciplines with the common denominator of optics, but the approach and the specific emphasis is different at the three places, and remains so today. [There is] some overlap, but also some differences. Our objective was to have students decide to come here, not because we were better than Arizona, or better than

Rochester, rather when they were looking at Arizona, or Rochester, that we would be in the mix. The students can decide among three great choices, which program best matches their specific interest. Any student interested in optics will get a good education and career at any of those programs. Which one you choose is up to you based on your specific interests. Look at the faculty and what they're doing, how that overlaps with your interests. Make your decision based on that. You will get a good education at any one of them. I think we have that reputation now, which is wonderful to have.



What's also wonderful, is that I'm now a faculty member of CREOL, the College of Optics and Photonics. I'm teaching astronomy, which is my first love, and because I also have a joint appointment in physics. I am teaching a course on human vision. I taught it for the first time last spring, which was very painful. I had never taken a course on that subject, much less taught one, and there's no textbook

for it. My wife said it seems like I'm back in graduate school again. Every night reading literature, trying to come up with material for this course. I am also having a wonderful time trying to get a lab established, doing some experiments. Part of CREOL is now located in the physics building, the iFAST lab, which is a lab that produces attosecond

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pulses. At various times they've held the world record. I'm not sure if they still hold it. But, I think when it was at 37 attoseconds they had the world's shortest pulse. I have a little spot in their beamline, where we are doing some laser damage experiments, getting back to my roots, but now doing laser damage experiments with optical pulses that have three optical cycles. Think about it. You have optical frequency 10 to the 14th hertz, and you have three cycles in the pulse. It's very interesting technology just in building the laser, very interesting physics that result when you take those pulses and interact them with an optical material. You

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something totally strange and new. That's how I keep myself amused these days.

**CP:** So, there is another CREOL building, being built in the back here.

**MJS:** We're adding to the CREOL building. It's an addition to the building. The first addition was the one that we did with the US Department of Economic Opportunity. We got some federal funding for that and matched it with some local funding and so forth to build that. This addition to the building is funded through standard university processes. We have two remote sites, shall we say. One is on campus, but it's over in what I call the slums. It's out where the little observatory is, where the greenhouse is, out of sight and sound. We can build some plain cinderblock buildings that don't meet the University architectural standards, and therefore cheaper. We have some of our materials activities at that site. One of the things that makes us different as an optics place is that we have faculty that are working in ceramic materials and infrared glasses. One of our most successful startup companies had to do with photothermal

refractive glass, new kinds of optical components that are used in lasers and used in all kind of applications, and spectroscopy, and beam combining for high power lasers. The third site is the Townes Experimental Facility, out at the Kennedy Space Center. It is a remote facility that has an optical range associated with it, and it is a secure facility. We're not doing any classified work there, but it is cleared through secret, so we can do classified work there, if we have an experiment that that would be classified. We can test systems in field conditions out there.

**CP:** Let me ask one question that's kind of a tough question, but what do you foresee in the future for lasers, new applications, new different fields of science and engineering. You mentioned earlier about these super-fast femtosecond lasers. What is your vision?

**MJS:** I have to correct you, not femtosecond second lasers that's old technology. This is attosecond lasers. Attosecond is 1/1000 of the femtosecond. It takes two big labs to make one

short-pulsed laser. So, what's the future? One of my favorite clichés, and I'm not sure who gets credit for it, sometimes Yogi Berra, but I don't think he came up with it: "It is hard to make predictions, especially about the future." But, every time you ask somebody in science and engineering to make a prediction, they almost never get it right. Probably because we're too close to what the problems are. The futurists and science fiction writers do a better job of predicting the future.

All that said, what things are driving optics and photonics now, is putting a whole optical system on a chip. That trend is coming into maturity now, and it will continue to be important for many years to come. Particularly the trillion-sensor world, where you're looking at the Internet of Everything; so, having sensors all over the place and, as human beings know, optics are wonderful sensors, right? It's the cosmic messenger in astronomy. If you're going to have sensors all over the place, optically based sensors are going to be an important thing. These

sensors will be integrated with silicon devices. Some call it Silicon 2.0. You integrate optical devices with Silicon devices. The drive toward shorter and shorter pulses will continue. What will we do with them? Who knows?

The story about [Theodore] Maiman when he announced the discovery that they made the first ruby laser — Somebody asked him, "What's it good for?" He paused and said, "It's a solution looking for a problem." He had no idea what it was good for, but it had to be good for something wonderful. If you look at the progress of science, every time we do something new and fundamental in science, the question is, well what good is it? Every time, fast forward a little bit, you find it's very profound. Charlie Townes had a great story he told when he was at Columbia, working on the MASER. His department chair, who was a Nobel Prize winner, brought him into the department and said, you need to get off this stimulated emission thing. You're wasting the university's money and the students' time. Townes said, "I had tenure, so I told him to go pound sand." Six months later, he was successful. Now 15% of the world's gross domestic product is enabled by optics and lasers.

People think that's hyperbole but think about it, telecommunications, microelectronics, all done by optical lithography. The iPhone has 20 different laser machining steps in making it. It has a fantastic camera integrated in it. The display is an optical device. This progress will continue - I think we're just getting on a roll with that stuff. What else will come? I

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think the real answer to what happens in the future will come from these young people you see around CREOL. They will do things that we old guys had not thought about. That's the way science works, how it worked in the past, and how it will work at future. Curiosity driven research is going to drive where the technology goes. It always has and always will. We do science because we're curious. We do it because it's interesting. If I have a message to students, it's don't do science unless you find it interesting. If you don't find it interesting, I'm sorry because it's so wonderful. But, if you find it interesting and you find yourself compelled to do it, then do it. For sure, there's no better place in science than optics and lasers.

**CP:** So, we have a young kid now. He's in high school. He is thinking about this. He's excited and interested. What advice would you give to that person to have a nice career, education-wise, which would lead him to a good job and future?

**MJS:** I would say to the young person, that thing that is going to lead to a good job and a good life is to do something that you're interested in. If we propose that they are interested in science, that part is already there. You are never going to be good at anything unless it's interesting to you. Because you have to work hard to be good at anything, especially about science. What to do? Well, study mathematics. It's the language of science. Find yourself a mentor, they're everywhere. They're at the high schools, they're around at your local junior college or college. There are people that, if a student shows the least bit of interest, they will take you under their wing and help you in ways that you could not imagine. I've seen students grow up in our laboratories. I've seen students go through high school here, not taking any courses, alright, and then come and do an undergraduate degree, and continue on.

**MJS:** The opportunities for a good job and good life are everywhere. There's never going to be a shortage of jobs in science. Never going to be a shortage of jobs in optics. It already enables 15% of the world's gross domestic product. Exactly what job you are going to have, I don't know. I would tell people don't worry too much about what your job will be, where you will get a job. Pursue your interest. Get very good at it. There will be all kinds of opportunities out there. If I would try to tell somebody now where the opportunity is, I can bet that it will be incorrect. Because by the time they're ready for that, there will be a different opportunity. But knowledge of basic science is never stale. It is it going to be useful everywhere. Optics has been an important part of science and technology forever. It will remain an important part of science and technology.

There is one of one of our graduates that has about \$100 Million in venture capital funding in a little company call Luminar about a mile from where we're sitting, employs over 250 people. What is the primary product that they are doing? Well, self-driving cars. They're not

making cars. They're making LIDAR systems for self-driving cars. That's the technology that's going to drive the self-driving car, no pun intended. So, who would have thunk it! When Mr. Maiman when he was asked for uses of his laser would never thought to say self-driving cars. But LIDAR systems for self-driving cars, laser radar systems, for self-driving cars, is something that's going to explode as self-driving cars explode. Self-driving cars will be much safer than human driven cars. Ten years ago I wouldn't have given a plug nickel for somebody looking for a job in laser radar for self-driving cars.

As we move to this so-called trillion-sensor world, where we have sensors everywhere, optical sensors will be a major player. We never tire of high bandwidth telecommunications. We always want more bandwidth. The only way you can get more bandwidth is through optics. There is nothing else that comes close. There will always be jobs in telecommunications, in manufacturing, in defense, in medicine, etc... I like to ask people, "What's the most common use of lasers?" Almost no one gets it right. Now I'll ask you, what's the most common use of lasers? If you take all the lasers that have ever been manufactured, what were they manufactured to do? Quickly.

**CP:** The most common?

**MJS:** Yeah.

**CP:** I would say in telecommunications now.

**MJS:** Buzz, wrong answer. That's the most economically significant answer, is in telecommunications. The most common used, the lasers, just the largest numbers of lasers that are built, were built to play rock and roll. You have a laser in your car. I have a laser in my car. It's a laser, it plays music. I mean, nobody ever thought you were going to use lasers to play music. But if you take all those lasers that have been made, add them all together, more were made to play music,



than to do anything else. Fifty years ago, nobody would have guessed that you were going to use lasers to play music. So, we always get it wrong when we try too hard to imagine what the applications would be.

There is one thing I learned in my administrative role as Vice President of Research and Commercialization: there is a difference between discovery and entrepreneurship. There are people that discover things, and there are entrepreneurs that understand needs, and they find technology that will meet those needs. The people that create the technology often don't have the right need.

I'll end this with one of our most successful startup companies. It's a company called Crystal Photonics. They make components for antimatter machines. What? What are you talking about? Come on! But it is true. There's a machine called a PET scan. Do you know what a PET scan is? The P in PET scan? Positron. It's an antimatter electron.

A positron, it's an electron with a positive charge, its antimatter. You make PET scans with that. You use optics to do that. How do you do that? Well if you make a positron by radioactive decay, [beta] decay, it finds an electron and they annihilate each other, producing a pair of gamma rays. To conserve energy, and to conserve momentum, they have to go off in equal, opposite directions. Precisely opposite

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directions. So you ring that with optical crystals that detect these gamma rays. And you use computer science (the computer chips are made by optical lithography) to make an image inside the body. Who would have believed it?

This company was started by Dr. Bruce Chai who we hired at CREOL to grow laser crystals. In order to make PET scans you want to have very short, excited-state lifetimes that determine the resolution. Well, Bruce spent most of his career trying to get laser host crystals to have very long excited-state lifetimes, so he could put energy into the crystals to come out as laser beams. If you understand the crystal physics to make long excited-state lifetimes, you probably understand the crystal physics to make sure short excited-state lifetimes. So, when the need comes for short excited-state lifetime crystals, you've got this science that goes into technology to make it.

It's impossible to predict what jobs will be available. However, I think with 100% certainty you won't go wanting for a job if you have a career in optics and lasers. There will be jobs. The number of those jobs increases all the time, and at every level, starting with technicians. The biggest gripe right now that we hear from industry, we don't have enough optical technicians. We are an undergraduate program in optics and photonics, and every single one of those graduates get hired. They're doing internship before they graduate. The demand for those people are high. Our PhD level students are placed at government labs, universities, companies, some of them start their own companies, and so forth and so on. Don't worry about it. If you're interested in science, pursue it because you're interested in it, then you will have a job. People will hire you, because you're going to have to work so hard to become good at it.

**CP:** I think we're great. I mean we've covered 99% of it. Is there something else you think we haven't covered and you would like to talk about?

**MJS:** I don't know, I've made some notes to try to think about things to talk about. I think I've managed to get most of the things covered.

I think one of the areas that's going to happen, is happening now, that is going to get more and more so, is to have monolithic devices. Where it's on a chip or a laser that is self-

contained. You still have to put some power into it, to get light out. But it has no observable mirrors, or cavities built into the material. We do that with this photothermal refractive glass that we make, that puts the optics in the glass holographically. Dope the glass with a laser impurity, a rare earth or something to give you the wavelength you want. Pulse it with something and out comes the laser light. Even laser spark plugs. Who would have thought about it? There is a reason to believe that you can get the higher efficiency internal combustion engines with laser spark plugs. They can't be very complicated lasers right, to replace the spark plug, and they have to be pretty rugged, because you have to put them where there's an explosion going on. I am confident that these unexpected opportunities will continue to arise.

I'll end with an example of laser application that some friends here at UCF did in anthropology. Anthropology? What would an anthropologist do with a laser? Well this couple, Diane and Arlen Chase spent their career down in Belize, in the jungle, exploring antiquity things. Well, if you go into deep forests you notice there's some sunlight that makes it to the forest floor. Not much, but you see little bits of light there. Now suppose you take a LIDAR system and a modern computer, and a small airplane, and you fly over the jungle, and you record the data. You can subtract off the canopy and see the ground underneath the canopy. From that, you can see fossil remains of pathways and roads that the Incans used, and entrances to tunnels and other caves and things that they perhaps used. You take what was 20 years of archaeology kind of work, and reduce it to 2 hours of flight time. Who would of thought! This is an example of the opportunities that exist as innovators find out about optics. They will drive the need for more optics, and in ways that we in optics don't have a clue about.

**CP:** MJ thank you very much for taking the time to talk to me. I hope your story will help motivate the new generation of photonics students.

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