# LIA TODAY

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## LIA TODAY

The Laser Institute's
Bi-Monthly Newsletter

# REACH OVER 17,000 SUBSCRIBERS IN THE PHOTONICS INDUSTRY

LIA TODAY is a full-color digital newsletter, published six times per year. It includes articles on the latest industry news to keep members and other laser professions current on important issues impacting the laser community.

Distribution includes all subscribed users involved in laser technology - from end-users to system builders and nurses to laser physicists. LIA TODAY readers consist of production managers, supervisors, safety professionals, and researchers, end-users, laser physicians and nurses.

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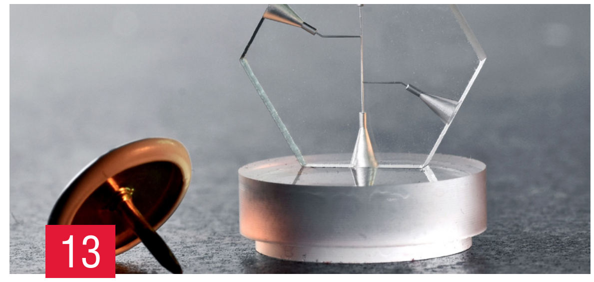

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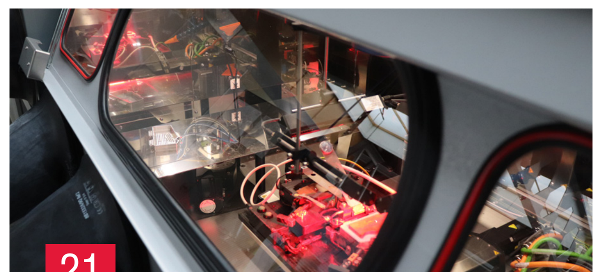
## ULTRA SHORT PULSE LASER 3D MACHINING OF TRANSPARENT MATERIALS USING SELECTIVE LASER-INDUCED ETCHING

By Martin Hermans, Jens Gottmann, Jürgen Ortmann, Ronald Schaeffer

Glass-like materials have always been difficult to work with because of their brittle nature, low heat capacity, and inherent hardness. For machining glasses with high precision and complex geometries, the current accepted method is using Computer Numerical Control (CNC) machines. Selective Laser-Induced Etching (SLE) is a new laser technology for rapid manufacturing of true 3D high precision devices made out of transparent materials.



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## A CASE STUDY IN MOVING FROM YAG TO FIBER LASERS — PYRAMID ENGINEERING & SPI LASERS

By Matthew Wallis

In 2019 SPI Lasers were approached by Pyramid Engineering to supply an evaluation laser for a new welding system being developed for a telecommunications customer. A test was done to investigate the alternative laser sources and processes for their systems, so Pyramid could be sure to offer their customers enhanced levels of speed, productivity and cost effectiveness as well as greater versatility with fiber lasers.

# 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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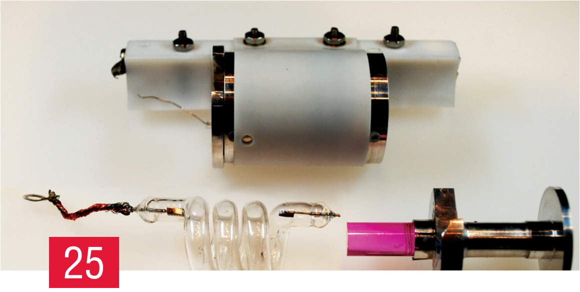
## LASER WELDING —
## A NATURAL FIT WITH INDUSTRY 4.0

By Jason Woolley

As manufacturers embrace the new technological era and begin their strategy assessments, one area they have found success with is bringing digitization to the laser welding process. The success of laser welding depends on the careful consideration of process parameters and its requirements.



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## LASER PIONEERS:
## INTERVIEW WITH DAN HULL

By Chrys Panayiotou

Dan Hull discusses his personal experiences in the early days of the invention of the laser and his journey through the last 60 years of laser history.

The purpose of this series is to help new generations of technicians understand the importance of lasers, optics, and the colleges where they are being taught.



# FEATURES



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|---|---|
| Orlando, FL | Jan. 22 - 24, 2020 |
| Orlando, FL | May 27 - 29, 2020 |
| Orlando, FL | Aug. 19 - 21, 2020 |
| Orlando, FL | Dec. 2 - 4, 2020 |
| **LASER SAFETY OFFICER WITH HAZARD ANALYSIS*** | |
| Orlando, FL | Jan. 27 - 31, 2020 |
| Orlando, FL | Jun. 1 - 5, 2020 |
| Orlando, FL | Aug. 24 - 28, 2020 |
| Orlando, FL | Dec. 7 - 11, 2020 |
| **MEDICAL LASER SAFETY OFFICER TRAINING** | |
| Orlando, FL | Jan. 25 - 26, 2020 |
| Orlando, FL | May 30 - 31, 2020 |
| Orlando, FL | Aug. 22 - 23, 2020 |
| Orlando, FL | Dec. 5 - 6, 2020 |

Visit www.lia.org for all course and event listings

## Course Highlight

### LASER SAFETY OFFICER WITH HAZARD ANALYSIS TRAINING

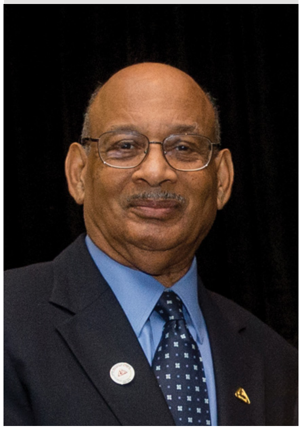
### ORLANDO FL
### MON, 01/27/2020 TO FRI, 01/31/2020

Every Laser Safety Officer has the same goal - to keep the workplace safe from hazards associated with lasers. Whether you are an engineer, laser operator or technician working in an industrial, military, education or research setting, this is a huge responsibility that you take very seriously.

At LIA, we take LSO training very seriously, too. In fact, this is our flagship course and it's designed to train LSOs, safety professionals, engineers, laser operators, and technicians on the leading-edge of safety. If you are required to perform laser hazard analysis, training and the administration of a laser safety program, this course is by far the best training solution for you.

In addition to the working knowledge you will gain, you will earn 4.5 BLS CM Points by the Board of Laser Safety, 36 CECs by AAHP, and eligible for ABIH CM Points.

# EXECUTIVE DIRECTOR'S MESSAGE



Each year at ICALEO, we hold our annual membership meeting. For those who were unable to attend this year's meeting, I would like to provide a few of the highlights and my own reflections.

The annual ballot to elect our officers and new board members was circulated to LIA members and closed on October 5, 2019. I am happy to announce our 2020 officers:

- President Elect | Henrikki Pantsar, TRUMPF Inc.
- Secretary | Islam Salama, Intel Corp.
- Treasurer | Aravinda Kar, UCF CREOL

A list of our 2020 board members will be included in the January/February LIA TODAY. Congratulations to our new officers and board members! Thank you for your constant support of LIA's growth.

In 2019, the efforts of the LIA staff have produced pleasing results, and in 2020 we will continue to move in a positive direction. The revamped Laser Safety Awareness Online Training is being beta-tested and is mobile-friendly. The quality of the LIA TODAY has increased and has transformed into a platform for LIA members to share information with the community. The LIA bylaws are being reviewed for improvements to our Board structure and presidential term limits. Our conferences in 2018 and 2019 brought record attendance of the previous five years. Most importantly, LIA is flying steady.

Among our goals for 2020 are the continued enhancement of our current online laser safety courses and exploration into the development of laser applications courses. At this year's ICALEO, we ran several experiments, which have provided data for improvement. We are also working closely with a new ICALEO steering committee headed by the 2019 LIA President Elect, Gil Haas. This committee consists of recent and past exhibitors as well as LIA Board members, and has already generated important feedback that will be implemented at ICALEO 2020. As a note, the post-conference surveys have been sent out, so I encourage all who attended the conference to submit your feedback as soon as you are able, as our planning for next year is well underway.

During the awards ceremony, I believe the spirit of ICALEO was embodied in the enthusiasm of Dr. William M. Steen, whom we were honored to have present to help confer the inaugural William M. Steen Awards and Theodore H. Maiman Award. At this year's ICALEO, the impact of mentorship was evident; Dr. Lin Li, winner of this year's Schawlow Award, and Dr. Jyoti Mazumder, ICALEO Executive Conference Chair, were both students of Dr. Steen. ICALEO general chair, Dr. Aravinda Kar, was a student of Dr. Mazumder, and Dr. Islam Salama, Microelectronics Track Chair of ICALEO, was a student of Dr. Kar.

As I reflect on the importance of those who have come before us and paved the way, I would like to encourage readers to read this issue's Laser Pioneer's article, which features Dr. Dan Hull, one of the architects of STEM learning for college students. He wrote one of the first theses on Q-Switches Ruby Lasers in 1963 and during his career placed a lot of importance on education in laser applications. Please enjoy the rest of the articles in this issue of LIA TODAY.

**Nat Quick**
Executive Director

ICALEO®

38th INTERNATIONAL CONGRESS ON APPLICATIONS OF LASERS & ELECTRO-OPTICS

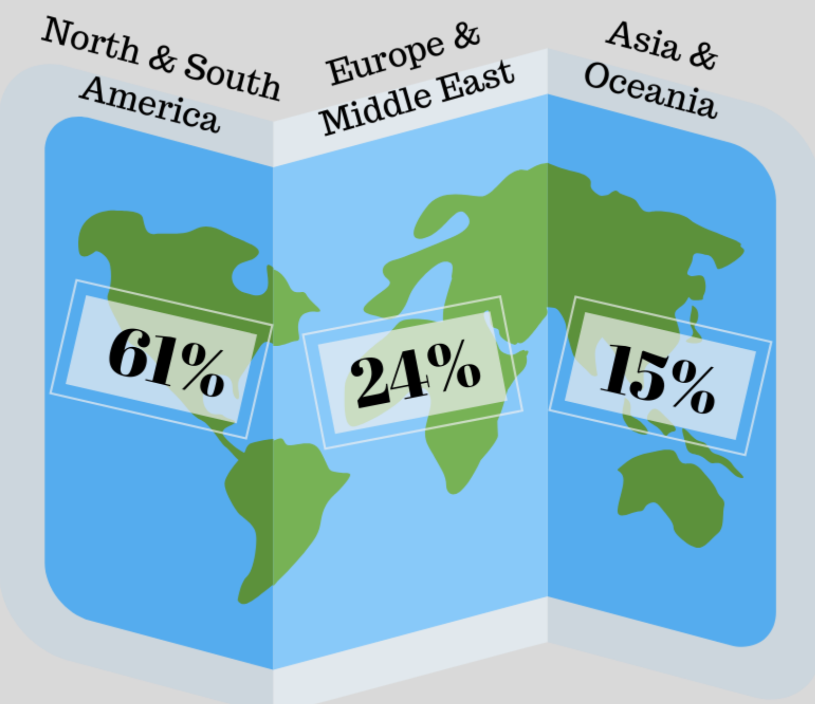
**2019: AT A GLANCE**

# Total Registrations: 471

## BY DAY:

| 428 | 434 | 430 | 416 |
| --- | --- | --- | --- |
| Mon | Tues | Wed | Thur |

## BY REGION:




Companies 252

Exhibitors 45

Presentations 280

# 2019 ICALEO AWARD RECIPIENTS

## 2019 JLA Best Paper Award

**Dr. Christian Weingarten** for his article, *"Laser polishing and laser shape correction of optical glass,"* J. Laser Appl. 29, 011702 (2017).

## 2019 LIA Fellows

**Dr. Markus Kogel**
Hollacher — Precitec — Neu-Isenburg, Germany

**Dr. Islam A. Salama**
Intel — Chandler, Arizona, USA

**Dr. Youping Gao**
Castheon Inc. — Thousand Oaks, California, USA

## 2019 William M. Steen Awards

| | |
| --- | --- |
| **Academic & Public Sector** | : Lawrence Livermore National Laboratory |
| **Aerospace** | : Lincoln Electric |
| **Automotive** | : K-Labs |
| **Defense** | : EOTech |
| **Medical Devices** | : Boston Scientific |
| **Microelectronics** | : Samsung Display |
| **R&D** | : Hitachi |
| **Specialized Manufacturing** | : Boss Laser |

## 2019 Theodore H. Maiman Award

**Samsung Display**

## 2019 Arthur L. Schawlow Recipient

**Dr. Lin Li**, The University Of Manchester - Manchester, United Kingdom

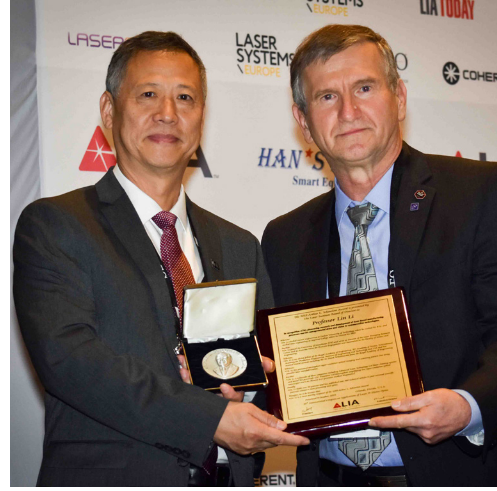
## 2019 Best Poster Awards

**1st Place** : Theresa Jähnig
**2nd Place** : Yusuke Takahashi
**3rd Place** : Monan Liu

## 2019 Student Paper Awards

**1st Place** : Lukas
**2nd Place** : Norbert Ackerl
**3rd Place** : Jannik Lind

# ARTHUR L. SCHAWLOW AWARD WINNER



The Arthur L. Schawlow award, established 1982, is the highest recognition that is given at ICALEO every year to recognize an individual who has made distinguished contributions to applications of lasers for science, industry, or education. This year, it has been awarded to Dr. Lin Li of the University of Manchester for his research and contribution to the evolution of lasers.

Dr. Li accepted the Schawlow award at Wednesday night's Awards Banquet (see pictured Dr. Lin Li, on the left, receiving the award from LIA Past President Dr. Milan Brandt, right). In the interview following, he said "I think this is really a great honor to me to receive the 2019 Schawlow Award. Schawlow was one of the inventors of the laser; I think giving the award in his name really gives scientists and engineers pride to be part of this exciting technology community". Dr. Li, as an LIA Past President and Fellow, has been an important part of this community for many years. The first ICALEO conference he attended was actually in 1986, so he has been watching it grow for over 30 years. When asked about what he believes the future will hold for the laser community, he stated "I would expect in the near future, laser manufacturing technology will claim a contribution to the next industrial revolution and I'm proud to be a part of that".

Dr. Lin Li received his PhD at Imperial College in laser engineering. From 1988 to 1994 he worked at the University of Liverpool as a postdoctoral research associate in high power laser engineering where he studied under Dr. William Steen, who also attended this year's ICALEO conference to distribute a newly introduced award named after him. Following his time with Dr. Steen, Dr. Li joined the University of Manchester (UK), where he currently serves as Director of the Laser Processing Research Centre and as Associate Dean for Business Engagement and Innovation in the Faculty of Science and Engineering. Along with all of these impressive titles, he is also an inventor of the microsphere super-resolution optical nanoscope with a 50 nm resolution, published in Nature Communications in 2011 and reported worldwide including BBC and New York Times. Despite all of these accomplishments, when we asked him in our interview which achievement stood out to him most, he talked about the 60 Ph.D. students and over 30 post doctoral researchers that have graduated from the Laser Processing Research Centre in the last 25 years. "I'm very proud of them for their achievements," he said smiling.

# ICALEO

## 38th International Congress on Applications of Lasers and Electro-Optics










**1** Stan Ream (right) admires Neil Ball's (left) ICALEO '19 t-shirt, designed and sponsored by Directed Light, Inc. *

**2** The President's Welcome Reception was held poolside at the Rosen Centre Hotel so attendees could enjoy the beautiful Florida weather. *

**3** The power duo of Dr. Henrikki Pantsar and Ron Schaeffer reunite once again for another live performance of the Beer's Law Band. *

**4** LIA President Dr. Minlin Zhong (left) and Past President Dr. Milan Brandt (right) welcome the new LIA Fellows, Dr. Markus Kogel-Hollacher (middle left) and Dr. Youping Gao (middle right).

**5** (Left to Right) LIA President Dr. Minlin Zhong, the esteemed Dr. William Steen, and LIA Executive Director Nathanial Quick enjoy a quick photo op at Wednesday's Award Banquet.

**6** LIA Past President David Belforte (right) receiving his president's watch from LIA Executive Director and Past President Dr. Nathaniel Quick (left).

**7** LIA President Dr. Minlin Zhong enjoys a drink with Dr. Bill Steen and Gilbert Haas during the night's Evening of Innovation networking event.

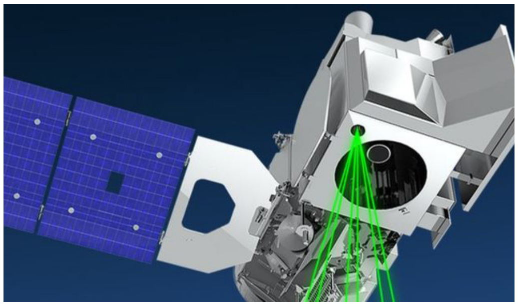
**8** The winners of ICALEO's new William M. Steen Award celebrate with Dr. Bill Steen himself (middle).

**9** Professor Lin Li (podium), this year's Schawlow Award recipient, gives his acceptance speech.

*** Credit: Johannes F. Trbola, Instagram: @delightphotos, Facebook: delight.photo.by.johannes.trbola**

# TRENDING IN THE NEWS:
## LIA'S TOP 4 ARTICLE PICKS

1

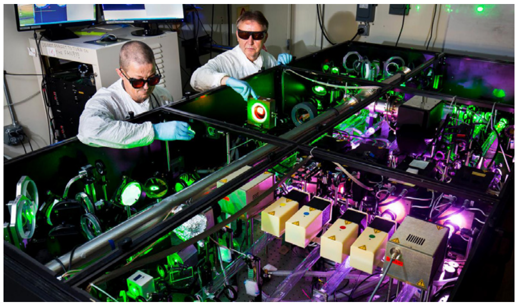


### NASA'S ICESAT SPACE LASER TRACKS WATER DEPTHS FROM ORBIT

The IceSat-2 laser mission has started to map the seafloor around low-lying Pacific islands and atolls, which will assist tsunami preparedness. It is also used to work out the volumes of inland water bodies to help quantify Earth's global freshwater reserves.

Read more

2

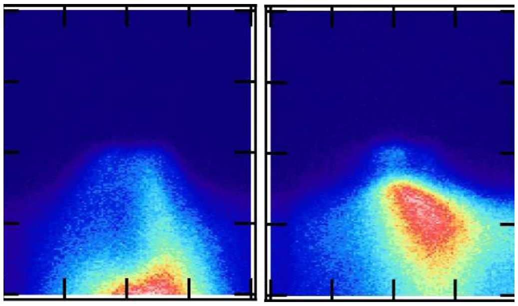


### THE MOST POWERFUL LASER IN THE U.S. IS IN THE WORKS

Zeus, a three-petawatt device (three petawatts is equal to three quadrillion watts) will be built at the University of Michigan. It will be used for basic and applied research like testing a leading theory on how the universe operates at a subatomic level, which could lead to advancements in medicine, materials science, and national security.

Read more

3



### LASER LIGHT COMPELS IRON COMPOUND TO CONDUCT POWER WITHOUT RESISTANCE

Researchers successfully used laser pulses to excite an iron-based compound into a superconducting state at higher temperatures, which means that it conducted electricity without resistance. It is hoped that this kind of research could greatly improve power efficiency in electrical equipment and electronic devices.

Read more

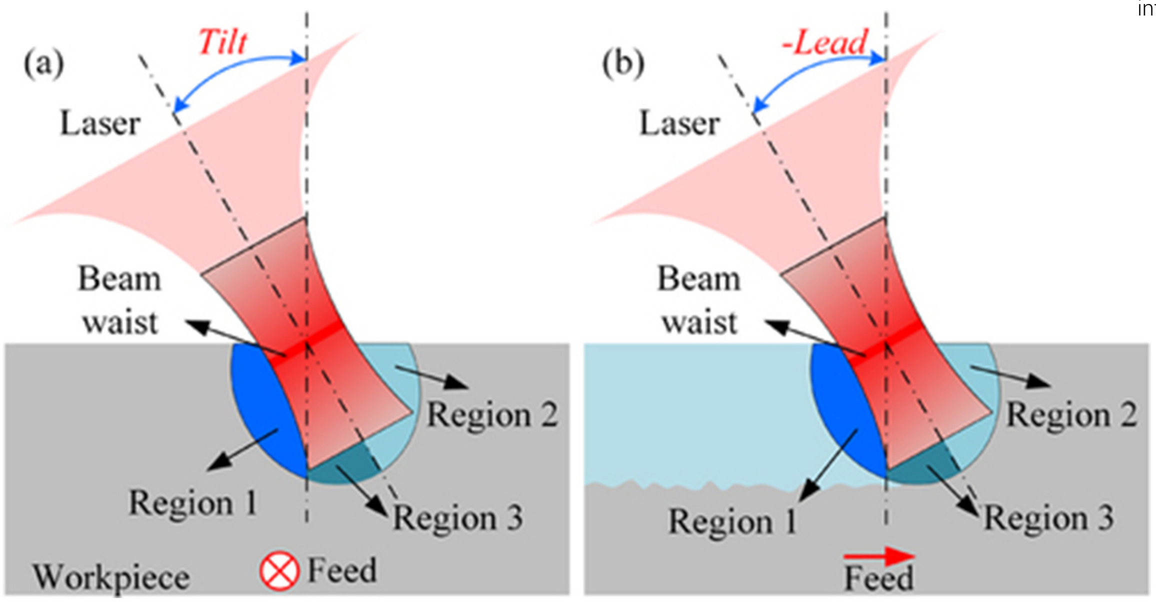
4


### STATE OF THE ART LASER TO BE DEVELOPED FOR DEEP TISSUE ANALYSIS

The "Deep Tissue" project uses a highly-specialized laser that's capable of analyzing potentially deadly diseases and gathers data from biological tissue like skin, bone, and even plant life. Possibly available at a third of the cost of what is available on the market, the tech will "open a host of new research areas including regenerative medicine, leukaemia, and Alzheimer's," says project lead, Dr Richard McCracken.

Read more

Diagram of laser processing for nonzero tilt angle (left) and nonzero lead angle (right), also showing the different laser-matter interaction regions.




# Effects of Laser Beam Lead Angle on Picosecond Laser Processing of Silicon Nitride Ceramics

By: Heng Wang, Xiaoxiao Chen, Wenwu Zhang

**Abstract**: Hard and brittle materials are widely used in aerospace, energy, medical, electronics, and other various fields. Multiaxis laser processing is an advanced technology with good development potential and is the key technology for manufacturing complex components from hard and brittle materials. In this work, the authors report the laser machining of silicon nitride ceramics by a five-axis computerized numerical control picosecond laser machine tool, which they use to investigate how laser-beam machining affects the workpiece surface with a zero lead angle, positive lead angle, and negative lead angle. The machining quality, material-removal rate, and energy distribution characteristics for different lead angles are analyzed. The results show that the machined depth and material-removal rate decrease as the absolute value of the lead angle increases. However, the machined surface becomes smoother as the lead angle increases.

**Journal of Laser Applications 31, 042011 (2019); https://doi.org/10.2351/1.5126920**

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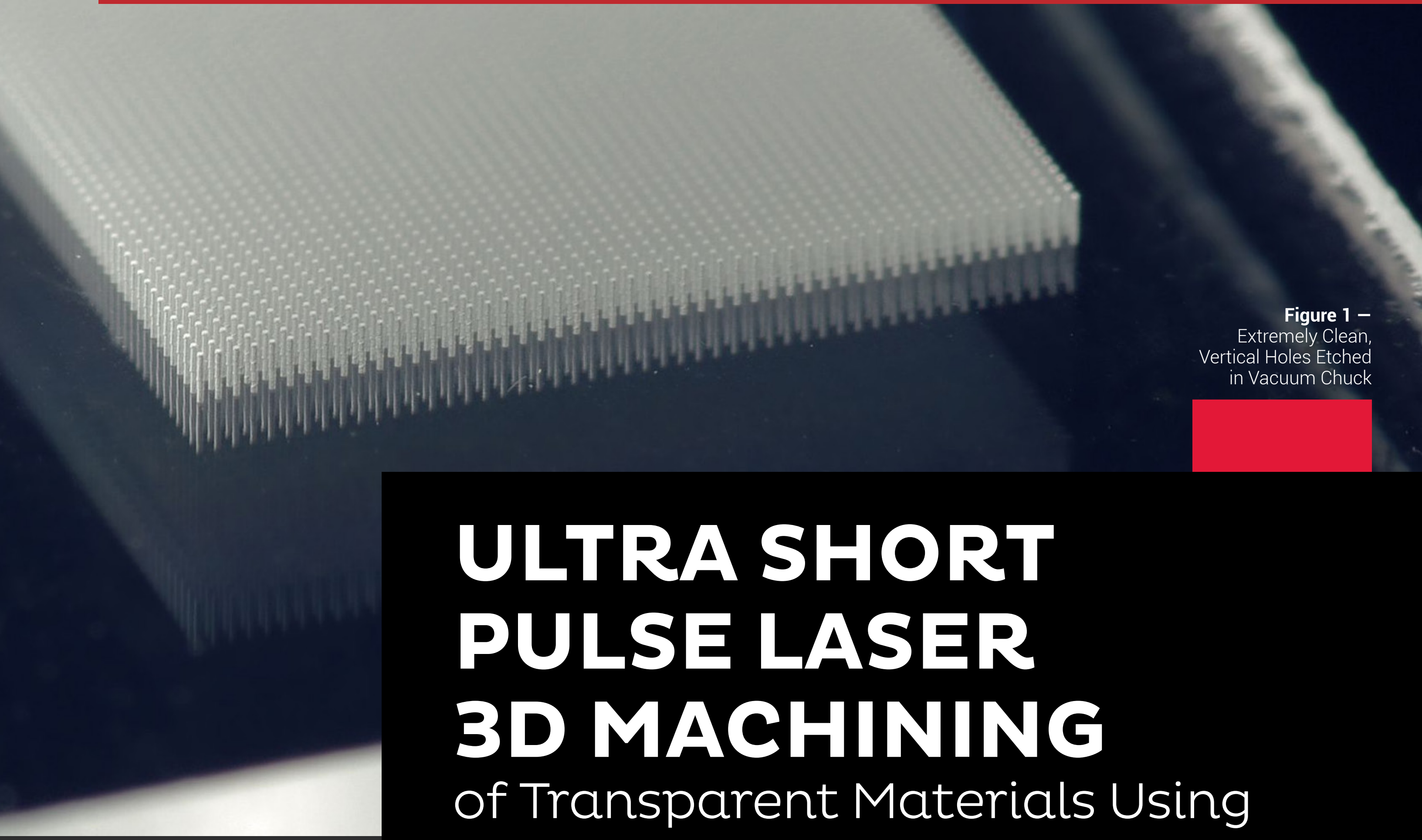


**Figure 1 —** Extremely Clean, Vertical Holes Etched in Vacuum Chuck

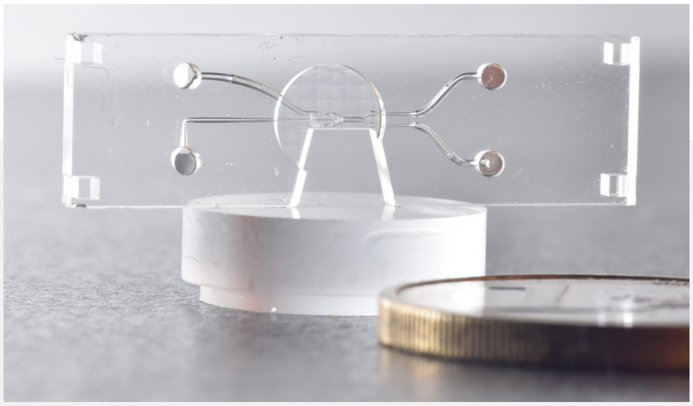
# ULTRA SHORT PULSE LASER 3D MACHINING

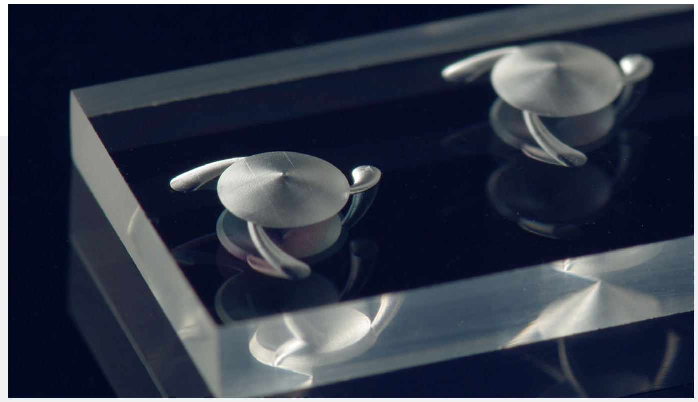
## of Transparent Materials Using Selective Laser-Induced Etching

Glass-like materials have always been difficult to work with because of their brittle nature, low heat capacity, and inherent hardness. For machining glasses with high precision and complex geometries, the current accepted method is using Computer Numerical Control (CNC) machines. CNC machines offer the highest amount of precision, flexibility, and repeatability when it comes to fabricating components beyond basic shapes. CNC machining has been used for manufacturing metal and plastic parts for decades, but is now pushing the boundaries of manufacturing glass and other optical materials. CNC machining can be used to machine a wide range of demanding materials, including ceramics, corundum, tungsten carbide, and even composites.

CNC machining offers numerous advantages over conventional grinding and polishing for fabricating optical components, including: 24/7 operation; the ability to make complex component geometries like bevels, deep holes, counterbores, chamfers, steps, slots, notches, and more; ease of operation and the ability to run several machines at once; and excellent repeatability. The main disadvantage of CNC glass machining is that there are structures that simply cannot be made using traditional machining methods. These include internal structures where the bits cannot reach and also very small structures that are smaller than any current tool bits.

Lasers can extend the range of capabilites of CNC machining and have been doing so for decades. The non-contact aspect as well as the ability to choose specific laser wavelengths and pulse lengths allow for processing a host of brittle transparent materials with smaller geometries, better quality, and in some cases, even faster and cheaper. While IR lasers are used in some applications like dicing, generally UV (excimer and DPSS) and USP (fs and ps) lasers are used in high precision laser based glass micromachining systems.





# SLE- Selective Laser Etching

Selective Laser-Induced Etching (SLE) is a new laser technology for rapid manufacturing of true 3D high precision devices made out of transparent materials like fused silica, ULE, or sapphire for example. With SLE, parts can consist of cavities, tunnels, arbitrary undercuts, and even mounted moving parts.

SLE is a two-step process:

In the first step, USP laser radiation is focused to a micrometer-sized spot into a material that is normally "transparent" to the wavelength of the laser that is used. It is only at the focal point that the laser radiation is absorbed due to non-linear processes occurring at the high intensities that are applied (>10 12 W/cm$^2$). The absorbed energy leads to internal heating and subsequent quenching of the material in a very confined volume, resulting in a permanent modification of the transparent material. This laser modification does not contain micro-cracks and can be applied with extreme precision. Starting at the bottom of the material, the laser dosage is applied line by line and layer by layer until a complete 3D connected volume is exposed inside the glass by scanning of the focus in x/y and z.

In the second process step, the workpiece is taken off the laser machine and placed into an etching bath where only the modified material is dissolved by the fluid etching chemical. The etching starts at the surface and works its way into the workpiece, washing out all the material that has been pre-modified with the laser radiation. This obviously means that there must be a connection of the internal modification to the surface so the etchant can reach the exposed areas. The high precision of the SLE technology is possible because of the high selectivity, where selectivity is the ratio of the etching rates of modified material vs. untreated material. For example, the selectivity in fused silica is greater than 1000:1, resulting in long fine channels with minimal taper coming from one single line of laser irradiation with subsequent etching. Other transparent materials that show elevated selectivity during the SLE process are Borofloat33, Sapphire, ULE, or soda lime glasses for example. High selectivity is the basis for more complex 3D structures. They are produced by simply rastering over a plane on target and moving upward in the z-direction to create a 3D structure.

On a side note, SLE should not be confused with the laser produced 3D pictures in glass that one can find in any souvenir shop. There are similarities in that the structures are otherwise transparent except at the focal point, they are made from the bottom up, and they modify the material. On the other hand, the actual mini-burst created at the

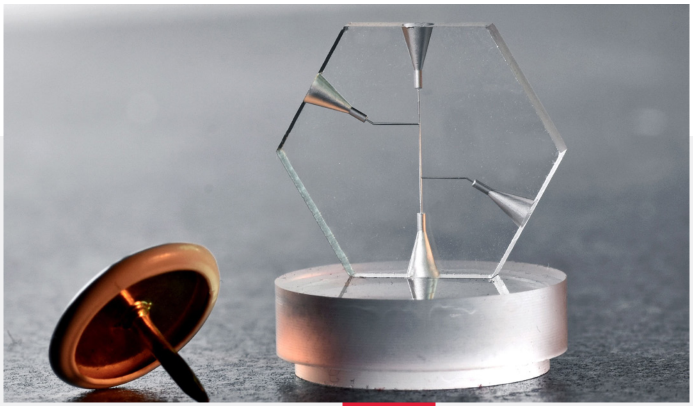


**Figure 2 a, b, c, d –** Various Microfluidic Devices with some Size Comparisons

focal point is the final product and there is no subsequent etching, nor is there a need to link the internal structure to the surface.

The advantages of SLE are the high precision that is possible (+-1µm) with no remaining stresses in the material after etching, as well as the true 3D capability. Due to several analogies to 3D printing the SLE technology can be considered as 3D printing for transparent materials, with the difference being that it works subtractively. Contrary to additive 3D printing, there is no need for supporting structures that have to be removed afterwards. In the SLE process the remaining glass or crystal is unmodified from the original and still has all the original specifications from published data sheets, because only the exposed glass material is removed. This means that the actual resulting devices are made in the unmodified material, so there is no need for new certification of the materials that are already certified for their specific application.

SLE surfaces have an initial roughness on the order of Ra ~200 nm. However, the surfaces do not have the micro cracks or sub-surface defects that can cause failure in the case of mechanical load. This makes applications in the field of flexure bearings possible – in other words the glass can actually move or 'flex' if there are no surface defects to incubate a crack or failure point. Currently, the state of the technology in fused silica (which is the most investigated material so far) is that machining is possible for complex 3D parts less than 7 mm in height, with a precision of about 10 µm and a maximum tunnel length of 10 mm – and these features can be achieved pretty much on the first run from the CAD file. Higher precision, longer tunnel length, and more complexity are feasible, but often require a few iterations of production and measurement before the part fits the precision requirements and matches the CAD data. On the other hand, the process is extremely reproducible, and once the proper conditions have been found it is possible to make continuous identical parts.

So far we have demonstrated that SLE is a manufacturing technology for fused silica parts for various fields of technology and with many different applications. This technology is not only for prototypes, but also for series production of devices and structures, such as: coupling chips for capillary electrophoresis that allow plugging together the capillaries without a detectable dead-volume - to be used in chemical analytics; a light actuated cell sorter for quicker antibiotic resistance tests which can be useful in bio-medical technology and production of food and detergents; new types of 3D nozzles for fuel injection and even inhalers that help with pulmonary diseases; large fields of ultraprecise micro-sized holes -not necessarily circular in shape- can be made in thin glasses or sapphire for semiconductor or electronics applications like thin glass vias (TGVs) or holes in display glasses; and monolithic MEMS devices that can clamp an optical fiber with a flexure bearing or act as a sensor for inertia.

**Figure 3 –**
This Reindeer is about 3 mm high. Not only do his antlers, nostrils and hooves exhibit structure, but his head and legs are also articulated using in-situ etched ball joints.

For example,

characteristics of the SLE process for fused silica are:

- High precision due to large selectivity (about 1400:1 using KOH)
- Very large processing window using ~1 ps, IR pulse lengths results in high process
- stability (The laser can fluctuate as much as 50% without effect)
- Since SLE is subtractive, tunnels and undercuts are possible
- No need for support structures
- Unchanged material left behind – all modifications are washed away
- High precision in 3D without post processing – 1 micron limited by measurement accuracy
- High writing speeds and easy scale up for mass production.

The SLE technology can be scaled up for large quantities. So far, the only known limit in terms of productivity is how fast the focal spot can be moved through the material. Thus, higher productivity can be achieved by accelerating the scan speed. By the design and integration of specialized beam deflection modules that are tailored to the part to be fabricated, an up-scaling is possible and offers the unique possibility of a rapid prototyping technology that can even go all the way to mass production. As such, Light Fab has developed a special 3D Printer with proprietary beam delivery, optimized for moving a small spot rapidly in 3 dimensions, and custom software to not only control the laser and motion, but also to optimize this process.

The 3D Printer includes a proprietary galvo scanner and special optics enabling tight focus by a microscope objective. The software includes 3D CAM with LightFab 3D printer driver and machine software (LightFabScan), which deliver precision and high speed. Most complex 3D precision structures with micron resolution consist of millions of short vectors that must be written to define the structure with sufficient accuracy. Using only translation stages to move the sample results in large accumulated times for acceleration and deceleration, thus the laser is only writing a fraction of the time. Galvo scanners reduce the acceleration time to <0.5 ms compared to 100 ms for a typical stage. Therefore, the stages are only used to index to the next position when making structures bigger than the galvo field (a few mm), resulting in a much faster exposure time. The 3D printer driver, SliceLas LightFab, which is part of the printer package, optimizes the file for the fastest execution of the job. Also, precision is optimized by using bent curves as part of an arc, removing the errors caused by polygons.

On-going developments involve hybrid processes where, for example, 2-photon-polymerized structures are created inside of SLE-fabricated microfluidic channels coming from the same machine. Laser polishing can be applied to surfaces that have been machined with SLE to pave the way for the future production of complex shaped optics (freeform, asphere, axicon). Finally, glass welding is possible and, as an option, software and clamping hardware have been developed by the Light Fab team to allow this to occur on the same SLE platform.

Selective Laser-induced Etching is limited in the materials it can address, it is a two-step process involving wet chemistry, and it requires somewhat expensive laser technology. However, the SLE process is very reproducible, it can be scaled up, the actual writing time is usually short, and – most importantly – it allows the manufacturing of features that are not possible in any other way, opening up the door to new devices and designs.

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# LASER WELDING:
## A Natural Fit with Industry 4.0

By:
Jason Woolley – Key Accounts Laser Group Manager; Abicor Binzel USA

### Industry 4.0 – The Smart Factory Concept

The history of manufacturing production throughout the ages has been consistently redefined by technological revolutions. Starting in the late 1700s with the mechanization of the textile industry and introduction of the steam engine, to the invention of the much appreciated assembly line 150 years later, technology in the manufacturing industry has not only brought an increase in production speed, but also a change in how the workforce interacts with and adapts to the new processes. Shortly after WWII, the third revolution ushered in change with the introduction of computers to the workplace.

Today's workforce is no different, facing yet another technological revolution aptly named Industry 4.0, as it represents the fourth recorded revolution that has occurred in manufacturing. This new industrial revolution, with its cutting-edge digital technologies, will serve as a major disrupter to both production operations and workforce needs.

Where the third revolution introduced the adoption of computers and automation to factories, Industry 4.0 will take this one step further by enhancing those systems with smart and autonomous systems fueled by data and machine learning. While what's happening with this revolution may not seem as severe as in the past, Industry 4.0 is bringing about so much disruption that it may be the most impactful revolution to date.

Perhaps the biggest disrupter in Industry 4.0 lies with the rapidity of change in how computers are connected and communicate with one another to ultimately make decisions without human involvement. This is a result of cyber-physical systems, the Internet of Things (IoT), and the Internet of Systems, allowing the "smart factory" to become a reality. As the factory machines keep getting smarter, they will continue to get access to more data, which will lead to factories becoming more efficient and productive with less scrap. In the end, it's the communicationbetween these machines, digitally connected to one another, creating and sharing information that results in the true power of Industry 4.0.

For a manufacturing plant to truly embrace Industry 4.0, an overall shift toward digital platforms must take place. There are many ways digitization can influence the factory operations. Some of the more common influential technologies and platforms include:

- Advanced automation and robotics
- AI and machine learning
- Cloud computing
- IoT or connected devices
- Smart and real-time data sensors
- 3D printing and digital fabrication mediums Data capture, software analytics, and processing
- Mobile technologies and platforms
- Smart vehicles and transportation
- Real-time data processing and communications

While many industries are exploring the concept of using some of these technologies, manufacturers seem prepared to truly embrace Industry 4.0. Preparing for this change starts with adoption of a strategy that fully addresses the technologies and options available, as well as reviewing the new skills and personnel needed to maintain a smart factory (such as software interface designers, digital innovation managers, data scientists, etc.). There must also be a plan for the purchase and implementation of new tools and software, new data inputs, and training for personnel on all of the above.

### Laser Welding Gets "Smart"

As manufacturers embrace the new technological era and begin their strategy assessments, one area they have found success with is bringing digitization to the laser welding process. The success of laser welding depends on the careful consideration of process parameters and its requirements. The effective laser material processing is often useful to get a theoretical estimation of expected process results. For example, heating sheet metal with a laser beam requires knowledge about the expected rise in temperature of the work piece, as the rise in temperature will affect the weld bead geometry, weld velocity, gas flow rate, work piece hardness, and microstructure.

There are many process parameters at play with laser welding applications and historically, the success has fallen to a knowledgeable factory worker to manually determine and make decisions throughout the process. Thanks in part to the Industry 4.0 revolution, laser welding technologies have gotten smarter, making the weld quality determination process easier.

| Parameter | Historical Process | Modern Technology |
|---|---|---|
| **Laser Power** | There are a lot of factors to consider when determining the power output needed for a laser welding application including material type, material thickness, joint configuration, full- or partial-penetration requirements. The operator must constantly monitor the output for quality consistency. | Today's lasers are sophisticated enough to control the laser power output within a few Watts of what is being requested. Thus, we now have tighter process control within the laser generator itself. |
| **Spot Size** | During the laser welding process, the spot size may fluctuate based on the distance of the optic to the part. When this occurs, the outcome could be a bad quality weld. When a spot size change is suspected, the operator must shut down the line to manually review and adjust to get back on target | In today's laser applications, the optics have autofocus capability. This feature constantly measures the distance from the optic to the part and adjusts the focus distance in order to maintain the same diameter spot on the work piece. |
| **Location** | Manual weld seam lineup of the laser beam to a master part. This method assumes all subsequent parts are placed in exactly the same location. | Seam tracking methods, both tactile and optical, place the beam directly on the joint. This involves real-time tracking either slightly ahead of where the weld is being deposited or at the weld location. |
| **Process Speed** | The operator must program and monitor the speed based on taught points along the weld path. At each of these points, typically determined by the parts geometric shape, the operator must manually adjust the process speed along with laser power and wire feed speed. | Technology has allowed for automatic detection of the changing speed and can automatically adapt the laser power, and wire feed speed accordingly, thus reducing quality issues. |
| **Wire Feed Speed** | Wire feed speed is critical to ensuring that the correct amount of fill is added at the right time. Just as with the process speed above, the operator must adjust the speed based on taught points. | The automatic detection of the process speed can drive the correct wire feed speed in order to ensure good part quality. |
| **Part Gap** | The threshold value of part gap should be within ten percent of the thickness of the thinnest part. This requires the work holding fixtures to contain enough clamps to ensure that the minimum gap is maintained. | Today, gap bridging is possible using laser triangulation. The gap is measured just ahead of the beam and automatically adjusts the laser power, spot size, beam location, and beam oscillation to melt more of the upper sheet to thus fill the varying gap |

## Using Data to Leap Into the Future

With manufacturing of the future relying heavily on data analysis, complicated algorithms, smart, flexible part flow, connected lines and machines, the only thing left is the tool to deliver it. Laser welding was a pioneer in digitization with its fast, flexible, teachable technology. The plant floor is rapidly changing and adapting to make way for these new technologies. No longer will factories rely on mechanical tool stations, but instead will populate the plant floor with programmable laser welding stations. These laser welding stations will be built on data that has the power to communicate with one another and adapt to the various data sets and parameters it encounters.

To stay ahead of the competition, manufacturers are embracing these new technologies to ensure that their products roll off the line in record time, with less scrap. Interconnectivity among welding power sources, software, and the workers makes this possible. Data accessed during the welding process ensures that the decisions are being made real-time, allowing for quick reaction and better output. It involves dynamic power sources, autonomous machines, highly specialized data collection, and storage systems, along with weld monitoring software that is able to feed the information to various platforms, instantly. All of this is integrated to provide the manufacturing worker with a complete picture of the entire welding process.

Industry 4.0 will, in effect, help bring many manufacturing plants into the future providing opportunities for production efficiency. The integrated process monitoring using both camera and sensor will help manufacturers of all sizes leap into the future based on real-time data and technology.

## Paving the Way Forward

Industry 4.0 may still be evolving; however, companies who are already adopting the technologies have realized Industry 4.0's potential, including the opportunity for manufacturers to optimize their operations quickly and efficiently by knowing what needs attention and how to maximize the lessons learned.

When the laser was invented in the sixties, many wondered what possible application we could have for such an invention. Since then, it has proven to be instrumental in applications in various industries around the world. The natural way laser welding aligns with the technologies achieved through Industry 4.0 is just one more example of the flexibility and adaptability of laser welding.

Industry 4.0 is indeed paving the way to the smart factory of the future. As we continue to discover and explore all the advantages this new revolution brings, manufacturers will need to embrace the tools and technologies in order to stay nimble and competitive in this environment.

It is true, we do not know with certainty what additional requirements will emerge with the advancement of the smart factory, but it is clear that laser systems are a great way to embrace whatever lies ahead.

**Figure 1** – The Finished System

A Case Study in

# Moving From YAG to Fiber Lasers

## Pyramid Engineering & SPI Lasers

By: Matthew Wallis, Head of Marketing Communications, SPI Lasers

**In 2019 SPI Lasers were approached by Pyramid Engineering to supply an evaluation laser for a new welding system being developed for a telecommunications customer (Fig 1).**

As a leading designer & integrator of high precision welding systems for the hermetic sealing of metal-can semiconductor and electronic packages, Pyramid were looking to replace their existing flashlamp pumped Nd:YAG laser sources in order to offer their customers enhanced levels of speed, productivity and cost effectiveness as well as greater versatility with fiber lasers.

The systems provided by Pyramid are bespoke, designed to suit a customer's particular requirements incorporating turnkey environmental systems covering gloveboxes, airlocks, vacuum gas-bake ovens, 3-way motion and complete with process control equipment including various levels of automation. In SPI Lasers they found the ideal range of products based on the redPOWER CW range of high power fiber lasers, offering the perfect blend of quality, repeatable laser sources combined with excellent customer service. Something that Pyramid were particularly keen on given how closely they would need to work with their chosen supplier on this initial system build.

## A Challenging Application

The majority of Pyramid's laser welding systems utilise at least one glovebox, which allow for a controlled or conditioned atmosphere, which is particularly challenging for welding applications.

The existing YAG solution used a fixed optical weld path and precise CNC motion-controlled welding table. SPI Lasers' solution was to introduce oscillation welding (a controlled spiral movement of the laser generates the weld pool), which uses a single mode high power laser with a scanner to rapidly move the laser beam to generate the weld pool. The high beam quality and small focused spot size creates a controlled key hole that minimises heat input into the part. The benefits of this process being that the weld depth and width can be controlled independently, and scanner parameters can be adjusted to control the weld shape. Control of the weld pool through oscillation can also greatly reduce weld spatter, resulting in higher quality welds as well as avoiding cracks in the weld.

Pyramid's focus is on delivering their customers the very latest technically advanced equipment, manufactured to the highest possible standards. This is why they were keen to investigate alternative laser sources and processes for their system(s); it quickly became apparent that a fiber laser and the oscillation welding process was indeed more suitable to Pyramid than their existing solution for a number of reasons:

### Oscillation Weld vs Fixed Optic Weld

- 10 x faster welding speed from a fiber laser vs YAG
- Part fit up 3x more forgiving in terms of seam gap and offset
- Independent control of penetration depth and seam width
- Better welds both structurally and visually
- Cost savings from both laser source and beam/part manipulation
- Lower heat input per unit length of weld vs YAG process

### Fiber Laser vs YAG Laser

- 130% wall plug efficiency vs. circa 2% for lamp-pumped YAG
- Cost savings as there are no flash lamps to be replaced
- Maintenance operation is considerably reduced
- Minimal spare part requirements – SPI Lasers utilise ‘Fit & Forget’ technology
- Reduced cooling and chiller requirements
- Substantial reduction in laser footprint
- No requirement for periodic alignment of the laser

## The Evaluation

A test station was created (Fig 2 and 3) and fitted with a redPOWER 2kW single mode laser (M 2 <1.1), with beam delivery optics of a 100mm FL collimator and a 255mm FL scanner objective lens, which generated a 51um (1/e 2 ) focal spot size.

The trial application was to successfully complete a hermetic fillet weld of an aluminium lid (grade 4047) onto a complex aluminium body (grade 6061-T6) which dictated a number of intricate and complex shaped welds.

Argon was used as a shield gas which was fed to the workpiece through 2 delivery tubes seen in the images below; the workpiece was enclosed in a ‘bath‘ to hold the shield gas around the part.

Initial trials proved successful by identifying a range of parameters that could weld these materials with good quality.

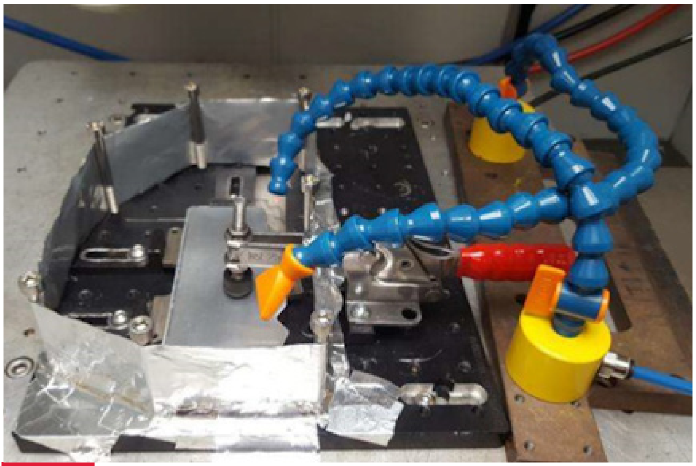

**Figure 2** – SPI Test station with enclosed bath and Argon gas delivery tubes

**Figure 3** – Image to show set up of Laser Glovebox

**Figure 4.1** – Image of welded Package, circular weld path

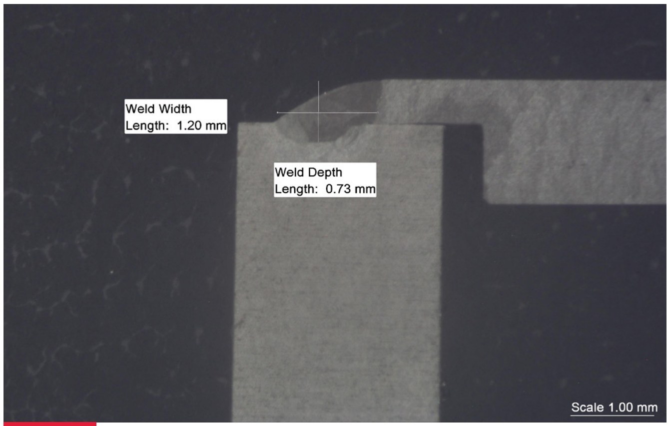


**Figure 4.2** – Image of welded Package, section cut through

The system was designed specifically to manufacture the customer's complex product, ultimately destined for the telecommunications industry. Two critical factors were specified:

1. the weld penetration was to be kept between 0.5mm – 0.75mm

2. minimise heat input due to package containing delicate optical components.

Using the oscillating (wobble) welding head, the weld path and pattern of weld can be configured; using a 50micron spot size the laser beam can be 'wobbled' to a width of 2mm, in a configurable path such as circular, linear or infinity symbol. The pattern was optimised to meet the customers critical factors (Fig 4.1 & 4.2).

Pyramid maintained a high welding speed over the whole of the unusually shaped package as it fitted within the scanner's field of view, meaning that other than the scanner, there were no moving parts. An integrated vision system delivers pre-weld and, where required, post-weld verification.

## Conclusion

The project showed that close cooperation on tackling the challenging requirements resulted in a successful outcome that has delighted the end customer. It has highlighted the significant benefits of using fiber lasers verses Nd:YAG lasers as well as the value of oscillation welding in tailoring weld profiles to meet specific requirements.

If you have a challenging welding problem or are looking for a bespoke manufacturing system for your business and need expert assistance contact Pyramid Engineering or SPI Lasers and start your journey towards enhanced manufacturing productivity today.

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# U.S. Department of Labor Approves **New Respirator Fit Testing Protocols** to Protect Workers from Airborne Contaminants

**WASHINGTON, DC** – The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) today issued a final rule that provides employers with two new fit testing protocols for ensuring that employees' respirators fit properly.

The new protocols are the modified ambient aerosol condensation nuclei counter (CNC) quantitative fit testing protocol for full-facepiece and half-mask elastomeric respirators, and the modified ambient aerosol CNC quantitative fit testing protocol for filtering facepiece respirators. Both protocols are variations of the original OSHA-approved ambient aerosol CNC protocol, but have fewer test exercises, shorter exercise duration, and a more streamlined sampling sequence.

These two quantitative methods add to the four existing in Appendix A of OSHA's Respiratory Protection Standard, which contains mandatory respirator fit-testing protocols that employers must choose from to protect employees from hazardous airborne contaminants. The rule does not require employers in general industries, shipyard employment, and construction to update or replace their current fit testing methods, and does not impose additional costs.

The rule becomes effective September 26, 2019.

Under the Occupational Safety and Health Act of 1970, employers are responsible for providing safe and healthful workplaces for their employees. OSHA's role is to help ensure these conditions for America's working men and women by setting and enforcing standards, and providing training, education and assistance. For more information, visit www.osha.gov.

The mission of the Department of Labor is to foster, promote, and develop the welfare of the wage earners, job seekers, and retirees of the United States; improve working conditions; advance opportunities for profitable employment; and assure work-related benefits and rights.

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# LASER PIONEERS

## Interview with Dan Hull

**July 23, 2019**
**By Chrys Panayiotou, Ed.D.**
**Executive Director and Principal Investigator of LASER-TEC**

### About the Author

Dr. Chrysanthos Panayiotou is the Executive Director and Principal Investigator of LASER-TEC, a National Science Foundation Center of Excellence in Laser and Fiber Optics Education. He is also a professor and chair of the Electronics Engineering Technology Department at Indian River State College, Ft. Pierce, Florida.

Dan Hull received his Master's in Electrical Engineering and wrote one of the first theses on the Q- Switched Ruby Laser in 1963. He started his career by building lasers for Westinghouse Electric in 1962 in Pittsburgh, PA. Afterwards, he worked at Sandia labs in Albuquerque on laser enabled explosive initiators and other related topics. In 1968, Dan started working for the Apollo program through Lockheed and NASA at Houston Space Center. He took part in the development of lasers, tracking systems, and radar systems for the Apollo program. In 1973, he left industry to work on creating laser and optics curricula and programs to support the new growing industry. He spent the last 46 years creating and promoting photonics technicians' programs as the CEO of CORD, and OP-TEC where he served as the executive director until August 2019.

I talked to Dan Hull 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.

The purpose of this series is to help new generations of technicians understand the importance of lasers, optics, and the colleges where they are being taught.

**CP. Dan, thank you very much for the opportunity to do this interview. I know how busy you are and appreciate the time that you are giving us. The purpose of this series is to help the new generation of technicians understand the importance of lasers and optics, and learn more about the photonics technician programs at 2-year colleges.**

**Let's begin by telling us about yourself, when and where you were born, what the state of technology was when you were in high school before you started college studies. Give us a picture of that time.**

DH: I was born in 1937 in Austin TX, and I had some great parents; they were good role models for me. Only one of my parents completed high school but they wanted me to learn as much I could, particularly in school. They understood that it was important to prepare to go to work, to have a job I enjoyed and could be useful in, and to make a strong contribution to our society. They encouraged me all through my schooling (elementary, middle, and high school years) to consider my future and make plans to prepare for it.

I lived within a few miles of the University of Texas. When I was college-age, tuition was very inexpensive; about $25 a semester. My family could not afford for me to have an expensive college experience, so I enrolled at the University of Texas, lived at home, and worked part-time to pay my college and other expenses.

**CP. Was that in Austin Texas?**

DH: Yes.

When I was in elementary school, junior high, high school, and college, I thought about what career I might want to pursue. My family gave me a chemistry set, and I started playing with the chemicals. I enjoyed mixing the chemicals to make them fizz, change color, and/or blow up. I thought that maybe I should become a chemical engineer or consider some other job in chemistry. I knew that engineering was a good career, so I visited a few chemical companies in the nearby area and I decided to enter the University of Texas to study chemical engineering.

After I took freshman chemistry I decided chemistry was not what I wanted as a major.

So, I explored other engineering fields and I talked to some engineers. I decided that I should study electrical engineering. At that time, if you completed a degree in electrical engineering you could work in electrical power production/distribution, or you could go practice electronics. While I was a student at UT, I worked at an electrical power company, so I thought maybe that would be the field for my career.

My courses in science and electrical engineering were not easy for me, but I was good in math and that helped me accomplish the science and engineering topics. Some of my professors were also very encouraging to me. I earned a Bachelor of Science in Electrical Engineering at the University of Texas and graduated in 1960.

There was not much in my science courses about optics, and lasers hadn't been discovered before I graduated. But I was introduced to optics for about two weeks in a sophomore physics course. While I was in college, transistors were introduced into electronics, but there were no lasers yet, and no information about computers; just calculators.

**CP. Did your parents have a technical background?**

DH: No, but they both worked very hard to support our family. My mother was an accomplished seamstress; she sewed clothes for people to earn money. After I entered elementary school, my mother began working in an office. My father worked as a clerk in a drug store. He worked 60 hours a week and performed any task that his employer assigned to him. Both of my parents always worked hard, and encouraged me to do the same.

**CP. How did you find your way into the field of lasers and photonics? Was there a specific instance or event that made you decide to enter this field?**

DH: When I graduated I chose to work with Westinghouse Electric Corporation, because I thought I would be able to work in electrical power. Westinghouse was hiring about 1,500 engineers a year. They would bring in a few hundred of us every three weeks to get orient and preview the different job opportunities. Then we would select four-week work assignments in different locations until we found one that we enjoyed and the particular manager felt was a good fit. I tried a couple of work assignments in electrical power, but the opportunities were not great, so I didn't choose them for permanent employment.

I did have one opportunity for a few weeks in computers and found out that that was not what I wanted to do. I finally decided to work in electronics, and was assigned permanently to the Westinghouse Electronics Defense Center in Baltimore, MD.

In the meantime, Westinghouse had sent me back to school and I was completing a Master's in Electrical Engineering at the University of Pittsburgh. I had finished most of the courses before I moved to Baltimore, and completed the courses I needed at Johns Hopkins University to get my MSEE University of Pittsburgh.

In 1962, while I was working at Westinghouse Defense Electronics, my supervisor met with me one day before lunch and told me about lasers being discovered. He said, "Bell Labs discovered the helium neon laser and Hughes had just built a ruby laser."

Westinghouse was interested in entering this emerging field and wanted me to let them know, after lunch, if I would like to work in laser development. I didn't take long to think about it. It was something new, and seemed like a technology I would enjoy. I wasn't highly enthusiastic about my assignments in electronics, so I said, "why not."

At first, I built a helium neon laser, like the one at Bell Labs. I think it was the second one in the country. It had a long (~1 meter) HeNe tube, and used flat mirrors. It had an output in the near infrared (1.153 microns).

Then we started building a ruby laser. That was shortly after Ted Maiman built the first operational ruby laser at Hughes. We built maybe the second or third. Then we used a short focal length lens to focus the beam and shoot a hole in a razor blade. I was already working in defense electronics and our lab was very close to Washington DC, so we notified the Department of Defense (DOD). When they learned about the potential of lasers for blasting metals like that, they immediately began to fund research and development (R&D) contracts for laser weapons. Westinghouse received some of those contracts directly from DOD, some were from the Wright-Patterson Air Force Base, and others were from the Air Force Special Weapons Lab in Albuquerque, NM. So, I worked with them, particularly in the laser weapons area. We were continually trying to build bigger, better, more powerful lasers.

The U.S. was in a race with the Russians to build powerful lasers for military and defense purposes. Although we worked in a classified facility, some strange, interesting situations occurred. Once, a bogus (published?) article, was discovered in our office that was written by two Russian scientists about a new type of a laser. Westinghouse wanted me to replicate the device, but I couldn't make it last. Later, we found it was a fake article; no such laser ever existed. But we continued to work on ruby lasers and other new ones. I became well-acquainted with Dr. Arthur Guenther, at the Air Force Weapons Lab (AFWL). He was the AFWL Chief Scientist, and I worked with him in laser weapons.

> ***"Another Apollo laser experiment in which I contributed, was creating a corner cube reflector, a prism that the astronauts put on the moon. A laser beam from earth was shot into the prism, and the time for the reflected beam to return was measured."***

In 1963 I finished my Master's degree at the University of Pittsburgh; I wrote my thesis on the analysis of a Q-switched laser cavity, using a spinning reflector. It was the first laser thesis that had been written and it wasn't hard for the faculty members to be interested—and it wasn't hard for me to defend it.

After I received my Masters, I wanted to move closer to home (near Texas). I found an opportunity to work in Albuquerque, with Sandia Corporation, which was part of the Atomic Energy Commission at that time. Sandia was the organization designing thermonuclear weapons, so they conducted R&D on explosive initiators, photosensitive explosives, and other related topics. I was assigned to work on the initiation of explosives with lasers: photo initiation.

I went to work for Sandia in 1964 and I was able to ignite many new explosives using lasers. I worked in that area until 1968, when I was approached by Lockheed Electronics Corporation (LEC), who was the major contractor in NASA's Manned Space Center. LEC hired me to work at NASA in Houston, helping them to develop lasers, tracking systems, and radar systems for the Apollo program.

I left Albuquerque in 1968, and moved to Clear Lake City, TX, at NASA's Manned Space Center, and began working for Lockheed. We lived in El Lago, TX, a neighborhood near NASA where ten or twelve Apollo astronauts also lived. I remember the time when Neil Armstrong landed on the moon, set foot on the surface and made his statement about "... one great step for mankind." I recalled that three weeks earlier I had seen him four houses from where we lived, mowing his grass in the front yard. What a coincidence.

While I was at NASA, working as a manager for LEC, we built a laser tracking system that was mounted on the lunar rover vehicle. It wasn't used in Apollo 11, but they used it in subsequent landings. As the astronauts rode around and picked up rocks and things from the moon, our laser tracker identified the precise location of where those rocks were taken. I also worked on the rendezvous radar, and the landing radar. Those were my experiences in NASA.

**CP. These are great stories! What did you study in school to prepare you for a career in this field?**

DH: Very little, in my undergraduate work. As I mentioned, lasers had not been created yet and I had no idea what engineering specialty I wanted to pursue at that time. I took courses in electronics, which included electrical power supplies and electronic detectors, which are used in lasers. I had several advanced math courses, and also enjoyed many practical lab experiences. I learned how to practice in a lab, how to be independent in labs, lab safety, and how to document processes and findings in the labs. Those were important to me.

When I started working in lasers while I was at Westinghouse in 1962 I didn't have any education or experience in this new field. However, in the previous year, while I was studying at the University of Pittsburg in graduate school, I took a course in quantum mechanics, so I knew enough to learn about quantum electronics; I just needed a lot more. When I studied at Johns Hopkins University in Baltimore, I took a course in physical optics, using a book in classical optics by John Strong. I took that course as well as other courses through support from Westinghouse. I also read reports and new books on optics and lasers. That's how I had to prepare for a career in this field.

**CP. What areas of science were most important to you in your career?**

DH: Well for the career I had in lasers, I think physics was most important, but all science and engineering courses that included lab experiences were useful. That's what helped me, not only in my undergraduate programs, but also quantum mechanics, when I was in graduate school.

**CP. Tell us about the state of the laser industry and education in the decade of 1960 through 74, when you worked in laser R&D, plus the Apollo program**.

DH: Of course, lasers were just discovered in the early 1960s. It happened while I was working in one of the very earliest laser teams in the country.

We were small groups throughout the country. Hughes, as well as some other organizations, had people working in lasers, and the military also had laser labs, but lasers were in a developmental stage mainly. In research and development, we were searching for new materials and high-powered lasers. We kept thinking; we're going to build a laser powerful enough to shoot down a rocket. At that point in time I thought the best way to get rid of the rocket was to throw the laser at it.

Throughout the 1960s to 1970, while I was working in the Apollo program at NASA, lasers were in an R&D, and useful applications gradually developed in fields such as medicine. One of the earliest applications was removing tattoos. After that came the use of the laser to correct eye abnormalities. There was interest and certainly some exploration in lasers to cut metals, drill holes, and weld. Laser applications in materials processing emerged in the late 60s and early 70s.


Another Apollo laser experiment in which I contributed, was creating a corner cube reflector, a prism that the astronauts put on the moon. A laser beam from earth was shot into the prism, and the time for the reflected beam to return was measured. This time, compared to the speed of light, was used to calculate the round-trip distance from the earth to the moon.

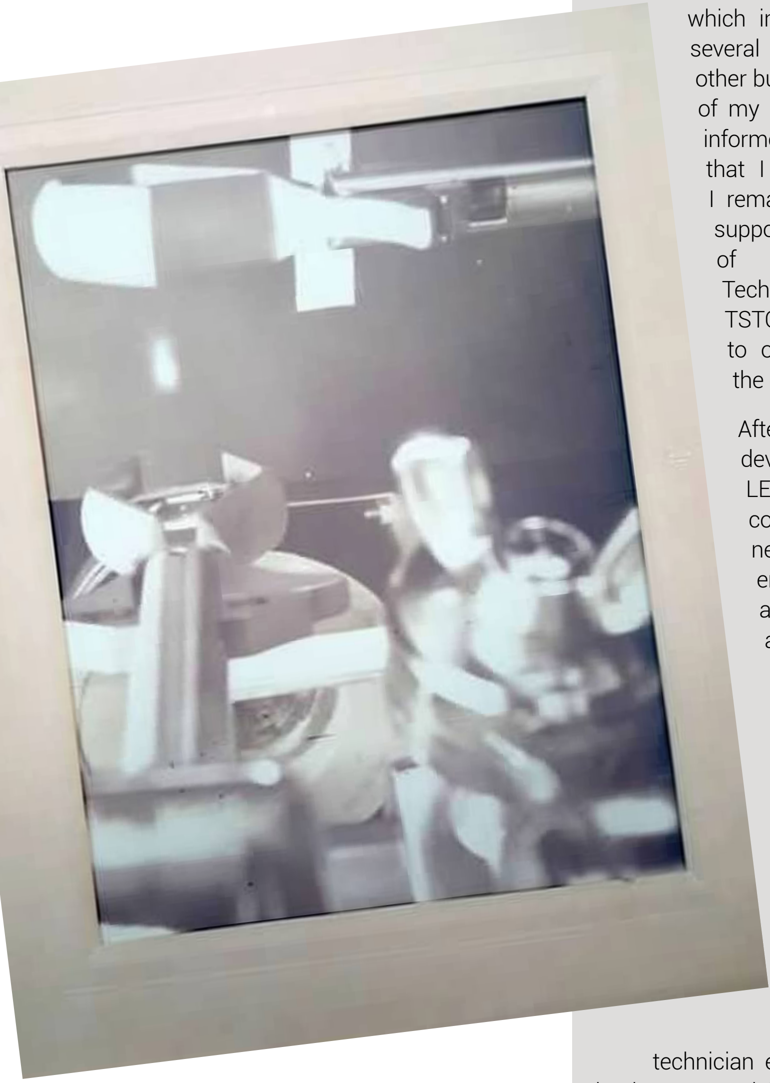
**CP. Describe why you left R&D and NASA and entered technician is education in 1974 until 2004, and during the same time you created CORD and you were the CEO.**

> ***"After I began the laser technician education leadership work for TERC, I became very excited about what I was doing and I decided not to return to NASA"***

DH: Mostly scientists and engineers were working in labs during the period of early laser R&D (early 1960's – early 1970's). We were learning about lasers during this early period of discovery and development. We were understanding about this new phenomenon, mostly from our lab experiences. In the early 1970's, useful applications of lasers began to emerge, which created a demand for more hands-on workers; the need for laser technicians was evident. Most of the technicians that were available had been educated and trained in electronics, but they needed new understanding and experience with lasers, optical devices, and related equipment.

While I was working at Sandia, I was assigned a technician who was incredibly capable. He could accomplish almost any assignment in the labs. I could design and begin to develop laser and optical equipment, which included electronics, but I couldn't make the equipment function properly. I could analyze the performance of the equipment and systems, but the technician could make the hardware work. My technician wasn't just a person that knew about tools and test equipment; he also had a solid math and / science background and could understand the operation and trouble-shooting of electronic equipment. He knew how to put devices and equipment together and how to make them work—and he knew how to learn about new tools, equipment and phenomena. I greatly appreciated the vital role of laser technicians because of this technician that worked for me.

When the need for laser technicians became apparent in the late 60s early 70s, I became part of a federally-funded initiative by serving on the project's national advisory committee. To stimulate the development of laser technicians, the U.S. Department of Education funded a major grant to a non-profit organization called Technical Education Research Center (TERC). TERC was based in Cambridge, Massachusetts, but they established an office in Waco, Texas, where the first two-year laser technician program was being conceived and developed at Texas State Technical College (TSTC).



I served on TERC's National Advisory Committee for Laser Technician Education in two-year colleges for over four years. As the initiative expanded TERC needed an experienced laser engineer to lead their staff, and they encouraged me to accept this position, to develop curricula and teaching materials for this project. In 1974, I took a leave of absence from my work at NASA so that I could move to Waco and complete this work.

After I began the laser technician education leadership work for TERC, I became very excited about what I was doing and I decided not to return to NASA. The TERC office in Waco grew, and became "TERC-SW", with a dedicated advisory board, which included Dr. Art Guenther, several laser industry reps, and other business people. At the end of my year's leave of absence I informed my former employer that I would not be returning. I remained at TERC where we supported the development of the Laser/Electro-Optic Technology (LEOT) program at TSTC, and began to reach out to other colleges throughout the country.

After supporting the development of 10-12 LEOT programs across the country, I discovered that we needed technicians in other emerging technical fields as well. I began looking at the broad need for technician education in the U.S. and how to support two-year colleges to educate technicians in advanced technologies. I also learned that high school students who were uniquely qualified to become technicians were not being recognized or encouraged to continue their education/training, because they were not identified as highly capable in science or math.

I learned that most high school students who were potential technicians were not ranked in the top quarter in their high school math and science classes because they were not abstract learners; they were applied learners

who were capable of learning math and science if these subjects were taught in the context of how they were used.

I developed a strong passion to help these people—and also to create courses and programs for two-year colleges to prepare technicians in many emerging technical areas. At TERC- SW we developed programs and teaching materials for nuclear technicians, electrical power plant technicians, and electromechanical technicians.

***"I began looking at the broad need for technician education in the U.S. and how to support two-year colleges to educate technicians in advanced technologies."***

As this area of educational R&D grew in the TERC-SW office, I (and my advisory board) realized that we were expanding beyond TERC's mission. With the encouragement of TERC and my TERC-SW Advisory Board, I formed a new nonprofit organization, the Center for Occupational Research and Development (CORD) in 1979. I served as CORD's President and CEO until 2006.

CORD's mission was to conduct research and development for secondary and post-secondary Career and Technical Education (CTE). Prior to that time CTE was called vocational education, but vocational education had become a "high school dumping ground" to train under-achieving students for short-term craft jobs, such as welding, machining etc. CORD's mission was to enable these "neglected students" to

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learn academics "in context" and prepare to enter associate degree programs in career-focused disciplines—particularly in many engineering technology fields.

The Department of Education encouraged us to design and develop applied learning courses for teaching mathematics and science to these students in high school that were mostly in the middle quartiles of their class. We developed what we called the applied academics: Applied Mathematics, Applied Biology and Chemistry, and Principles of Technology (applied physics). In 1981, the State Directors of Career and Technical Education provided CORD over $7 million to develop and test student texts (w/labs) and teacher resources to support these applied academics courses, for high schools to use in all 50 states.

In the next decade, CORD printed and distributed these materials to the states, totaling up to $11 million a year. CORD also established and operated an Applied Academics Teaching Center (with labs) where we taught over 2000 teachers that came to Waco, TX to learn how to teach mathematics and science and applications. From 1985-2006, CORD also developed curricula and teaching materials for technician education in other emerging fields.

I collaborated with my friend, the president of the American Association Community Colleges, named Dale Parnell. We focused on what he called the Neglected Majority of high school students who are the applied learners. Our efforts developed into a national movement called Tech Prep. While I was at CORD, I formed the National Tech Prep Network, which included teachers, administrators, and state education departments from the country. By 1999, Tech Prep transitioned and the idea of career pathways was emerging. To lead this effort, I wrote 7 books on Tech Prep, Career Pathways, technician education (STEM), the neglected majority and applied academics. In the early 2000s, after I wrote the 1st book on career pathways, CORD formed the National Career Pathways Network (NTPN). I continued that work with CORD until 2006 when I began to consider retiring or moving toward ward.

*"I learned that most high school students who were potential technicians were not ranked in the top quarter in their high school math and science classes because they were not abstract learners;"*

**CP. Describe the NSF/ ATE Funded National Center for Optics and Photonics Education Center and its work to support technician education.**

DH: In the early 2000s, from 1998 to 2005, CORD had several grants from the National Science Foundation to help us develop new teaching materials for laser technicians. I learned about the Advanced Technological Education section of the National Science Foundation that ATE had. Before I retired from CORD as the CEO, I applied for a grant to establish a national photonics technician center. The grant was initially funded in 2006 through CORD, and I became the principal investigator, where I served as executive director of the National Center for Optics and Photonics Education (OP-TEC). Within a few years, the OP-TEC grant was transferred to the University of Central Florida. I was PI/ executive director of the NSF/ ATE grants for OP-TEC through August 2019, supporting colleges and developing over 1000 pages of teaching materials to help colleges educate photonic system technicians and precision optics technicians. We supported the creation, the restoration


and the improvement of 36 colleges that teach photonic systems technicians and precision optics technicians.

We also assisted two colleges that were outstanding in their development to form regional photonic centers, so that we could expand the work through more NSF/ATE grants to support photonics technician education.

**CP. What advice would you give to a student entering college who is unsure what to study? Include those who would prefer technician education as opposed to science or engineering.**

DH: I've had an opportunity to talk about this to my children and grandchildren, as well as many of their friends. I've also talked to a lot of others, including at some of the schools my children and grandchildren attended. I've offered several suggestions:

If students have an interest in science and technology, and if they have demonstrated competence in math, they should consider a career in engineering or physics.

If they are interested in science and technology, but they struggled with abstract math, calculus, and things like that, there are still great opportunities for them. I suggest they consider going to a 2-year college to prepare for careers in laser or optics technicians.

> ***"I wrote 7 books on Tech Prep, Career Pathways, technician education (STEM), the neglected majority and applied academics."***

**CP. What, in your opinion, are the educational opportunities and keys to success for someone starting a technician career in the laser and photonics industry today?**

DH: The U.S. demand for technicians working in lasers and optics and fiber optics is extremely high. Starting salaries are relatively high and opportunities for career advancement are abundant.

OP-TEC staff and consultants have conducted extensive needs studies with photonics employers; we've asked them what they want these people to know. We developed national skill standards in these various areas. In the needs assessment studies, we've found that during the last 8 to 10 years we were needing 600 to 800 new technicians a year. The demand is continuing to grow.

When OP-TEC was formed 13 years ago, the colleges were producing about 150 technicians a year. As the number of colleges grew and enrollments increased, the number of new photonics technicians has grown to about 500, but we're still not meeting the demand. The demand now is much greater than 800. The U.S. two-year colleges, that are educating students with AAS degrees in these technician areas, are seeing their completers receive 3-5 job offers, with starting salaries ranging from $50k to $65k per year.

I think it's also important for students considering a career as a photonics technician to understand that they could not only be building new lasers, but they could also be working in assignments where lasers are applied. They need to explore the incredibly broad applications of photonics in manufacturing and materials processing, defense, medical equipment, fiber-optics communications, displays, energy, metrology, entertainment, etc. Opportunities for successful and rewarding careers in this field are abundant.

Now we do have a laser that can shoot down a rocket, and it can be shot it down in less than a minute. I didn't develop that laser but there's a lot of videos about it on line.

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