LIA TODAY

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LIA 50 YEARS 1968–2018

3D rendering of light dispertion through a prism [Image Credit: ktsdesign/Adobe Stock]

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LIA™ 50 YEARS

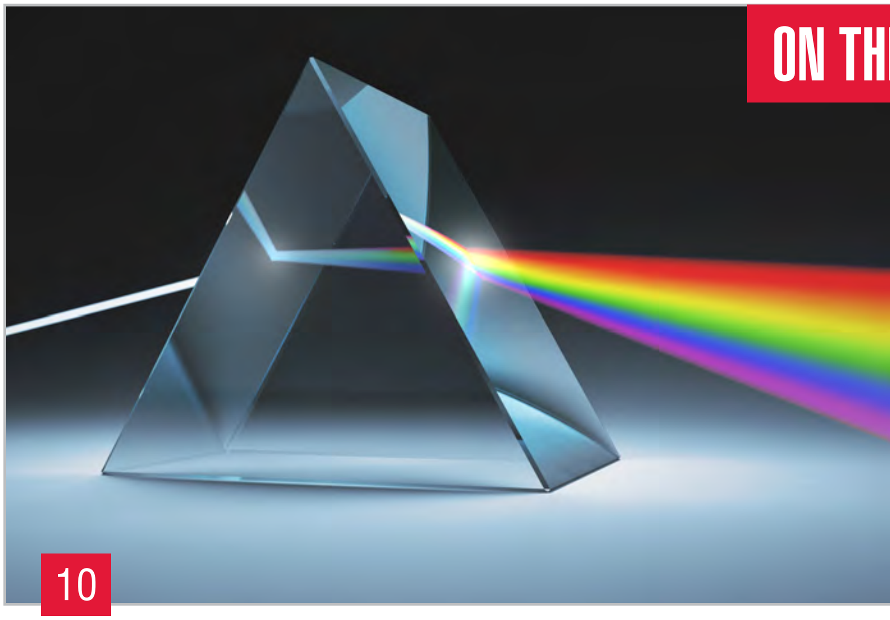

XVT™ Technology
OK
Reset
See in
FULL
COLOR.
Optical Density (index)
0
1
2
3
4
5
6
7
380
480
580
680
780
880
980
1080
1180
Wavelength (nm)

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.

ON THE COVER: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3D rendering of light dispertion through a prism [Image Credit: ktsdesign/Adobe Stock]

FULLY TUNABLE WAVELENGTHS: THE FINAL FRONTIER?

Laser systems have come a long way over the past 60 years, but we still have yet to see a fully tunable laser for industrial use. Is this the final frontier? Ron Schaeffer weighs in.


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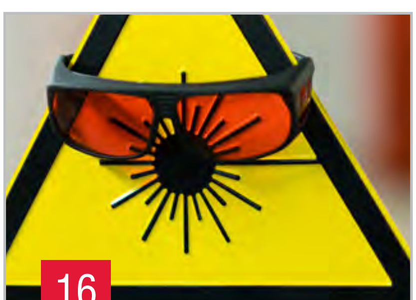
Ct scan of the human brain tile [Image Credit: Sved Oliver/ Adobe Stock]

KILLING CANCER AT THE SPEED OF LIGHT: LASER INTERSTITIAL THERMAL THERAPY (LITT)

According to the National Cancer Institute, cancer is among the leading causes of death worldwide. Learn how Laser Interstitial Thermal Therapy (LITT) is being used to help fight cancer in part one of this three part mini-series on lasers in cancer treatment.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Laser safety glasses on an area warning sign [Image credit: Fokussiert / Adobe Stock]

SAFETY WITH TUNABLE LASERS: THINGS TO LOOK OUT FOR (NOT THINGS TO LOOK INTO)

As technology advances, safety professionals must also keep pace with it. Handling multiple wavelengths in a single location presents a unique challenge to laser safety officers, whether there are multiple lasers, or a single tunable laser. Laser safety professionals Jamie King and Dr. Mike Woods share thoughts on the safety challenges presented by multiple wavelengths.

FOLLOW US!

Be sure to follow LIA on social media for updates and event information.

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What's New at LIA?

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Message
Today 9:13 AM

C

Conferences Dept.

ICALEO registration is open! We're using a new service that makes the process much smoother for attendees. If you're a presenter or session chair, don't forget to register by September 7!

Oh, and we're now taking abstracts for ILSC 2019! The deadline is October 4, 2018, so get your papers in!

We are very excited to announce the release of the revised American National Standard Z136.3 - 2018. You can read the press release on page 20. :-)

S

Standards Dev.

M

Membership Dept.

LIA members can now download a digital copy of their membership certificate right from their profile. All you have to do is log in to your LIA account.

+ Join the discussion! Send

UPCOMING LIA Conferences

INDUSTRIAL LASER CONFERENCE 2018

SEPTEMBER 12, 2018
CHICAGO, IL

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Laser Safety Officer with Hazard Analysis*	
Kansas City, MO	Sept. 17-21, 2018
Orlando, FL	Oct. 15-19, 2018
San Antonio, TX	Nov. 5-9, 2018
** BLS Certified Laser Safety Officer Exam offered after the course.*	
Industrial Laser Safety Officer Training	
Novi, MI	Nov. 14-15, 2018
Medical Laser Safety Officer Training*	
Kansas City, MO	Sept. 15-16, 2018
Orlando, FL	Oct. 13-14, 2018
San Antonio, TX	Nov. 3-4, 2018
** BLS Certified Medical Laser Safety Officer Exam after the course.*	

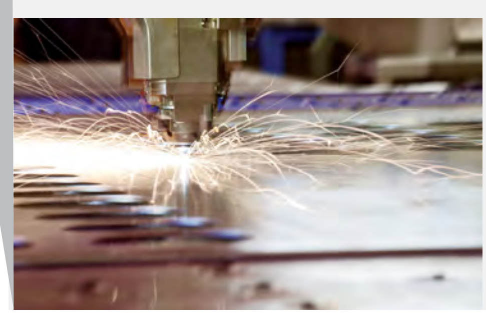
Visit www.lia.org for all course and event listings

COURSE HIGHLIGHT

LSO WITH HAZARD ANALYSIS

Hosted in **Kansas City, MO**, this course takes a mathematical approach to laser safety, designed to teach LSOs administrative duties and hazard analysis calculations that will help them develop, implement and maintain laser safety programs while meeting the training requirements as outlined by the ANSI Z136.1 *Safe Use of Lasers* standard and OSHA.

SEPTEMBER 17-21, 2018



President's Message

As I write this message it is only seven weeks until ICALEO 2018, so if you have not registered yet I urge you to do so as soon as possible as this is shaping up to be one of our best ICALEOs. This is especially significant, as we'll also be formally celebrating the 50th year of LIA and laser technology and applications that are the cornerstone of much of what we do as a laser community.

Before highlighting some of the areas and research topics in the Advance Program, I want to report that LIA is moving forward. Your Executive Director and the Board have put in place a range of measures and actions since the beginning of the year which are now demonstrating positive impact on the Association's operation. Our FY2019 budget has been rebuilt from the bottom up for each business unit, and is now a dynamic tool with features that track revenues and expenses to provide alerts when modifications are required. We have developed a new marketing plan. It includes launching a new social media and marketing campaign that is currently in the final stages of planning. This will rebuild our digital footprint and increase our social media presence which is critical to promotion of the Association's activities. Several initiatives have also been launched with regards to refinement of many of our sales verticals. These include membership categories that have been refined and simplified to reduce confusion and increase participation, as well as a new pricing structure for the Z136 series of laser safety standards.

Returning to ICALEO, there are again three conferences: Laser Materials Processing, Laser Microprocessing, Nanomanufacturing, and a Business Forum and Panel Discussion. Christoph Leyens from Fraunhofer IWS Dresden, the General Chair of ICALEO and his conference chairs, Klaus Kleine (Coherent), Friedhelm Dorsch (TRUMPF), Eric Mottay (Amplitude Systemes), Robert Braunschwig (Lasea), Yongfeng Lu (Univ. of Nebraska-Lincoln), Klaus Loeffler (TRUMPF) and Bo Gu (Bos Photonics) have put together a very exciting program. Over 200 papers have been submitted to the ICALEO conferences; 89 of these manuscripts are now going through the second round of the peer review process. Of these submissions those that have been peer reviewed will be featured in the Journal of Laser Applications (JLA). The plenary session titled "Emerging Laser Technologies: a Path to Disruptive Businesses" will feature key industry players, developers and users of laser technology, Islam Salama (Intel Corporation), Jason Eichenholz (Luminar Technologies Inc.) and Milton Chang (Incubic Management LLC). The closing plenary session will feature Andrés Fabian Lasagni (Technical University Dresden), Youping Gao (Castheon), and Eckhard Beyer (Fraunhofer IWS). All in all, this is a great event and opportunity to learn about advances in laser technology and applications while networking with leading global researchers in the field.

Finally, I look forward to seeing and meeting many of you at the President's Reception on Monday, October 15th.

M. Brandt

Milan Brandt
President, LIA

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Executive Director's Message

In this issue of LIA TODAY, we open a conversation about the idea of broadly tunable lasers, and also begin a series on laser treatments of cancer. True, broad, wavelength tunability from the far infrared to extreme ultraviolet does not yet exist; however, the invention of such a laser system has potential benefits for industrial applications. Dr. Ron Schaeffer uses his background in spectroscopy to muse on this concept. While thinking on this subject, the question of how to prepare for the safe use of such a technology naturally arises. How does a Laser Safety Officer (LSO) ensure safety for personnel in the presence of multiple wavelengths? In promoting the advancement of technology, it's also our responsibility to consider how safety must evolve alongside it. Finally, we are beginning a three-part series featuring laser technologies applied to cancer treatments and therapies. In the first of this series, an overview is given of magnetic resonance imagery-guided Laser Interstitial Thermal Therapy (LITT), which can destroy brain tumors that previously have been considered inoperable because of their location. Future articles will focus on other types of laser applications in oncology.

Due to feedback we received about our last issue, LIA is making a greater push to include safety content in this and future issues. We encourage readers to continue to take an active role in improving the LIA TODAY, whether it be through feedback, or submitting content.

The 2018 revision of the American National Standard Z136.3 Safe Use of Lasers in Health Care was released for sale by LIA in early August. This standard covers any interaction of lasers with human and animal tissue and was approved by the American National Standards Institute in May, thanks to the hard work of the ASC Z136 volunteers and our Director of Standards Development, Barbara Sams.

We have two conferences approaching within the coming weeks. On September 12, 2018, we have the Industrial Laser Conference (ILC) which will be located at the International Manufacturing Technology Show (IMTS). We request those of you attending IMTS to also attend ILC. ILC spans topics from selecting applications for laser processing to laser processing research and development support. If you have any questions, please contact the LIA Conference Department.

We are rapidly gearing up for the October 14 launch of ICALEO 2018, celebrating LIA's 50th year. The staff, operating as cross functional teams, is covering all bases to make this an outstanding and unique event. We welcome all members to attend and participate in this 50th year anniversary banquet. Schawlow award winners, fellows and past Presidents are invited to participate in panel interviews and presentations throughout the conference, to discuss recollections of LIA's development and its contributions to the international laser community. We will also have presentations discussing current and future LIA initiatives. These presentations will be grouped by decade. We also appreciate any photos you are willing to share, which will be shown throughout the evening. A new special session titled "Advanced Laser Technologies for Microelectronics and Integrated Circuit Fabrication" has been added to the Laser Microprocessing conference. The complete Advance Program for ICALEO was released in late August and is available for download.

We are excited about your participation at ICALEO 2018. Spread the word and we welcome you to Orlando.

Nat

Nat Quick, Executive Director
Laser Institute of America

LIA EDITORIAL STAFF

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The editors of *LIA TODAY* welcome input from readers. Please submit articles of general interest and letters to the editor by email to: lia@lia.org

FULLY TUNABLE WAVELENGTHS

The Final Frontier?

ABOUT THE AUTHOR

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BY RON SCHAEFFER

In the early 2000's I wrote a monthly column ("Seeing the Light") for a magazine in the printed circuit industry called CircuiTree. In the December 2002 issue I talked about a Holiday Wish List in these words:

Oh, what a dream to have another option (besides excimer lasers) as a UV source. In particular, a UV source with very short pulse length (1 ps or less), high repetition rate (> 50 kHz), high power (> 10 W), low M2 and with a flat top, collimated beam, all in a compact and reliable package.

Maybe I should have dreamed bigger because all of the above are currently available from a number of manufacturers – most of whom are members of LIA. The flat top beam does not currently come from the laser, but it can be introduced pretty easily using external optics. All other specifications have been met or exceeded and notice I did not even introduce cost considerations at that time, thinking that if this laser existed anyone would surely pay a high price for it – but these lasers are not only available, they are coming down in price and are almost commodities at present.

Fast forward to the AKL Conference this past Spring in Aachen, Germany where, as a member of the Press, I had a chance to relate the above story to Prof. Reinhart Poprawe (Past LIA President and ICALEO 2017's Schawlow award winner) and ask him where he thought the next frontier was in lasers. His answer was that the power space and the pulse length space have been pretty well explored, but what has not been really explored is the wavelength space.

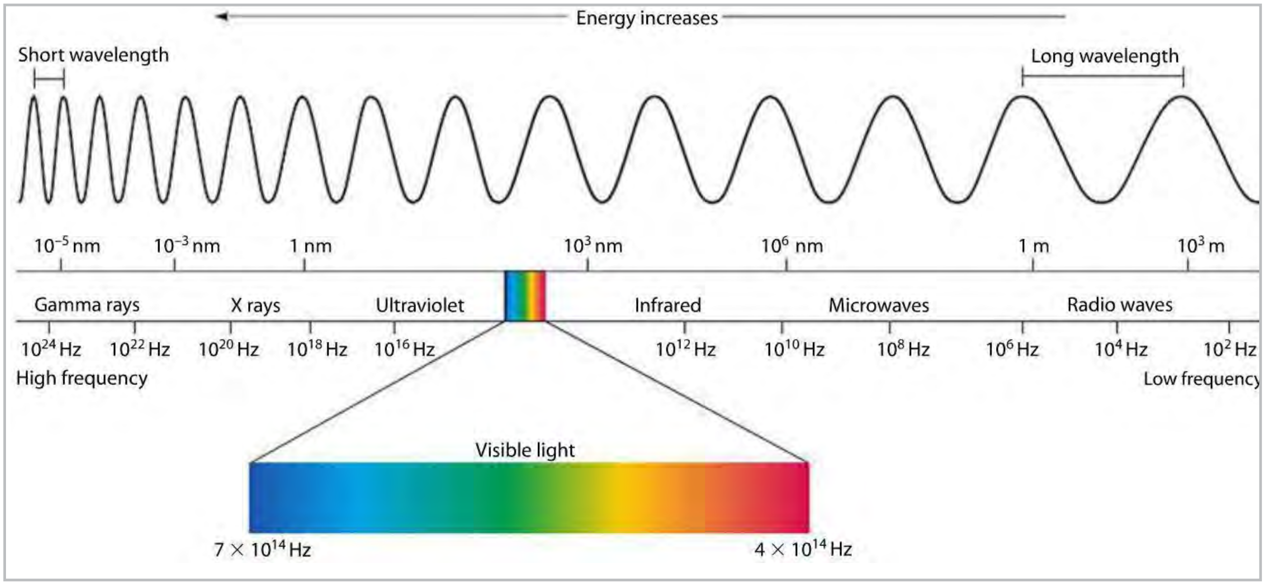
If a single wavelength, tunable source of laser light with sufficient power could be used for materials processing, it would allow the user to dial in to an exact wavelength of light. This would excite only the preferred motions, which might be optimized for the process at hand whether it be welding, drilling, etc. Not only would you be able to excite a single motion to the exclusion of others, but you would also have higher efficiency because the wavelength chosen would have a higher percentage absorption.

So, sixteen years later, I would like to modify my wish list to the following:

Please bring me a laser that :

- Has wavelength tuning capability over at least some range – of course the most beautiful scenario would be a laser continuously tunable from the far IR to the vacuum UV, but let's not get crazy ….
- Short pulse length and variable over at least some finite range – again it would be incredible to have a laser that can tune from 100 fs to cw, but …..
- Power tuning over some large range by controlling both the energy per pulse (non-cw) and the repetition rate
- Low M2 – 1.3 or better
- With a flat top, collimated beam, all in a compact and reliable and affordable package

Figure 1. Electromagnetic Spectrum



WHAT COLOR IS A LASER? WHY WAVELENGTH MATTERS

Figure 1 shows a graph of the electromagnetic spectrum. All these entities are different forms of 'light' including the visible spectrum as we experience it, the UV, IR, microwaves, radio waves, gamma rays, etc. As different forms of light, they have associated wavelengths and frequency, according to the equation:

$$c = \lambda v$$

where c is the speed of light in m/s, lambda (λ) is the wavelength in meters and nu (ν) is the frequency in s^{-1}.

So, what color is a laser? This is determined by its wavelength. Lasers operate from the far infrared (IR) through the visible spectrum and into the deep ultraviolet (UV). The wavelength or color of the laser greatly influences both the absorption in a specific material and also the mechanism by which energy is transferred into that material. These factors affect processing results.

ADDRESSING THE ABSORPTION SPECTRUM WITH TUNABLE WAVELENGTHS

Nature, in its infinite wonder, has conveniently provided for molecules to have energy levels arranged such that the difference in these energy levels is equal to, or at least close to, the photon energy available from many lasers. On the high energy side of the spectrum, UV lasers in principle have enough photon energy to interact with the outer electrons, especially of a pi-electron system. This leads to photochemical bond breaking and ejection of material via a first order bond breaking mechanism. On the low energy side of the spectrum, IR lasers only have enough photon energy to interact with the vibration/rotation energy levels, thereby ejecting material via a thermal mechanism. Another point is that the absorption, when present, is not always 100% at any particular wavelength and indeed, the intensity of absorption varies widely across the spectrum from zero to near 100%. Therefore, while you may get absorption at an available wavelength, it might not be optimized absorption. Using a laser with a precise wavelength output for a particular application instead of using a laser 'close enough' could have serious advantages.

Some materials absorb pretty uniformly across the wavelength spectrum – polyimide is a good example. Other materials absorb well in the IR, but not in the UV (TeflonTM for instance unless you get into the far UV) and vise versa. Since the most important criteria for laser interaction with any material is absorption (intensity), it is important that the 'color' of the laser be chosen so that there is maximum absorption.

Figure 2 shows a low resolution IR absorption spectrum of water using a scale called 'wavenumbers', which is typical in spectroscopy and relates to microns by the equation:

$$\text{Wavelength (microns)} = 10{,}000 / cm^{-1}$$

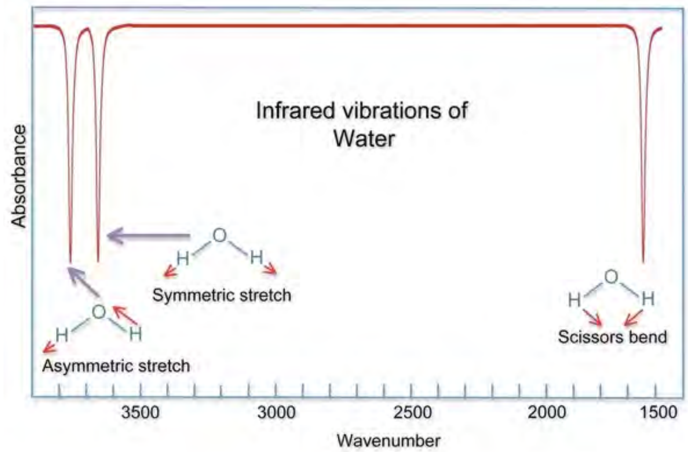


Figure 2. Low Resolution Water Molecule IR Absorption Spectrum

The three primary IR degrees of freedom can be seen at approximately 2.6, 2.7 and 6.4 microns wavelength. In fact, this low resolution spectrum does not show much structure, but Figure 3 shows a higher resolution spectrum showing the vast number of molecular transitions. Every one of these absorption lines corresponds to a precisely defined rotation/vibration of the molecule and these absorptions distort the shape of the molecule from the ground state in different ways. Therefore, having a precisely tunable laser to address all of the spectrum of interest would be of great value.

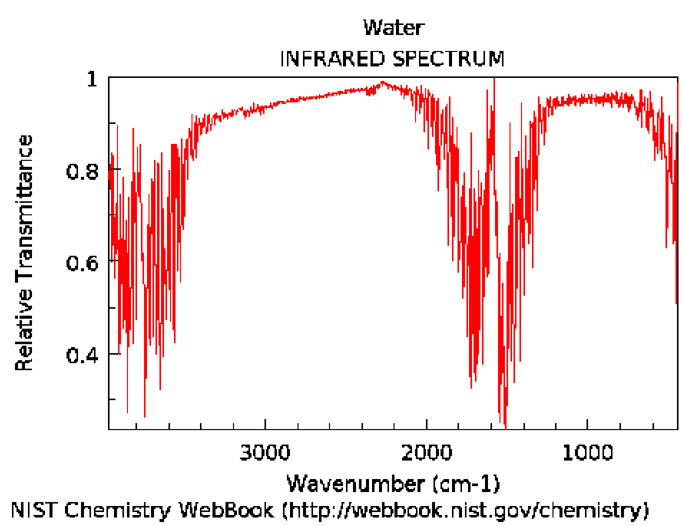


Figure 3. Higher Resolution Water Molecule IR Absorption Spectrum

(Continued on page 12)

DON'T WE ALREADY HAVE TUNABLE LASERS?

Currently, there are ways to get wavelength tunability, but only using dyes or Optical Parametric Oscillators (OPOs) that limit the output power to what's useful only for looking at things (spectroscopy) and not enough power to actually perform work – materials processing. Also, these tunable lasers are currently laboratory tools for the most part and have not been industrialized.

At present, we have lasers that emit at for instance 1 micron (YAG, fiber and others), 2 microns, 10 microns (CO_2), 532 nm (doubled wavelength), 355 nm (tripled), 266 nm (quadrupled) and a few other miscellaneous wavelengths throughout the spectrum.

One laser capable of delivering 'colors' across the spectrum and that can be used to illustrate the point is the Nd:YAG laser (and its derivatives). The fundamental output wavelength is 1.064 microns – in the IR. This wavelength happens to couple very well with most metals and therefore a fundamental YAG laser is a very good choice when processing metals. The majority of applications involving these lasers still use the fundamental frequency which has very high total output power and is a very well known and fairly mature technology. The fundamental wavelength is used in micromachining applications as well as welding, soldering and joining applications because of the first order thermal effects. Joining lasers typically are cw (continuous wave) or at least have very long pulse lengths in addition to the IR wavelength in order to maximize heat input. Machining lasers are typically pulsed in some manner in order to increase the peak power on target.

Because of its fairly short pulse length and high pulse energy, this fundamental output can be focused into a non-linear crystal to give a different wavelength – at exactly twice the frequency of the fundamental, or 532 nm – in the green part of the visible spectrum. The conversion efficiency is not 100% (in fact, usually closer to 50%), so there is a price to pay in total laser output power, but the availability of 'green' photons is very helpful for some applications. First, it couples very well with some metals, notably copper containing compounds. Second, it is very useful for processing thin films on visibly transparent glass or polymers. A notable example is Solar Panel processing of the P2 and P3 scribes. These scribes are made backside, in other words, the laser is focused through the back side of the glass and the material is blown off the 'bottom'. The P1 scribe of the transparent conductive coating (tco) is done using a fundamental laser as the tco is only transparent in the visible spectrum. Then, for increased efficiency, a green laser is focused through both the glass and tco to process the a-Si layer (P2) and the metallic conductor (P3). This is a current example of using two lasers that are basically the same except for the output wavelength to process two different stacked layers on one part.

Frequency tripling gives UV photons at 355 nm wavelength. This is a good all-around UV wavelength that couples well with many materials including metals, ceramics, polymers and other dielectrics. It is reasonably gentle on optics and does not require extraordinary safety precautions. Commercial lasers are available from a couple of Watts up to over 50 W output power with pulse lengths down into the femtoseconds. Frequency quadrupling gives UV photons at 266 nm. This wavelength couples even better than 355 nm with almost all materials, but they are commercially available with only a few Watts power output and the optics (external to the laser as well as internally) degrade faster than 355 nm optics. In general these lasers, if available, are only available with nanosecond pulse lengths.

By using well known and understood conversion methods, one can get 4 different wavelengths from one laser – with the caveat that total output power goes down about 50% with each conversion step. However, while the above example shows how one laser can be used to get many different wavelengths, it is not a continuous change of wavelength, so in practice you use the wavelength that is 'close' to the maximum absorptions of the molecules of interest.

WHEN WILL WE HAVE A FULLY TUNABLE LASER?

Tunable wavelength lasers have been available almost since the invention of the laser itself; but, like fiber lasers in the early years , they are in general only capable of emitting lower power output without using complicated and expensive amplifiers. The bio-sciences in particular make use of tunable wavelength lasers when analyzing or manipulating things like cells. However, not a lot of effort has been put into manufacturing such a laser for industrial applications, I think primarily because the Risk/Reward equation has not been satisfied. For instance, manufacturers could clearly see that higher power and shorter pulse length lasers could open new markets immediately, whereas there may be some concern on whether the effort required to deliver a fully tunable, high power (potentially also short pulse length) laser would have immediate payback. This is especially true because there already exist lasers (e.g., Nd:YAG, 1064 nm, Nd:YAG 532 nm-frequency doubled, Nd:YAG 355 nm –frequency tripled, Nd: YAG 266 nm –frequency quadrupled) that cover the wavelength space from IR to UV, just not continuously. I am not aware of much research that has been done in the field concerning how wavelength tuning might benefit materials processing, or if the benefits would be global or only useful for certain specific applications. My feeling is that existing lasers are 'good enough' for most currently foreseen applications, but may not be useful or optimized for some specific applications. Processing control of composite, heterogeneous, nano and organic material structures as well materials designed for specific electrical, magnetic photonic and even quantum properties, may benefit since a precise wavelength that fully optimizes critical processing parameters, such as absorption, can be accurately set.

I would be very happy to hear from anyone who has ideas or thoughts about wavelength tuning for industrial applications. Is this really the Final Frontier? Is this Frontier being explored by any of our readers? Are there any thoughts about specific applications where wavelength tuning might really help an industrial application? If this is an area of interest, what needs to happen next? Again, like fiber lasers in the early years, There are a lot of unanswered questions. Perhaps, like fiber lasers, once higher powers are available new applications will blossom and a whole new market space will emerge. Of course, the ultimate may be a tunable, high power fiber laser!

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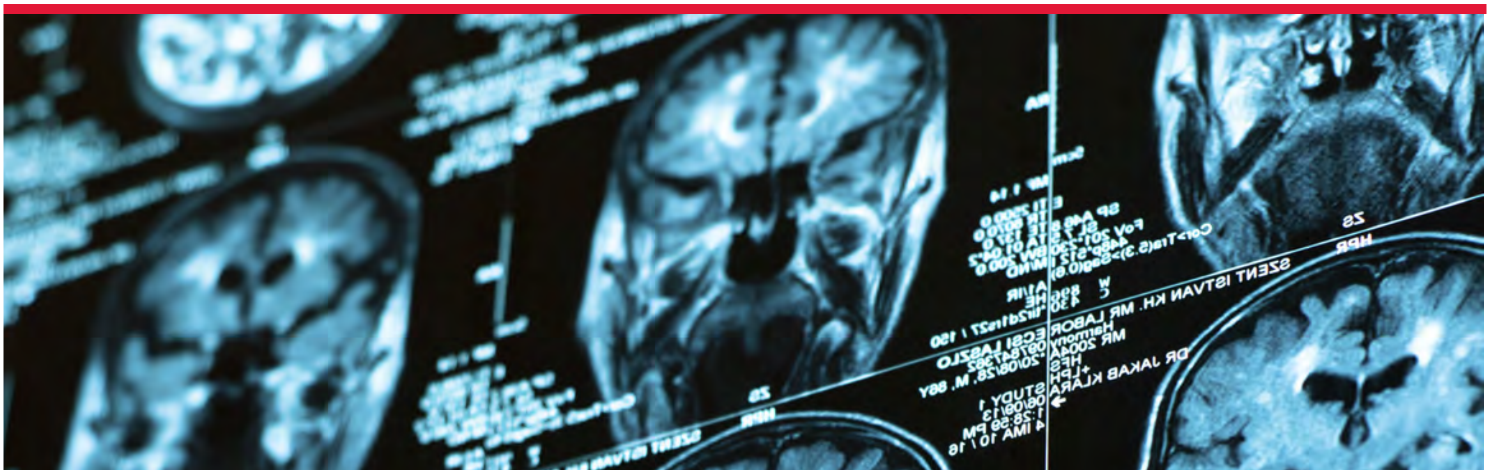
Killing Cancer at the Speed of Light

Laser Interstitial Thermal Therapy (LITT)



Ct scan of the human brain [Image Credit: ©Sved Oliver/ Adobe Stock]

BY LILIANA CALDERO

The National Cancer Institute (NCI) estimates that in the U.S., about 1,735,350 new cases of cancer will be diagnosed in 2018 alone, and according to their estimation, 609,640 people in the U.S. will die from this disease this year. Despite these overwhelming numbers, there is hope. Between 1990 and 2014, the overall cancer death rate has dropped by 25% in the U.S., and is falling a little more each year as research and technology continue to produce new life-saving procedures and treatments.

Over the years, media depictions of cancer have imprinted upon the popular imagination a picture of traditional treatments such as radiation therapy and chemotherapy, along with their unpleasant and sometimes painful side effects. Today, we see that these are often part of broader treatment programs involving a range of therapies and procedures. Research institutes such as Moffitt Cancer Center are leading the way with numerous cutting-edge techniques for treating cancer patients. Among the tools they are using – lasers.

LITT

Brain cancers make up about 1.4% of all new cancer cases in the U.S. (NCI, 2018). Surgery is an important part of managing these cancers, with the goal of removing the tumor when possible. Doing this safely can present a challenge when the tumor is located in critical areas of the brain such as the brainstem, basal ganglia, or thalamus. This is where Laser Interstitial Thermal Therapy, or LITT, is offering hope to patients.

According to Dr. Arnold B. Etame, a Neurological Surgeon and Scientist at Moffitt Cancer Center, Magnetic Resonance Imaging (MRI) guided LITT is being used to treat brain tumors that were once considered inoperable with traditional surgery due to their location. LITT can be used to destroy tumors in critical areas, while minimizing the potential for damaging healthy brain tissue and also offering an incredibly short recovery time.

HOW IT WORKS

Using highly advanced MRI-guidance technology, the surgeon identifies critical areas of the brain in relation to the tumor, and then maps out the entryway and target. A very small incision, about 3-4 mm wide, is made at the entryway, and a laser fiber probe is inserted and guided into the target. New technology allows the MRI to occur at the same time, providing the guidance needed for precision during the procedure. From behind a protective barrier, the surgeon operates the laser remotely while monitoring the patient. Using pulsed laser energy, the tissue of the tumor is ablated, or burned away, while the surrounding healthy brain tissue remains.

As incredible as this treatment approach is, Etame is sure to point out that LITT is only one of many important techniques used in the treatment of brain cancers, and that there are many situations in which traditional surgery would be effective based on the treatment goals. “Traditional approaches have come a long way – we use MRI-guided functional mapping for language or movement, we also use tractography to look at white matter fibers in relation to the tumors, as well as keep patients awake during procedures to monitor their functioning. The laser is reserved for more challenging situations.” Situations like radiation necrosis.

"It's a new technique," says Etame, "which over the past few years has been shown to have some utility in specific cases. These scenarios include tumors or lesions in difficult-to-reach areas of the brain, tumors near critical structures where precise targeting is required, radiation irritation of the brain (this is known as radiation necrosis), or recurrent aggressive tumors that progress despite prior surgery and radiation." Etame also refers to several studies in which LITT has been effective with recurrent gliomas and glioblastomas in challenging locations such as the Thalamus. He explains that when compared with standard craniotomies for resection of brain tumors, the recovery time after LITT is significantly quicker, and there are significantly fewer complications. "Patients can resume other important cancer therapies, such as chemotherapy and radiotherapy, very quickly."

THE NEED FOR RESEARCH

Continued research is shedding light on the other potential applications of LITT. "One area where it has been applied heavily," Etame says, "has been the destruction of seizure causing tissue. When an area of the brain that causes the epileptic seizures can be identified, removal or destruction of that area with the laser can help with seizure control. This is currently used a lot for epilepsy of the temporal lobe in children, as well as in some adults."

Moffitt Cancer Center is one of the few facilities in the U.S. currently utilizing LITT. "Not every center has the technology; that in itself could be a limitation," says Etame. "For certain things, traditional surgery can be used as an alternative to [LITT] and surgeons may use a technique based on their comfort level with that technique." So what would it take for more facilities to adopt LITT as a treatment modality? "I think what is important is conduction of large prospective studies to better understand which tumor pathologies are much more amenable to the long-term benefits of laser ablation, which will improve patient selection."

Like other treatments, LITT is only as effective as the selection of the patient and the tumor. For example, there are situations where a tumor is highly vascular, meaning that a lot of blood is flowing to it. This essentially turns it into a heat sink, which would make LITT ineffective. There are also situations in which a biopsy of the tumor tissue is needed to identify which treatments the cancer will respond to best. In that case, destroying the tissue with the laser would cause the loss of valuable information, although Etame notes that it is possible to perform a biopsy first and then ablate the tumor after, if the situation calls for it.

Photonic materials processing continues to change lives for the better; in this case the material is living tissue. LITT, Photodynamic Therapy (PDT) and Photobiomodulation (PBM) are becoming increasingly familiar terms within the medical community. Stay tuned for future articles about how lasers are changing cancer treatment!

ABOUT

ARNOLD B. ETAME, MD, PHD

Dr. Etame is a Neurological Surgeon and Scientist specializing in Neuro-Oncology at the Moffitt Cancer Center, and is an Assistant Professor of Oncology at the University of South Florida, College of Medicine. He directs the awake-brain tumor surgery program, minimally invasive laser-guided ablation program, and image-guided surgery program at the Moffitt Cancer Center for brain tumors.

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Safety with Tunable Lasers

Things to Look Out For (Not Things to Look Into)

BY ANDREW ALBRITTON

Laser safety glasses on an area warning sign [Image credit: ©Fokussiert / Adobe Stock]

Tunable lasers in one form or another are popping up in all sorts of applications, from Medical to Research and Development. In a previous article, Ron Schaeffer discussed his dream of having a fully tunable laser dynamic enough for various applications. For the purposes of this article, a fully tunable laser is a device that is capable of changing the operating frequency of the wavelength within one laser system. With the unprecedented process performance improvements this technology promises, it is inevitable that before too long we will see this technology fully integrated into industrial processes. Unfortunately, off-the-charts performance is not all these devices bring to the table. Where does a Laser Safety Officer (LSO) start when it comes to protecting their team and others from every photonic wavelength from far infrared (IR) to extreme ultraviolet (UV)?

To answer this question, LIA reached out to two Board of Laser Safety (BLS) Certified Laser Safety Officers (CLSO) who are also members of the Accredited Standards Committee (ASC) Z136: Jamie King, EFCOG Laser Safety Task Group Chair at Lawrence Livermore National Laboratory, and Dr. Michael Woods, Laser Safety Officer at SLAC National Accelerator Laboratory.

SO, FULLY TUNABLE LASERS: ARE THEY REALLY AN ISSUE?

Jamie King thinks so, as he explains, "With the acceleration of technology in lasers, keeping up for the laser safety officer (LSO) is getting more difficult each day. It was not too long ago that a single pair of 'brown' colored laser protective eyewear covered every wavelength that you could fit on an optical table. Today that is far from the truth, especially in the R&D labs." Even without fully tunable lasers, there are systems where multiple wavelengths are present on a single optical table. This is thanks to technological advancements which decrease size and innovate what can be done within a single system. King continues, "Now comes fully tunable lasers, where you can have everything from the UV through the infrared IR available at your fingertips. This poses serious issues to the laser safety professional." It seems like some LSOs already have a lot on their plate even before a fully tunable laser comes under their responsibility.

"With the acceleration of technology in lasers, keeping up for the laser safety officer (LSO) is getting more difficult each day."

- Jamie King

WHAT ABOUT SAFETY EQUIPMENT? IS IT KEEPING UP WITH NEW TECHNOLOGY?

While King acknowledges safety equipment manufacturers are making improvements to their offerings in leaps and bounds, they are also reacting to the movement of new inventions and innovations. It can be difficult to get in front of a developing technology when you have to respond to the rapidly developing laser market. "In the case of a tunable laser, we may be asking too much." King states "The only real option to cover all of the wavelengths would be to stick a solid opaque material in front of your eyes. Viewing windows and laser protective barriers, allowing one to look into the Laser Controlled Area (LCA), will be a thing of the past." Dr. Michael Woods has much the same to say about safety goggles as an option for fully tunable lasers, "For eyewear, it's easy to have broad coverage in the UV and IR, but the visible region is more difficult." But, in that visible region, there are far too many wavelengths to cover with one set of eye protection. "Eyewear covers some but not all wavelengths," says Woods. "A user here may be able to switch between eyewear. If you get to a wavelength where you don't have protection, you can leave the room to operate remotely." LIA's own Gus Anibarro, Director of Education, clarifies that a given set of protections might not be sufficient for applications which use multiple wavelengths. The system may need to be completely contained, and the user may have to rely on viewing the process via a computer monitor and camera to protect against potential ocular damage.

Ron Schaeffer mentioned in his article that we have already had tunable lasers to some extent for some time. Since this technology is not science fiction, surely this has been covered in existing Z136 standards?

Currently, there are no specifics in the Z136.1 (Safe Use of Lasers) or in the Z136.8 (Safe Use of Lasers in Research, Development, or Testing) for broadly tunable lasers, but this isn't necessarily a problem. Dr. Woods comments, "[In the Z136 standards] there is not much discussion specifically on tunable lasers and there's a lot of reliance on the LSO to apply guidance from the standards."

Woods explains that one goal of the standards is to provide guidance that can be applied to a variety of situations, as it would be challenging to write guidelines for every possible unique scenario. Even without specific guidance on fully tunable lasers, the standards are wide-ranging enough to provide guidance on multiple wavelengths. According to Woods, it's not uncommon for labs to have multiple lasers of varying wavelengths, and in some ways the controls could be compared to what may be needed for a broadly tunable laser:

"We have a hierarchy of controls – we start with engineering first, administrative procedures, and lastly eyewear. Can I fully enclose the setup? Can I configure it to put in wavelength separators and filters so that I have full protection eyewear for the beams I'm using, and can I put in enough diagnostics with cameras and sensors so that the system can be operated remotely so I do not have to be physically present?"

Enclosure is usually the preferred engineering control, but it's not always possible. If engineering controls do not reduce the hazard sufficiently, then other controls must be implemented. In this situation, an LSO should conduct a hazard evaluation and take steps to prevent any unprotected exposure by using administrative controls such as setting standard operating procedures. Finally, as part of their assessment, the LSO will assign proper eyewear for the system. The Z136 standards state eyewear that will attenuate the wavelength is mandatory for any open beam Class 3B or 4 laser system.

Jamie King also has his own concerns about fully tunable lasers and what the Z136 Standards have to say on the matter. "Very high output lasers, we'll call them Class 5 for the sake of this, may leave an LSO scratching their heads. This is especially true when performing a failure modes and effects analysis (FMEA), which is a definite requirement for these very high output lasers (10s of kW average power). Let's say that you rely on different laser eyewear for the tunable wavelengths. One must count on the laser operator to ensure that they know at what point you must change eyewear. Do they now leave the room to change them? There is a failure point here in that one must be sure that all personnel don the correct pair of glasses." The LSO now has to rely on a user operator to remember to change their eyewear at certain stages of a process in the case of a system with a fully tunable laser. It may come as no surprise, but human error has certainly led to accidents and incidents before. King continues, "Another failure point is control of the laser itself. Whether you are using a dial or graphical user interface (GUI), the laser operator must ensure they do not make a mistake in overshooting the wavelength. This is much like using the same control on a kW class laser to go from an alignment (mW) mode to full power (kW). Mistakes happen." Once again, we see that the potential for human error is a factor that should be considered heavily in an LSO's evaluation of a system. An LSO should strive to ensure that this element is addressed during the engineering stage by automating processes as much as possible. The same level of care should be present during the administrative stage by deploying proper safety precautions, signage, and training, as at this point in time one set of eyewear will not adequately protect an operator from all settings on a fully tunable laser.

OK, SO WHAT DO WE STILL NEED TO DO TO PREPARE FOR A TRUE, FULLY TUNABLE LASER?

Woods suggests that in the future, we may benefit from more examples on how to apply the controls as an appendix in a Z136 standard. He also believes that an important part of staying on top of changes in technology is networking and consulting with colleagues. "In DOE (Department of Energy), we have a network of LSOs in the different labs and we can consult with each other with the questions that we have. A lot relies on having a good LSO and having good training. That's where LIA comes in, or ILSC (International Laser Safety Conference), or the DOE Workshop. It would be hard to have a complete enough discussion in the standards as they are only revised every five-seven years."

King also has some suggestions, "On the lower end of the scale, this might not be a big issue. A neutral density filter may provide all of the protection that you need, outside of the IR. Add a KG glass filter and you might be covered. One is not so fortunate if you are pushing the bounds of science and technology; when looking at high output lasers, you might look to procuring several different filters for the various wavelengths, or even doubling and tripling up on these same filters in a single pair of glasses/goggles. That is a lot of glasses, or you are also dealing with another hazard, the worker cannot see. You pick your poison here.

"Do we need to prepare for the coming of tunable lasers in different settings? Yes, just like we need to prepare for what is happening in the ever increasing output of lasers available to the general public. Don't even get me started on white light lasers. Oh yes, wait until you are asked to come up with controls for that."

(Continued on page 18)

WHAT IS THIS NOW ABOUT WHITE LIGHT LASERS?

According to Woods, with a white light continuum laser, you have all of the wavelengths at the same time. "Tunable lasers generally operate at a single wavelength or within a narrow-range, but you can then tune that over a broad range. Continuum lasers can be more difficult to address. It's easier to consider alignment eyewear for the lower power levels, but higher levels will likely need more engineering controls and enclosing," says Woods. King adds, "For a supercontinuum white light source, you use a pump laser (typically a Nd:YAG 1064 nm laser). You can control this administratively by tuning down the output such that you only have the 1064 nm pump hazard. You can align the system this way with laser eyewear. You would then implement engineered controls (enclosure) to contain the beam. Then you tune it up and create your broadband white light." King points out there's something more out there. "A white laser is far different. Arizona State University (ASU) developed a semiconductor where they can combine a red, green, and blue laser to create a white laser on the semiconductor. This is sure to be tunable, but where someone may want a broadband of wavelengths rather than a discreet one, it will create issues for controls. Luckily, this laser is not yet available to the masses." In other words, white light laser beams operate at multiple wavelengths simultaneously but tunable lasers can operate over a dynamic range of wavelengths one at a time. Both of these devices can operate at a reduced capacity where full protection eyewear is manageable for setup and calibration, but when operating at full capacity or at varying wavelengths other protections are mandatory. You can see an example of the multiple wavelengths produced by a supercontinuum white light laser in Figure 1.

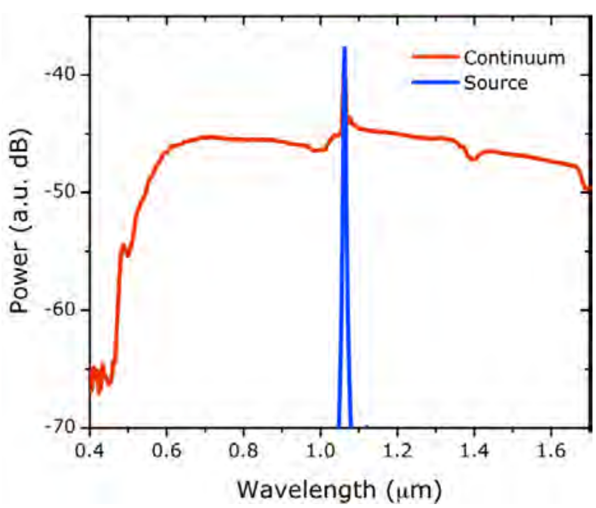

Figure 1. Graph showing the spectrum of a 1 μm pump source and the spectrum of the resulting supercontinuum generated in a photonic crystal fiber. [©Burlyc/ Wikimedia Commons]

Dr. Woods offers the following recommendations for managing a white light laser: Enclose the device, or try to confine the beam to as small an area as possible by using barriers and keep all beams in the horizontal plane. Reduce intensity during setup and alignment tasks. Use wavelength separators or filters to help ensure that you still have full protection with your eyewear. Always block the beam when it's not needed and don't propagate the beam any further than you need to for the task that you're doing. Dr. Woods cautions that engineering controls are critical as a mistake can lead to a specular reflection, and with the various wavelengths these devices operate at, an injury is possible.

With so many safety challenges on the horizon due to the inevitable rise of fully tunable lasers, companies and research institutes will have to rely on their LSOs now more than ever to evaluate systems and protect system operators. As an LSO, one of the best ways to keep your skill set sharp is to invest in a course like LIA's Laser Safety Officer with Hazard Analysis, then validate this knowledge by becoming a CLSO. As mentioned by Dr. Woods, networking with colleagues is invaluable; with ILSC coming up in March 2019, your opportunity to meet and learn from these and other laser safety professionals is right around the corner.

SPECIAL THANKS TO

Mr. Jamie King, Lawrence Livermore National Laboratory

Dr. Michael Woods, SLAC National Accelerator Laboratory

LEARN MORE

ASU's White Laser Technology
https://asunow.asu.edu/20151117-discoveries-asus-white-laser-technology-one-years-top-breakthroughs

RGB White Light Laser Source for Underwater Illumination
https://www.laserfocusworld.com/articles/print/volume-54/issue-08/newsbreaks/underwater-communication-and-illumination-uses-rgb-white-light-laser-source.html

Z136 Series of Laser Safety Standards
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International Laser Safety Conference 2019
https://www.lia.org/conferences/ilsc

Department of Energy Past LSO Workshops
http://efcog.org/safety/worker-safety-health-subgroup/laser-safety-task-group/doe-laser-safety-officer-workshops/

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ORLANDO, FL – Lasers used for medical procedures can be found in a variety of health care environments such as hospitals, surgery centers, dental and veterinarian offices, laser hair removal salons, laser tattoo removal clinics, and spas. The ANSI Z136.3-2018 *American National Standard for Safe Use of Lasers in Health Care* serves as a guideline for all personnel who use or are exposed to a laser or laser system that is used as a medical device for a health care application. It is meant to aid in the establishment of medical laser safety policies, procedures and training programs, which keep both patients and staff safe from laser-related hazards.

With sections covering topics specific to health care facilities, such as endotracheal tube fires and infection control, this standard is a must-have for all Medical Laser Safety Officers (MLSOs).

The 2018 revision reflects current thinking and practice. Updates include:

- Refinement of the roles and responsibilities of the Laser Safety Officer (LSO), Deputy LSO (DLSO), Laser Safety Site Contact (LSSC), and Laser Safety Specialist (LSS), with additional information regarding these positions discussed in a new normative appendix
- Revised sections on laser plume
- Expanded guidelines for 3rd party laser rentals
- Introduction of the newly defined Class 1C, which includes laser products designed explicitly for contact application to the skin, i.e., intended for hair removal, skin wrinkle reduction, and acne reduction
- Other notable changes to the Z136.3 that MLSOs will need to consider:
- More clearly defined control measures, including the specification of laser operator responsibilities during a procedure
- Changes to area warning signage in both design and signal words

The Z136.3 Standard has helped thousands of MLSOs lend credibility to and implement medical laser safety policies and procedures. John Sakaris, a Board of Laser Safety (BLS) Certified Medical Laser Safety Officer (CMLSO) explained, “It recently helped me reinforce a laser maintenance issue; I was correct, not on my own authority, but because of the ANSI Z136.3 standard. I am considering doing a presentation on this topic at our next International Laser Safety Conference (ILSC) in 2019!”

Laser safety professionals find that this standard is essential to ensuring the efficacy of their health-related laser safety program. BLS CMLSO Leslie Pollard, who has trained hundreds of medical staff in the safe use of lasers in health care settings stated, “The best foundation for an effective and compliant medical laser safety program is a basic understanding of the health care laser safety reference document, ANSI-approved Z136.3.”

The revised ANSI Z136.3-2018 standard is now available for purchase in both print and electronic formats from the LIA online store at www.lia.org/store/laser-safety-standards

MEMBER INNOVATIONS

EHLA RESEARCH TEAM WINS RENOWNED BERTHOLD LEIBINGER INNOVATIONSPREIS 2018

BY PETRA NOLIS, LEADER COMMUNICATIONS GROUP FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

The research team of the Fraunhofer Institute for Laser Technology ILT and the Chair of Digital Additive Production DAP of RWTH Aachen University will be honored with the Berthold Leibinger Innovationspreis 2018 for their development of the “Extreme High-Speed Laser Material Deposition” (EHLA). This process can be used to coat, repair or additively manufacture components in a particularly economical and environmentally friendly way. On September 21, the Aachen scientists will receive the first prize of the laser innovation prize awarded by the private foundation Berthold Leibinger Stiftung in Ditzingen, Germany, every other year since 2000 for outstanding research and development on the application or generation of laser light.

The timing was simply right: The research team heard on May 16, 2018 – the first International Day of Light – that it was invited to the jury session in Ditzingen as a finalist. On July 13, 2018, Thomas Schopphoven (Fraunhofer ILT) represented the team which includes his colleagues Andres Gasser (also Fraunhofer ILT) and Gerhard Maria Backes (Chair of Digital Additive Production DAP, RWTH Aachen University). He presented and explained their innovation alongside seven other finalist teams from all over the world.

FRIDAY, JULY 13TH: A LUCKY DAY FOR THE EHLA TEAM

This particular Friday turned out to be a lucky day because the EHLA process, developed by the Aachen researchers, convinced the prominent, international jury to choose them for the first prize. On September 21, they will receive the award, endowed with 50,000 euros, at a festive ceremony in the headquarters of the TRUMPF Group in Ditzingen. The second prize goes to the project group DELPHI for the industrial application of femtosecond laser lithography in integrated optics. The third prize honors Prof. Jürgen Popp and Prof. Ute Neugebauer for developing a laser-based method for the rapid determination of antibiotic resistance.

“In the laser industry, this is one of the world’s top-class awards,” says Thomas Schopphoven, head of the Productivity and Systems Engineering team in the Laser Material Deposition Group at Fraunhofer ILT. “We are extremely pleased about the recognition of our work on energy- and resource-efficient production with laser light.” The Aachen researchers were already awarded the Joseph von Fraunhofer Prize in 2017 and the Steel Innovation Prize in 2018 for EHLA.

SUCCESS WITH SPEED AND PRECISION

The innovation is based on a well-known procedure: laser material deposition, which has proven itself as a repair method, e.g. for turbine blades. However, the low process speed has prevented LMD from being used as a standard when large components are coated. Schopphoven and his team have overcome this process-related disadvantage by melting metal powder particles directly in the laser beam during the EHLA process. Thus, the process speed can be increased from a maximum of a few meters per minute to up to 500 meters per minute. At the same time, the layer thickness that can be produced decreases from previously over 500 down to a range from 10 to 250 microns. Thanks to these two innovations, the Aachen invention can be used as an alternative to the usual hard chrome plating with controversial chromium (VI) compounds or thermal spraying.

Juror Prof. Wolfgang Marquardt (Chairman of the Board of Directors of Forschungszentrum Jülich, left) and award winner Thomas Schopphoven from Fraunhofer ILT at the announcement of the winners of the Berthold Leibinger Innovationspreis 2018. © Berthold Leibinger Stiftung, Ditzingen, Germany.

The concept is successful: Since 2015, the Dutch IHC Vremac Cylinders B.V. from Apeldoorn has been using EHLA to coat hydraulic cylinders for worldwide offshore use. The several hundred cylinders have lengths of up to ten meters and diameters of up to 500 millimeters; they are coated with wear- and corrosion-resistant alloys, which meet the highest demands. ACunity GmbH from Aachen, a spin-off of Fraunhofer ILT, is targeting the offshore market in China. It recently delivered three large EHLA systems to the Chinese company Hebei Jingye Additive Manufacturing Technology Co., Ltd. for environmentally friendly coating of offshore hydraulic cylinders.

FIRST OFFSHORE, NOW AUTOMOTIVE INDUSTRY

But the offshore market is just the beginning – the team leader and scientist is sure. Schopphoven: "The EHLA process is particularly suitable for the automotive industry, such as for the coating of brake discs, which were previously difficult to coat because of the high loads and high demands on efficiency and environmental friendliness."

The finalists of the Berthold Leibinger Innovationspreis 2018 at the jury session on July 13 in Ditzingen.
© Berthold Leibinger Stiftung, Ditzingen, Germany.

Award-winning protection: The research team of Fraunhofer ILT and the Chair of Digital Additive Production DAP of RWTH Aachen University won the Berthold Leibinger Innovationspreis 2018 for the EHLA process.
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The Fraunhofer-Gesellschaft is the leading organization for applied research in Europe. Its research activities are conducted by 72 Fraunhofer institutes and research facilities at different locations throughout Germany. The overall workforce of approx. 25,000 works with an annual research budget totaling more than 2.3 billion euros. Of this, about 2 billion euros are allotted to the division 'contract research.' The Fraunhofer-Gesellschaft generates over 70 percent of this division's turnover from orders for the industry and from publicly funded research projects. Its international cooperation with excellent research partners and innovative companies ensures it has direct access to the most important present and future scientific and economic sectors.

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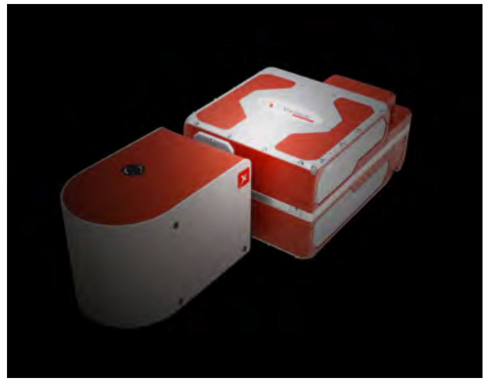
MEMBER INNOVATIONS

FLEXIBLE SPATIAL AND TEMPORAL BEAM SHAPING INCREASES THE APPLICATION RANGE OF ULTRAFAST LASER PROCESSING

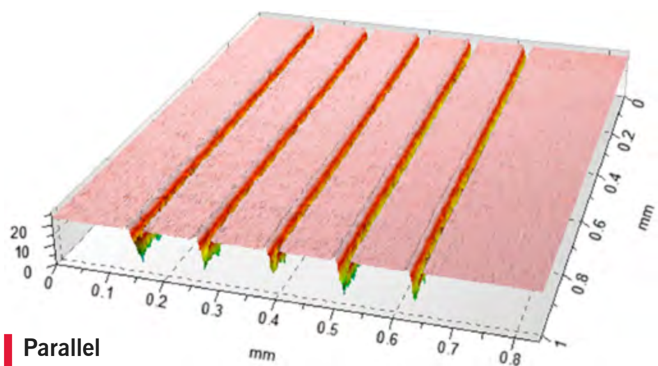
BY ERIC MOTTAY, PRESIDENT AND CEO, AMPLITUDE

Over the past decade, ultrafast lasers have opened a large number of applications across many sectors, such as ophthalmology, display, semiconductor or medical device manufacturing. Their ability to process virtually any material with an unsurpassed quality and precision make them the tool of choice for high precision micro-machining. Nevertheless, the requirement for high throughput in mass production applications raises further challenges, from both the laser and process development points of view.



Industrial Ultrafast Laser with Spatial Light Modulator

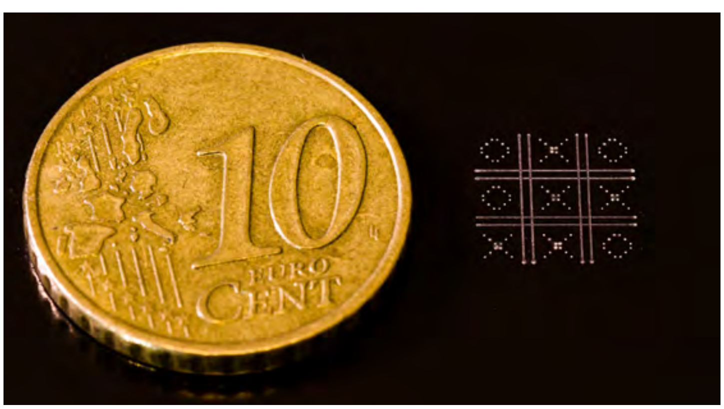
New industrial ultrafast lasers, with high processing speed and high average power, are well suited for these demanding applications. However, new processing approaches are required to take advantage of these new lasers: With power exceeding 100 Watts, and an industry roadmap aiming for kW levels, detrimental thermal effects can lead to a reduction in processing quality. Among the approach considered are high-speed scanners or multi-beam processing with diffractive optical elements.



Parallel processing of stainless steel

Temporal and spatial beam shaping is another extremely attractive approach for high throughput micromachining. Fast modulation of the laser pulses with extremely high accuracy, including flexible burst modes enable the use of high speed scanners, precise optimization of the ablation process, and are used in high speed glass cutting for display applications.

Flexible spatial beam shaping can also benefit advanced micromachining applications. Programmable Spatial Light Modulators (SLM) combine flexibility, efficiency and ease of use while maintaining a high spatial resolution compatible with complex optical functions like multi beams, non-diffractive structured beams or multiplexed lenses. A custom phase function displayed on a phase modulator leads to a custom intensity distribution on sample, and consequently provides a customized laser tool. With conversion efficiencies reaching 95%, phase-only beam shaping is considered as an energy efficient solution. As such, a variety of functions can be implemented with the same tool, for example advanced longitudinal beam shaping for glass cutting, beam splitting for parallel processing, or control of the intensity distribution in the focal point for process optimization.



Programmable beam shaping for marking applications

Flexible spatial and temporal beam shaping increases the application range of ultrafast laser processing, from glass cutting to high-speed surface texturing.

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MEMBER INNOVATIONS

NEW TECHNOLOGY USES MACHINE-LEARNING TO PREDICT QUALITY ISSUES RELATED TO LASER HEAT TREATMENT PROCESSES

AUTHORS: JAVIER DÍAZ AND M. ANGELES MONTEALEGRE. R&D PROJECT MANAGERS

Laser beam hardening offers technically rewarding solutions, especially for manufacturers of small and/or complex-shaped components for mold and automotive industries. However, one of the major challenges for laser hardening is its adjustment to uneven surfaces, such as those with sharp edges or holes. Overheating problems due to the differences in the surrounding volume of the material often arise, leading to unacceptable treatment results, rejection of the pieces due to no quality. For a laser surface heat treatment process control, the main objective is to regulate the amount of energy deposited over the treated surface by the laser beam source, which is responsible for increasing the temperature of the surface.

As a response to these quality issues, Talens Systems, Etxe-Tar Group, has developed DSS (Dynamic Spot Shaper), a completely original controlling software. By scanning a simple small Gaussian beam through different high frequency paths, arbitrary free-form energy distributions on the treated workpiece can be generated (see Figure 1). This disruptive technology proposes an original method for a high flexibility customization of the laser beam delivery. It is able to provide customized energy density patterns thus allowing the homogeneous laser heat treatment of these critical areas with full control of material evolution and a fully precise laser energy tailoring suitable for every workpiece geometrical singularity.

To address quality compliance of the laser hardening process, Talens Systems, together with its R&D Department has developed a Machine Learning-based technology to process data streams with a proprietary industrial-grade computing device called RAIO that, in combination with sensors, is able to predict quality issues related to laser heat treatment processes. A 1,000 fps thermal camera, together with positioning encoders at the scanning system, are implemented into the machine to provide timely feedback about the quality, becoming an on-line quality control system. The data stream acquired by RAIO is then analyzed, taking advantage of its integrated FPGA- field-programmable gate array to accelerate ML algorithm performance. The system, based on kernel density estimation algorithms, learns the normal behavior of the process, laser spot positioning and energy distribution, giving an anomaly score that is monitored. Figure 1 shows the probability distribution of the data stream used to calculate the anomaly score on a real process, where the red color triggers an alarm labelling the workpiece for further inspection into the production line.

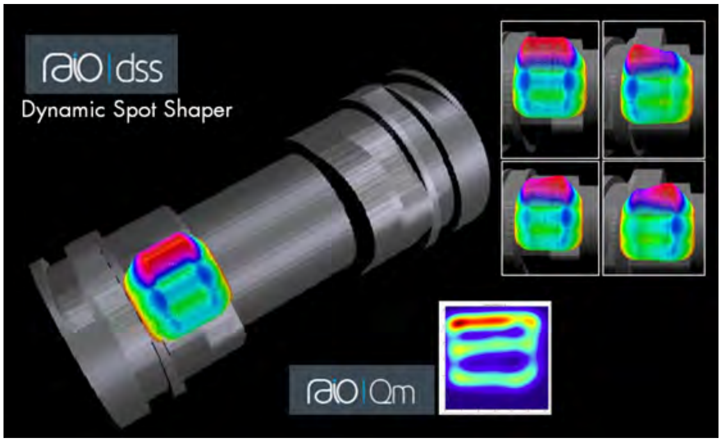

Figure 1. shows the probability distribution of the data stream used to calculate the anomaly score on a real process, where the red color triggers an alarm labelling the workpiece for further inspection into the production line.

This technology is already working in a major world automotive O.E.M., operating at millisecond range, far below the process requirement and helping the laser heat treatment to be considered to be on the way to become a conceptually improved industrial standard.

With this proprietary laser technology along with its top-notch on-line quality control solution, the end-users are enjoying its attractive return-on-investment, improved by a reduction on inspection and testing needs.

TALENS
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About Talens Systems, Etxe-Tar Group

Talens Systems, Etxe-Tar Group, a technology-based innovative enterprise committed to development and commercialization of turnkey solutions for laser applications, presents its disruptive technology, developed for laser heat treatment.

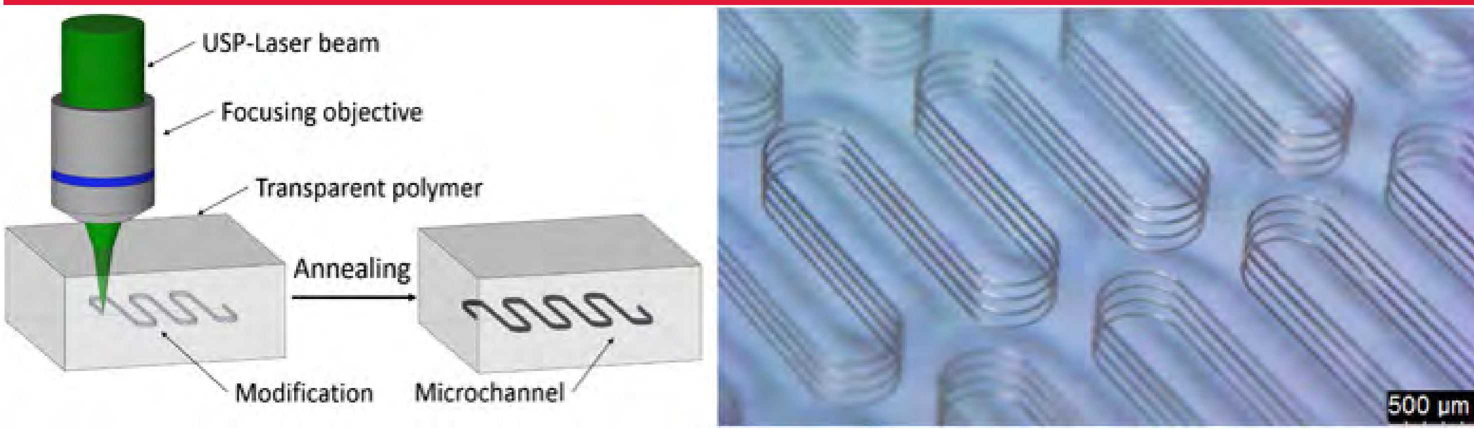

FIG. 1. Schematic illustration of the femtosecond laser generation of 3D microchannels inside bulk polymers (left) and tilted view on a four non-intermittent level meander shaped channel architecture demonstrating full 3D capabilities of the studied process (right).

Control of femtosecond laser generated microfluidic channels inside poly(methyl methacrylate)

G.-L. ROTH, C. ESEN, AND R. HELLMANN

In this study, the authors report on femtosecond laser direct generation of microchannels inside poly(methyl methacrylate) with variable dimensions ranging from a channel height of 20 to 350μm and an aspect ratio down to 1.2. Focused ultrashort laser pulses are used to trigger a material modification in the focal area which can be selectively opened by a subsequent annealing process. A 3D microchannel architecture can easily be realized by moving the specimen using motorized stages, allowing freely chosen complex shaped channel layouts. While the laser wavelength is identified as one of the main parameters determining process effectiveness, another core of this study is the variation of channel dimensions by the numerical aperture of the applied objective to focus the laser. The authors find that both size and shape of the modified region and the resulting microchannel can be controlled by altering the numerical aperture.

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