

# PLI

## CONFÉRENCES

LIMOGES  
01 & 02  
juillet  
2026

# ACTES DE CONFÉRENCES

## CONFERENCE PROCEEDINGS



LE RENDEZ-VOUS INCONTOURNABLE DÉDIÉ  
AUX PROCÉDÉS LASER INDUSTRIELS

The must-attend event dedicated to industrial laser processes

Organisateurs




Partenaires



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**Optimisez vos processus  
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en procédés laser**

**MERCREDI 1<sup>er</sup> JUILLET / WEDNESDAY 1<sup>st</sup> JULY**


► **SESSION PLÉNIÈRE D'OUVERTURE / PLENARY OPENING SESSION**

Salon Panoramique / Modérateur : John Lopez

	08:30	Accueil café / Welcoming coffee	
	09:00	Ouverture / Opening talk	
	09:20	<b>Philippe Roy et Benoit Beaudou</b> XLIM & GLOphotonics	Fibres optiques innovantes fabriquées à Limoges : fibres à cœur solide dopées pour la génération d'impulsions laser de haute puissance et fibres à cœur creux pour le dépôt de faisceaux laser <i>Cutting-edge optical fibers from Limoges: solid-core doped fibers for high-power laser pulses generation and hollow-core fibers for laser beam delivery</i>
	09:50	<b>Petra Paiè</b> POLITECNICO DI MILANO	Microfabrication du verre par laser femtoseconde pour le développement de plateformes avancées d'imagerie microscopique <i>Femtosecond laser micromachining of glass for advanced microscopy applications</i>
	10:20	<b>Jan Brajer</b> HILASE	Développement de la technologie de peening par choc laser et capacités actuelles au Centre HiLASE <i>Laser shock peening technology development and actual capabilities at HiLASE Center</i>
	10:50	Pause-café / Coffee break	

► **SESSION SOUDAGE LASER / LASER WELDING SESSION**

Salle de Restaurant / Modérateur : Maxime El Kandaoui

	11:30	<b>Peter Kallage</b> COHERENT	Influence des profils d'intensité du faisceau sur la stabilité du keyhole pendant le soudage au laser <i>Influence of beam intensity profiles on the stability of vapor capillaries during laser welding</i>
	11:50	<b>Paul Sauvion</b> CEA VALDUC	Micro-soudage laser en mode conduction de feuilles d'aluminium pur à 515 nm pour la fabrication des cibles du Laser Mégajoule <i>Laser micro welding in conduction mode of pure aluminium foils at 515 nm for Laser MegaJoule target manufacturing</i>
	12:10	<b>Ferrody Chetan</b> IREPA LASER	Simulation numérique du bain de fusion dans le soudage au laser – Étude de la mise en forme du faisceau <i>Numerical simulation of the melt pool in laser welding – Study of the beam shaping</i>
	12:30	Pause déjeuner / Lunch break	


► **SESSION SÉCURITÉ LASER / LASER SAFETY SESSION**

Salon Panoramique / Modérateur : Laurent Gallais

	11:30	<b>Marc Le Parquier</b> UNIVERSITÉ DE LILLE / CERLA	Sécurité des sources super continuum : Analyse de risque et stratégie de sécurisation <i>Safety of supercontinuum sources: Risk assessment and mitigation strategies</i>
	11:50	<b>Manon Deveugle</b> ALPHANOV / PYLA	Comment prendre en compte la sécurité laser dans l'organisation des espaces de travail ? <i>How to take laser safety into account in the organization of workspaces?</i>





► **SESSION POSTERS / POSTERS SESSION**

Salon Panoramique / Modérateur : Laurent Gallais

12:10	Pitch des doctorants / PhD student pitch	
12:30	Pause déjeuner / Lunch break	





► **SESSION MICRO-USINAGE LASER / LASER MICRO-MACHINING SESSION**

Salon Panoramique / Modérateur : Frédéric Mermet

14:00	<b>Marc Faucon</b> ALPHANOV	De l'ablation à la fonctionnalisation de surface avec une source femtoseconde en mode rafale GHz <i>From ablation to surface functionalization with a GHz burst mode femtosecond source</i>	
14:20	<b>Valentin Maffei</b> GROUPE HEF	Hybridation laser et revêtements fonctionnels pour l'architecture des surfaces <i>Laser-coating hybridization for functional surface architectures</i>	
14:40	<b>Manuel Gómez Marzosa</b> UNITED MACHINING MILL AG - CHARMILLES	Usinage au laser à impulsions ultracourtes des diffuseurs des trous de refroidissement dans des aubes de turbine revêtues d'un système de barrière thermique céramique (TBC) <i>Ultrashort pulse laser shaping of diffuser cooling holes in TBC coated turbine blades</i>	
15:00	<b>Volkan Yavuz</b> TRUMPF	Préparation de surface par laser : nettoyage et structuration de pièces gigacast et d'autres matériaux <i>Laser based surface preparation – Cleaning and structuring of gigacast parts and other materials</i>	
15:20	Pause-café / Coffee break		





► **SESSION MICRO-USINAGE LASER / LASER MICRO-MACHINING SESSION**

Salon Panoramique / Modérateur : Girolamo Mincuzzi

15:50	<b>Tony Hajj</b> ICUBE – INSA STRASBOURG	Mode rafale pour le soudage laser de diélectrique : du verre au SiC <i>Burst mode in dielectric material laser welding: from glass to SiC</i>	
16:10	<b>Joëlle Harb</b> ARGOLIGHT	Réseaux de Bragg volumique de Type-A inscrits par laser femtoseconde utilisant un masque de phase et une exposition en mode rafale <i>Type-A volume Bragg Gratings inscribed by femtosecond laser using phase-mask and burst-mode exposure</i>	
16:30	<b>Akhil Kuriakose</b> CELIA CNRS	Structuration colonnaire améliorée dans le silicium par traitement laser à rafales GHz <i>Enhanced columnar structuring in silicon via GHz-burst laser processing</i>	
16:50	<b>Vincent Rouffiange</b> AMPLITUDE	Lasers ultracourts dans le semi-conducteurs : des procédés aux marchés, opportunités et défis technologiques <i>Ultrafast lasers in semiconductors: from processes to markets, opportunities and technological challenges</i>	
17:10	Fin des conférences / End of the conferences		

► **SESSION APPRENTISSAGE MACHINE & IA / MACHINE LEARNING & AI SESSION**





Salle de Restaurant / Modérateur : Michael Jarwitz

14:00	<b>Boubakar Sehili</b> PRECITEC	Comment la surveillance de process laser améliore la production <i>How laser process monitoring enhances manufacturing</i>	
14:20	<b>Eric Mottay</b> H-NU	Capteurs multimodaux et machine learning pour l'amincissement laser du silicium <i>Online multimodal sensing and machine learning for silicon laser thinning</i>	
14:40	<b>David Bruneel</b> LASEA	Prédiction par IA de paramètres de micro-usinage laser femtoseconde <i>AI-driven optimization of femtosecond laser micromachining parameters</i>	
15:00	<b>Nicolas Dalloz</b> ORACLASE	Développement de procédés lasers autonome assisté par IA avec optimisation multi-objectif et vision par ordinateur <i>AI-aided autonomous laser process development with multi-objective optimization and computer vision</i>	
15:20	Pause-café / Coffee break		



► **SESSION FABRICATION ADDITIVE & CONTRÔLE DE PROCÉDÉS / ADDITIVE MANUFACTURING & PROCESS CONTROL**

Salle de Restaurant / Modérateur : Jérôme Wursthorn

15:50	<b>Anika Langebeck</b> BIAS - BREMER INSTITUT FÜR ANGEWANDTE STRAHLTECHNIK	Fabrication de pièces en cuivre pur à haute densité par PBF-LB au laser bleu <i>Blue-laser PBF-LB to manufacture high-density pure copper parts</i>	
16:10	<b>Philippe Lefebvre</b> AIR LIQUIDE	Optimisation de la qualité en LPBF : Cartographie haute précision des flux gazeux par robotique cartésienne <i>Quality optimization in LPBF: High-precision gas Flow mapping via cartesian robotics</i>	
16:30	<b>André Eltze</b> LASERLINE	Rechargement laser : Nouvelles applications, nouvelles têtes, nouvelles senseurs <i>Diode laser cladding: new applications, cladding heads and sensor systems</i>	
16:50	<b>Camille Godel</b> SHOCKLITE	Système laser fibré haute puissance crête conçu pour la robotisation des procédés de choc laser <i>High peak power fibered laser system tailored for the robotization of laser shock applications</i>	
17:10	Fin des conférences / End of the conferences		

► **SOIRÉE NETWORKING / NETWORKING EVENING**



18:20	Rendez-vous à l'arrêt de bus « Place Winston Churchill » / Meet at the "Place Winston Churchill" bus stop		
19:00	<b>Apéritif dinatoire à la Chapelle Saint Martin</b> / Cocktail party at Chapelle Saint Martin		
23:00	Fin de la soirée networking / End of the networking evening		
23:30	Retour en bus au centre-ville / Return by bus to the city center		



**JEUDI 2 JUILLET / THURSDAY 2<sup>nd</sup> JULY**

► **SESSION MICRO-USINAGE LASER / LASER MICRO-MACHINING SESSION**

Salon Panoramique / Modérateur : Vincent Rouffiange

	08:30	Accueil café / Welcoming coffee	
	9:00	<b>Eric Audouard</b> <b>AMPLITUDE</b>	Structuration laser femtoseconde des électrodes de batteries Li-Ion : démonstration et perspective pour la production roll-to-roll <i>Femtosecond laser structuring of Li-Ion batteries electrodes: demonstration and perspective for roll-to-roll production</i>
	9:20	<b>Frédéric Mermet</b> <b>IREPA LASER</b>	Optimisation de la productivité par stratégie multi faisceaux : limites et performances <i>Productivity optimization through multi-beam strategy: Limitations and performance</i>
	9:40	<b>Girolamo Mincuzzi</b> <b>ALPhANOV</b>	Traitement laser femtoseconde haute puissance des batteries de nouvelle génération : évaluation des performances de découpe et de structuration de surface <i>High-power femtosecond laser processing of next-generation batteries: Cutting and surface structuring performance evaluation</i>
	10:00	<b>Sylvain Georges</b> <b>MANUTECH USD</b>	Texturation 3D et caractérisation de nano-objets pré-structurés à l'aide d'un faisceau laser en forme d'anneau <i>3D texturing and characterization of pre-patterned nano-objects using a donut-shaped laser beam</i>
	10:20	<b>Alberto Aguilar</b> <b>IOTAMETRIX</b>	Métrie topographique 3D sur grandes surfaces de céramiques texturées par DLIP par microscopie confocale en super-résolution <i>Large-area 3D topographic metrology of DLIP-textured ceramics via super-resolved confocal microscopy</i>
	10:40	Pause-café / Coffee break	


► **SESSION FABRICATION ADDITIVE & CONTRÔLE DE PROCÉDÉS / ADDITIVE MANUFACTURING & PROCESS CONTROL SESSION**

Salle de Restaurant / Modérateur : Laurent Menuat

	9:00	<b>Stefan Holesch</b> <b>PRIMES</b>	Vers la caractérisation systématique des faisceaux lasers annulaires <i>Towards systematic characterization of ring-shaped laser beams</i>
	9:20	<b>Gwenn Pallier</b> <b>CAILABS</b>	La mise en forme du faisceau laser comme levier pour le passage à l'échelle de la fabrication additive <i>Laser beam shaping for scalable high-power additive manufacturing</i>
	9:40	<b>Jérôme Wursthorn</b> <b>IREPA LASER</b>	Procédés DED laser poudre et fil au service de la prévention, réparation et du remanufacturing : retours industriels et perspectives avec le projet RESTORE <i>Laser powder and wire DED processes for prevention, repair, and remanufacturing: industrial feedback and prospects with the RESTORE project</i>
	10:00	<b>Yuri Chivel</b> <b>MER PHOTONICS</b>	Fabrication de pièces 3D multi-matériaux par fusion laser sélective <i>Multi-material 3D parts production by selective laser melting</i>
	10:20	<b>Wilfried Vogel</b> <b>MKS OPHIR SPIRICON EUROPE</b>	Ouvrir la voie à la prochaine ère des lasers à fibre – pourquoi et comment la métrologie doit suivre <i>Unlocking the next era of fiber lasers – why and how metrology must keep up</i>
	10:40	Pause-café / Coffee break	





► **TABLE-RONDE / PANEL SESSION**

Salon Panoramique / Modérateur : Gwenn Pallier

11:10	Table ronde thématique : Les céramiques techniques / Thematic panel session: Technical ceramics	
12:20	Pause déjeuner / Lunch break	

► **SESSION PLÉNIÈRE DE CLOTURE / PLENARY CLOSING SESSION**

Salon Panoramique / Modérateur : Eric Mottay

14:00	<b>Christophe Salomon</b> LABORATOIRE KASTLER BROSSEL	La mesure du temps : la révolution des atomes froids <i>The measurement of time: the cold atom revolution</i>	
14:30	<b>Jared Speltz</b> UDRI	Méthodes de couplage de fibres optiques par laser femtoseconde pour applications industrielles <i>Methods of femtosecond laser fiber coupling for industrial applications</i>	
15:00	<b>Ali Gökhan Demir</b> POLITECNICO DI MILANO	Développement de procédés et de systèmes basés sur le laser pour la fabrication de batteries dans la mobilité électrique <i>Laser-based manufacturing process and system development for battery manufacturing in electric mobility applications</i>	
15:30	<b>David Bruneel</b> LASEA	Montée en puissance du micro-usinage, des watts aux kilowatts : pertinence accrue des lasers femtosecondes pour les applications industrielles <i>Micromachining upscaling from W to kW: increase of femtosecond laser relevance in industrial applications</i>	
16:00	Discours de cloture / Closing talk		

# CLUB LASER ET PROCÉDÉS

Association for the development and the promotion of laser applications in industry

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# Cutting-edge optical fibers from Limoges: solid-core doped fibers for high-power laser pulses generation and hollow-core fibers for laser beam delivery

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The “powder sintering technology” enables the synthesis and the processing of silica glass rod materials with unique homogeneity properties and exceptionally uniform distribution of dopants, overcoming the limitations encountered with CVD processes [1]. Combined with Stack and Draw technics, the exceptional properties of synthesised materials using powder-based methods make it possible to design of laser or delivery optical fibres with outstanding properties. In this presentation, we will show some examples of custom optical fibres and associated laser sources that have demonstrated the emission of high-energy/high peak power pulses without reaching non-linear thresholds. Single-mode propagation in a core with a cross-sectional dimension in the 40-100  $\mu\text{m}$  range can indeed be achieved with flexible/rigid active or passive optical fibres [2,3 and 4].

In the second part of the talk, we will review the development of a new class of hollow-core photonic crystal fibers (HCPCFs), known as inhibited-coupling (IC) fibers which was first introduced in 2007 [5]. Today, these fibers can offer ultra-low loss (below 0.1 dB/km), broad transmission bandwidth spanning from UV to mid-IR, and negligible overlap with the silica material. These unique properties of IC guidance have proven particularly transformative for laser beam delivery applications. Specifically, these fibers can serve as flexible, ultra-low-loss conduits for ultra-short pulse laser beams, ensuring delivery without temporal distortion [6]. The recent results obtained by our group will be then discussed. Among them we count ultra-short pulse handling at the milli-Joule energy level [6-7], record UV delivery demonstrations down to 213 nm [8-9] and significant improvements in power and polarization stability for seamless industrial integration [10].



Figure 1 (a) The image shows the fibre-cross section of a fiber with an aperiodic design. (b) The image shows a USP-laser engraving on a glass slide where the beam was delivered directly from the output tip of a 10 m-long HC-PCF in a manner similar to pen writing.

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- [1] K. Schuster. et al. Material and technology trends in fiber optics, *Advanced Optical Technologies*, vol. 3, no. 4 (2014).
- [2] M.-A. Malleville et al., Pre-compensation of thermally induced refractive index changes in a depressed core fully aperiodic large-pitch fiber for high average power operation, *Optics Letters* 46, 2956-2959 (2021). <https://doi.org/10.1364/OL.424743>
- [3] A. Chervet, et al., 40  $\mu\text{m}$  core diameter ytterbium-doped VLMA fiber for high-peak-power nanosecond pulse amplification, *Applied Optics* 65, 1466-1471 (2026). <https://doi.org/10.1364/AO.580121>
- [4] B. Leconte et al., “1.8 mJ pulses at 1560 nm based on a 55  $\mu\text{m}$  core pure-erbium-doped VLMA fiber,” *Optics Letters* 49, 6293-6296 (2024).
- [5] Conyn et al., “Generation and Photonic Guidance of Multi-Octave Optical-Frequency Combs”, *Science* 318, 1118 (2007).
- [6] Debord et al., “Multi-meter fiber-delivery and pulse self-compression of milli-Joule femtosecond laser and fiber-aided laser-micromachining”, *Opt. Express* 22, 10735 (2014).
- [7] Debord et al., “2.6 mJ energy and 81 GW peak power femtosecond laser-pulse delivery and spectral broadening in inhibited coupling Kagome fiber”, *CLEO US*, paper STh4L.7 (2015).
- [8] Leroi et al., “UV 20W-class single-mode nanosecond pulse delivery using a vacuum-free/ambient air inhibited-coupling hollow-core fiber”, *Applied Physics B* 129,116 (2023).
- [9] Delahaye et al., “Demonstration of deep UV fiber delivery patchcord down to 213 nm”, *CLEO Europe*, paper CJ-12.2 (2025).
- [10] Beaudou et al., “Innovative hollow core fibre beam delivery solutions for Ultrashort Pulsed Lasers”, *AILU Workshop: Optics & Beam Delivery*, invited paper (2026).

# Femtosecond laser micromachining of glass for advanced microscopy applications

Andrea Ciceri<sup>1</sup>, Andrea Bassi<sup>1</sup>, Roberto Osellame<sup>2</sup>, Francesca Bragheri<sup>2</sup>, Petra Paiè<sup>\*3</sup>

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Femtosecond laser micromachining has emerged as an extremely powerful and versatile fabrication platform for the three-dimensional structuring of transparent materials [1]. Owing to the highly nonlinear interaction between ultrashort laser pulses and matter, this technique enables precise and localized material modification with minimal collateral damage. In glass substrates, ultrashort laser pulses allow a broad range of controlled modifications, including surface and bulk ablation, localized refractive index enhancement for waveguide inscription, and the fabrication of hollow microstructures through laser irradiation followed by selective chemical etching. By properly tuning the irradiation parameters, these different modification regimes can be selectively accessed within the same substrate. These capabilities make it possible to realize complex and multifunctional integrated architectures, such as optical waveguides, microcavities, microlenses, and microfluidic channels, all embedded within a single monolithic glass platform.

In this contribution, we discuss the use of femtosecond laser micromachining for the fabrication of compact and integrated devices specifically designed for advanced biological imaging applications. The integration of 3D photonic circuits, thermo-optic dynamic components, micro-optical elements, and microfluidic networks (some illustrated in Figure 1) enables the realization of highly miniaturized and mechanically robust platforms tailored for high-performance microscopy. The possibility of fabricating all these functional elements within a single substrate ensures intrinsic alignment and structural stability, while reducing the need for external components.

Applications will include three-dimensional imaging, super-spatial-resolution microscopy [2], and ultrafast time-resolved imaging. By integrating light delivery, beam shaping, and sample handling functionalities within a single glass chip, these devices aim to enable automated, user-friendly, and cost-effective advanced imaging systems. Such a high level of functional integration contributes to improving system compactness and reliability, ultimately paving the way toward a broader dissemination of high-end microscopy techniques in biological and biomedical research environments.

Particular emphasis will be placed on the fabrication processes, including process parameter optimization and post-processing strategies required to achieve the desired structural and optical properties. We will discuss the main technological challenges encountered during device development, together with the solutions implemented to meet the targeted optical performance and functional requirements

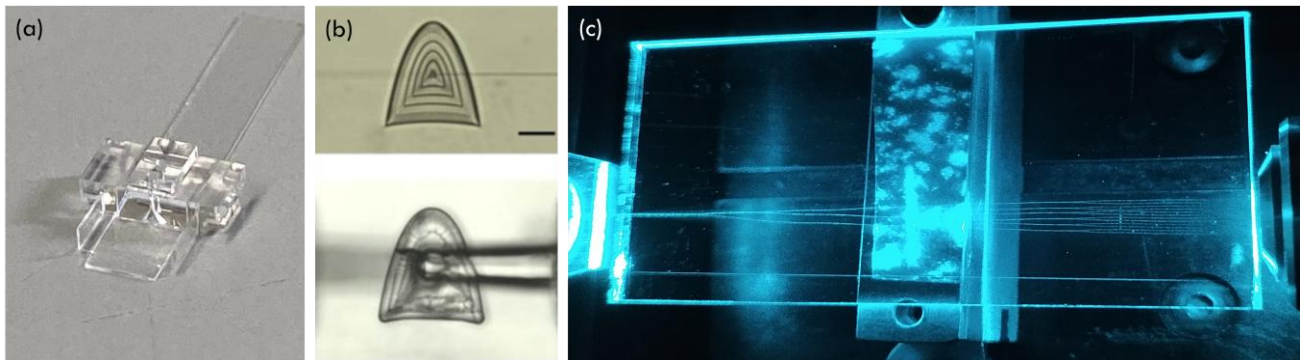


Figure 1 (a) Picture of a microfluidic channel fabricated in glass. (b) Integrated microlenses before and after the etching process. Scale bar is 100  $\mu\text{m}$  (c) Integrated beam splitter fabricated by laser micromachining, for imaging applications.

[1] S. Piacentini, F. Bragheri, G. Corrielli, R. Martínez Vázquez, P. Paiè, P. and R. Osellame "Advanced photonic and optofluidic devices fabricated in glass via femtosecond laser micromachining." *Optical Materials Express* 12.10: 3930-3945 (2022).

[2] P. Paiè, et al. "Structured-light-sheet imaging in an integrated optofluidic platform." *Lab on a Chip* 24.1: 34-46 (2024).

# Laser shock peening technology development and actual capabilities at HiLASE Center

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Laser Shock Peening (LSP) activities at the HiLASE Centre were initiated in 2013. In the early stages, the focus was placed on the design of a dedicated laser system, diagnostics of processed materials, and exploration of the technological potential and application scope of LSP. Initial samples were processed in collaboration with leading experts in the field, namely Prof. José Ocaña in Madrid and Prof. Jean-Pierre Berthe in Paris, to whom we express our sincere appreciation for their support and cooperation.

A major milestone was achieved in 2016 with the commissioning of the Bivoj laser at HiLASE—one of the world’s most powerful diode-pumped solid-state lasers, delivering up to 1 kW of average power with nanosecond pulse durations. This system became the technological backbone of LSP implementation at HiLASE. In 2017, the first industrial LSP application using the Bivoj laser was carried out on aluminum alloys to enhance their mechanical performance and fatigue resistance. Subsequent efforts expanded to titanium alloys, stainless steels, cobalt–chromium alloys, and other advanced structural materials.

Since 2019, systematic research has been conducted through targeted case studies addressing key industrial sectors, including aerospace, mechanical engineering, automotive, tooling, biomedicine, and energy. The unique capabilities of our high-power laser systems and advanced process stations enable us to address highly demanding applications, including those relevant to the space industry. Projects implemented in these domains have reached a cumulative value of several million USD.

In January 2021, the spin-off company Hi-Beams was established, focusing on combining LSP with advanced surface engineering techniques, particularly Physical Vapor Deposition (PVD).

A further significant development occurred in 2022 with the construction of the second robotic laser workstation (LSP2). This advanced facility consists of two interconnected rooms: one housing laser sources, including the Litron system and the in-house developed laser. The workstation incorporates state-of-the-art robotic and laser safety systems and is prepared for full industrial automation. Additionally, it integrates a 9 kW diode laser suitable for welding, hardening, and cladding.

The integration of multiple laser-based technologies within a single platform represents a unique capability of the HiLASE processing station. Components can now be hardened and treated by LSP in a single clamping setup, achieving both high surface hardness and enhanced resistance to crack initiation and propagation. Particularly promising is the combination of Pulsed Laser Deposition (PLD) with cladding or even additive manufacturing, enabling the production of components with entirely novel and otherwise unattainable material properties.

This contribution presents the evolution of LSP at HiLASE, key technological milestones, and selected industrial applications demonstrating the transformative potential of integrated laser-based surface engineering. [1-5]

[1] J. Kaufman, M. Böhm, J. Brajer, S. Zulić, O. Stránský, S. Pathak, “Surface integrity of SLM manufactured meso-size gears in laser shock peening without coating,” *Journal of Manufacturing Processes*, (2023).

[2] Z. Špirit, J. Brajer, J. Kaufman, M. Chocholoušek, M. Böhm, J. Kott, J. Strejcius, “Effect of Laser Shock Peening parameters on residual stresses and corrosion fatigue of AA5083,” *Metals*, vol. 11, (2021).

[3] J. Kaufman, J. Racek, M. Cieslar, P. Minárik, M. A. Steiner, S. R. Mannava, J. Brajer, “The effect of laser shock peening with and without protective coating on intergranular corrosion of sensitized AA5083,” *Corrosion Science*, vol. 194, (2022).

[4] J. Kaufman, M. Bohm, J. Brajer, S. Zulić, “Laser shock peening of aluminium alloys to enhance surface properties,” *MM Science Journal*, (2019).

[5] A. Cunha, R. O. Giacomelli, J. Kaufman, J. Brajer, T. S. Pereira, “An overview on laser shock peening process: from science to industrial applications,” *SBFoton International Optics and Photonics Conference (SBFoton IOPC)*, (2021).

Small extract : This presentation will demonstrate the effect of adapted beam intensity profiles on the stability of keyholes, which is essential for consistent process results in production lines using laser welding as a joining method. State of the art process monitoring systems will be used to show a correlation between process parameters and process emissions and penetrations depth. Influence on applications for our new core fiber laser with two rings would be presented as well.

## Laser micro welding in conduction mode of pure aluminium foils at 515 nm for Laser MegaJoule target manufacturing

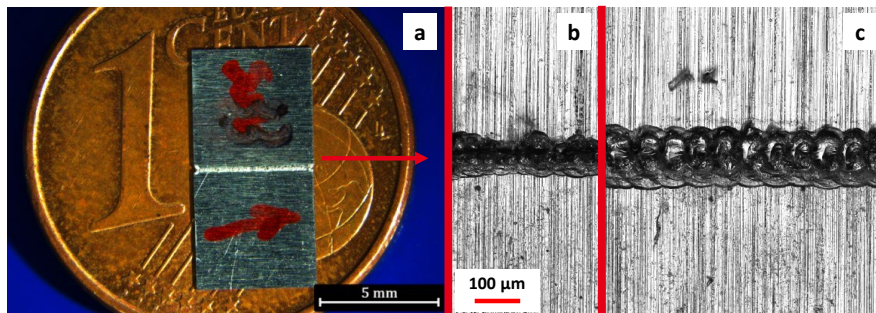
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CEA conducts laser-matter interaction experiments on the Laser Megajoule (LMJ) facility. The experimental objects, known as targets, are complex assemblies of various materials and shapes. Mechanical structuring is primarily achieved through adhesive bonding; however, the use of glue can sometimes be detrimental or unsuitable. To address this issue, the department responsible for designing, studying and manufacturing targets is developing a laser welding process dedicated to thin metallic foils and 3D parts. Welding such materials — particularly pure aluminium foils around 100  $\mu\text{m}$  thick — poses significant challenges due to their high thermal conductivity and high optical reflectivity. These intrinsic properties promote rapid heat dissipation and limit energy coupling, resulting in a very narrow and sensitive process window. Controlling energy deposition without inducing excessive penetration or peripheral thermal damage is therefore a central issue. This work focuses on the optimization of laser welding parameters for the edge-to-edge joining of thin, high-purity aluminium foils using a 515 nm pulsed green disk laser. The objective is not only to demonstrate feasibility, but to rigorously define and control the operating window, with particular attention to the transition between conduction mode and keyhole (capillary) mode. In such reduced thicknesses, the threshold between these two regimes is extremely sharp: a slight increase in power density can rapidly shift the process from stable surface melting to full capillary formation and through-penetration [1], as shown in the figure below.



Butt welding of two pure aluminium foils with a thickness of 100  $\mu\text{m}$ . (a) Illustration of the realization scale. (b) Capillary mode welding, degrading the joint (perforated areas, irregular quality). (c) The beam is defocused and the fluence drops below the vaporization threshold: the conduction mode allows assembly without perforation.

A systematic parameter study was conducted to identify stable conduction mode conditions and to precisely characterize the threshold toward capillary onset. The ability to remain just below the keyhole threshold, or to transiently approach it without instability, is a critical aspect of process optimization [1]. In this context, the use of a green wavelength slightly improves coupling and, more importantly, contributes to a more localized and controlled energy input, especially for aluminium [2]. To support the experimental analysis, numerical simulations were developed using COMSOL Multiphysics. A coupled thermo-fluid model was implemented to study heat transfer, melt pool dynamics, and fluid flow. This combined experimental and numerical approach strengthens the understanding of laser-matter interaction and enables more precise definition of a robust operating window. Overall, this work highlights that successful welding of thin, highly conductive and reflective pure materials relies primarily on rigorous parameter optimization and fine control of the conduction regime. The green laser wavelength, combined with pulsed operation and careful thermal management, offers a controlled and adaptable solution for precision applications where limiting global heat input and avoiding neighboring thermal degradation are essential.

[1] M. Haubold, A. Ganser, T. Eder, et M. F. Zäh, « Laser welding of copper using a high power disc laser at green wavelength », *Procedia CIRP*, vol. 74, p. 446-449, 2018.

[2] P. Bono, I. Metsios, J. Blackburn, et P. Hilton, « Laser processing of thin copper and aluminium thin sheets with green (532nm) and infrared (1064nm) pulsed laser beam sources », *ICALEO 2013 - 32nd Int. Congr. Appl. Lasers Electro-Opt.*, p. 520-528, 2013.

# Numerical simulation of the melt pool in laser welding—Study of the beam shaping

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Under certain operating conditions, laser welding is prone to undesirable phenomena, such as melt instabilities and defect formation, which can compromise the integrity of the welded parts. The difficulty of controlling these defects depends on the materials studied. This study focuses on materials such as aluminum, which are both reflective and good thermal conductors, making them attractive for the manufacture of many industrial components. Indeed, laser welding of aluminum in an industrial context (energy density  $\geq 1 \text{ MW/cm}^2$  [1], penetration  $\geq 1 \text{ mm}$ ) is characterized by fluctuating keyholes and unstable melt flows. It results in beads potentially affected by defects (notably porosity defects), detrimental to the integrity of the welded parts.

In addition to this materials issue, there is a new technological challenge: recent advances in laser technologies offer a wide range of operating parameters (continuous increase in welding power and speed, diversification of usable wavelengths, particularly with the advent of green and blue lasers, and beam shaping techniques). Consequently, there is a challenge in choosing the optimal parameters. In this context, multiphysics simulation is a key tool for understanding, predicting, and deciding.

We have developed a complete thermohydrodynamic model of the melt pool (CFD) that includes heat transfer, fluid dynamics, and keyhole deformation, as shown in Figure 1. An innovative approach is used to simulate multiple beam reflections in the keyhole. First, the model is used to explain the mechanism of porosity formation. Next, we studied the influence of using a double beam (core + ring) on the melt pool flows and the quality of the welded joints. All models are validated by experiments. The objective of this communication is to present all these results and show how numerical simulation can contribute to a laser welding project.

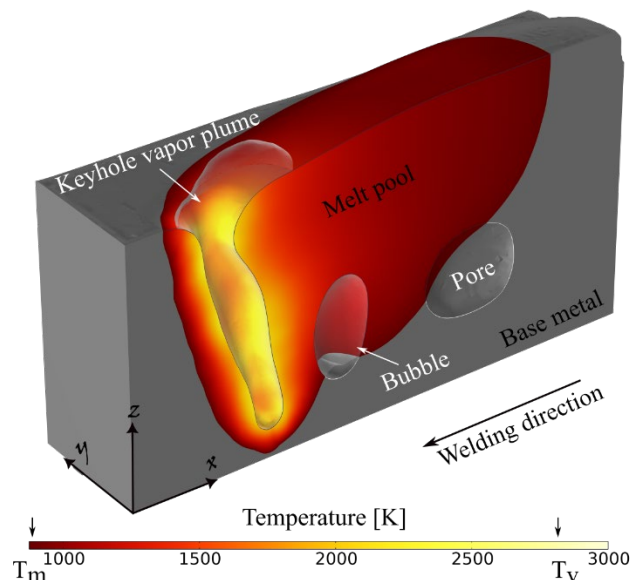


Figure 1: Full 3D view of the numerical result, showing all metal phases and the temperature field within the melt pool.  $T_m$  and  $T_v$  are respectively the temperatures of melting and vaporization. Process parameters: Aluminium A2219, Laser power is 2 kW, welding speed is 6 m/min. The laser beam has a BPP of 4.32 mm.mrad and was focused on the top surface, where its diameter is 300  $\mu\text{m}$ .

[1] M. Dal and R. Fabbro, 'An overview of the state of art in laser welding simulation', *Opt. Laser Technol.*, vol. 78, pp. 2–14, Apr. 2016, doi: 10.1016/j.optlastec.2015.09.015.

# Safety of Supercontinuum Sources: Risk Assessment and Mitigation Strategies

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Commercial supercontinuum sources, available for two decades, are increasingly integrated into research infrastructures and various industrial applications. However, the implementation of these sources presents an increased optical hazard due to their broad emission spectrum. Providing adequate eye protection for personnel involved in the operation, alignment, and development of associated applications remains highly complex. Because these sources emit across a continuous range of wavelengths, they are often perceived as impossible to secure effectively. This study challenges this consensus and provides a framework for enhancing the safety protocols for personnel working with these sources.

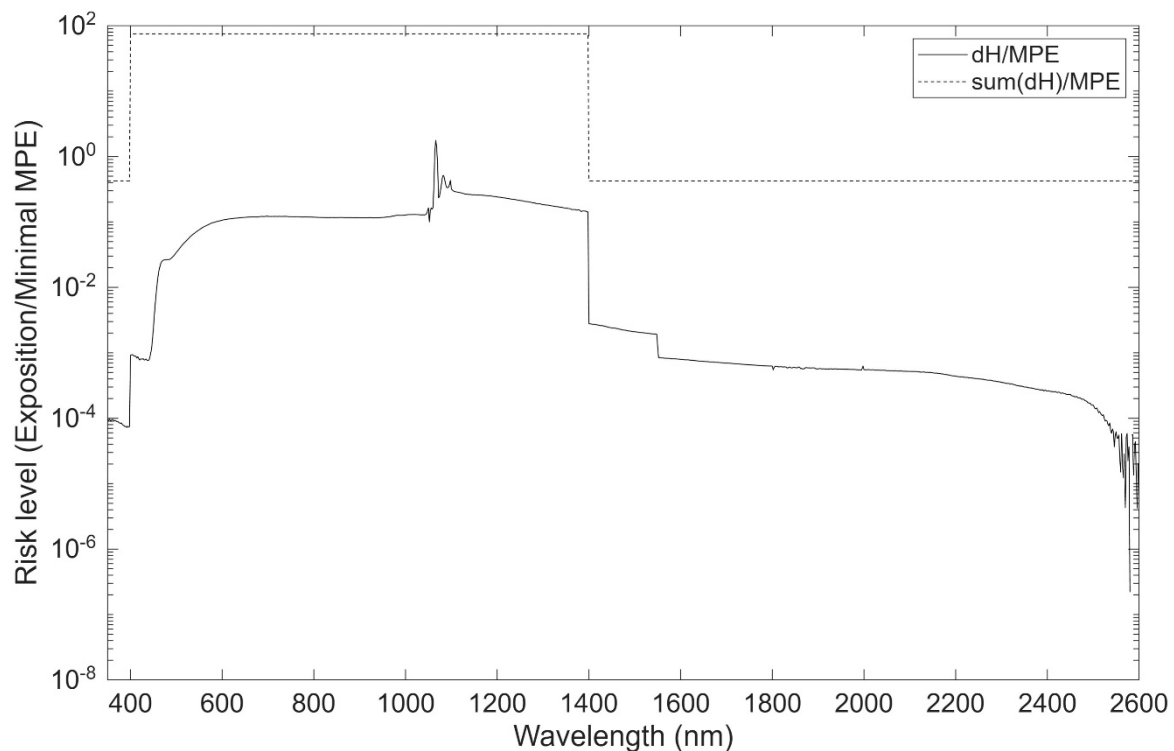


Figure 1 : Risk factor

Plain line : individual exposure  $dH(\lambda)$  divided by minimal MPE of additivity range of  $\lambda$ . This is the risk spectral contribution of individual  $\lambda$ .

Dashed line: sum of individual risk ( $dH/MPE$ ) on the additivity range:  $[315-400] \cup [1400-2600]$  and  $[400-1400]$ . This represents the standard risk considering additivity.

For this “low power” source (100mW), the risk analysis produces two risk levels: approximately 75 for the 400 nm–1400 nm range and approximately 0.3 for the other additivity range.

Strategy describe in this study can reduce risk below one even with brightest source up to few W.

# Comment prendre en compte la sécurité laser dans l'organisation des espaces de travail ?

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Trop souvent perçue comme une contrainte coûteuse, susceptible de freiner la productivité ou de complexifier les opérations, la sécurité laser peut au contraire devenir un levier d'efficacité lorsqu'elle est correctement dimensionnée et adaptée aux usages réels des utilisateurs. Elle est souvent résumée à la formation des utilisateurs, la désignation des responsables sécurité et la mise en place d'équipements de protection individuelle et collective. Si ces éléments sont effectivement essentiels et indispensables, un levier important reste encore sous-estimé : l'organisation et l'aménagement des espaces de travail au sein des salles laser.

Traiter ce sujet à la manière de ce que l'on ferait dans le cadre du « lean manufacturing » permet à la fois d'assurer la sécurité des personnes exposées, le confort au poste de travail ainsi que la performance industrielle globale. Qu'il s'agisse alors de concevoir une nouvelle installation (laboratoire R&D, plateforme technologique ou atelier de production) ou de réaménager/optimiser un espace existant, l'intégration de la sécurité dès la phase de conception constitue un facteur extrêmement important. Une conception anticipée et bien réfléchie permet également d'éviter des coûts inutiles liés à des équipements inadaptés ou à des modifications tardives des installations.

Dans cette présentation, nous nous appuyons sur un cas d'usage concret de réorganisation d'un laboratoire d'optique à partir d'un outils logiciel développé en interne afin d'illustrer les choix d'aménagement possibles, les compromis à opérer et les leviers permettant d'améliorer simultanément la sécurité, l'ergonomie et la conformité réglementaire, sans pénaliser la productivité.



Illustration générée par logiciel interne ALPhANOV – Tous droits réservés



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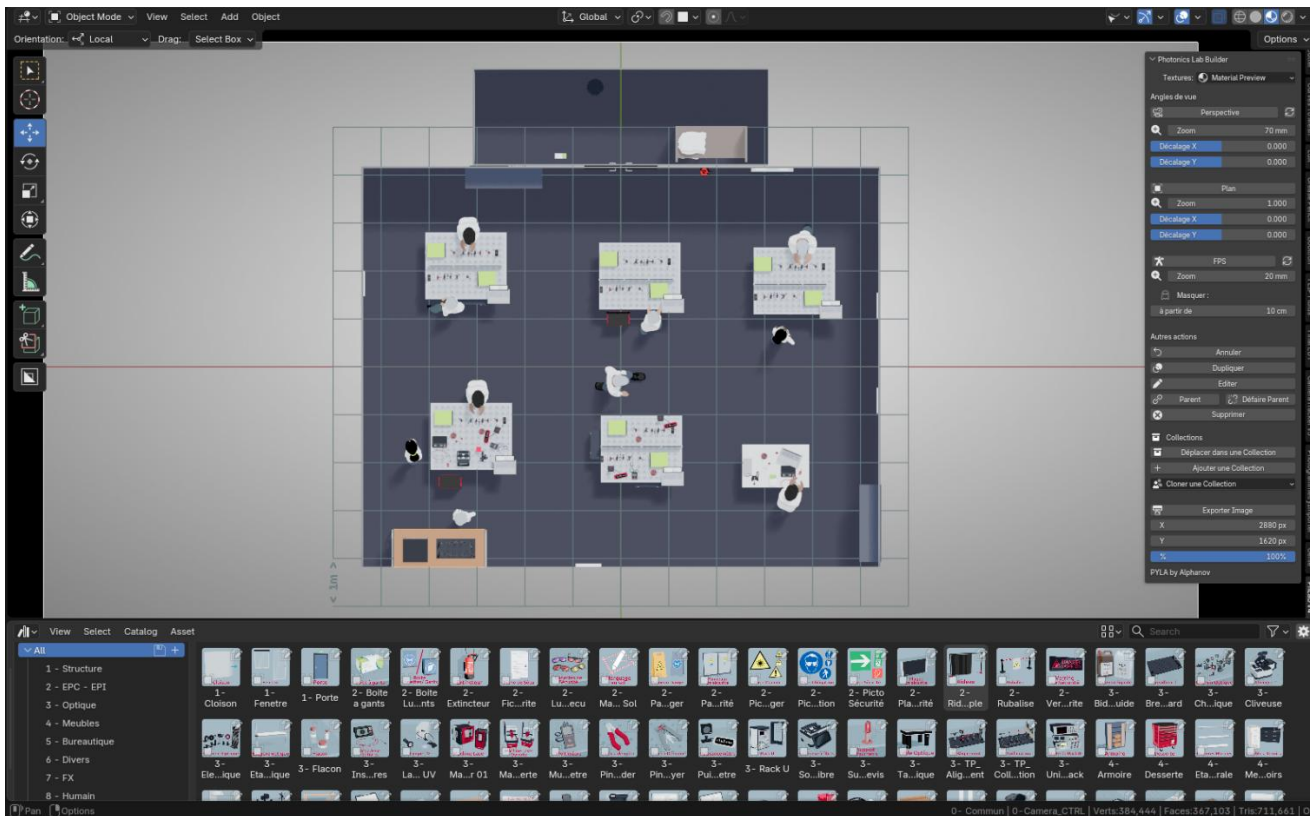


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# From ablation to surface functionalization with a GHz burst mode femtosecond source.

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Femtosecond laser processing operated in the GHz burst regime has attracted increasing attention in recent years due to its unique ability to finely control thermal effects during laser–matter interaction. This capability has enabled the emergence of novel processing strategies in the femtosecond regime, unlocking higher process efficiency and opening new application fields that were previously inaccessible.

An implementation is presented to showcase the versatility and industrial applicability of GHz-burst femtosecond laser processing. Microfluidic devices are commonly fabricated by bonding injection-moulded polymer inserts, requiring moulds with tight dimensional tolerances ( $\pm 10 \mu\text{m}$ ) and low surface roughness ( $R_a < 0.5 \mu\text{m}$ ) to ensure proper bonding and device functionality. Conventional micro-milling is typically used to produce such moulds, resulting in long fabrication times (several hours) and high costs (several thousand euros per part). The results presented here show that GHz-burst femtosecond laser processing can reduce production time to less than one hour and lower the manufacturing cost to a few hundred euros. A single GHz-burst fs laser source enables both high-throughput precision engraving and in-situ surface polishing, achieving final surface roughness values below 300 nm while maintaining good dimensional accuracy.

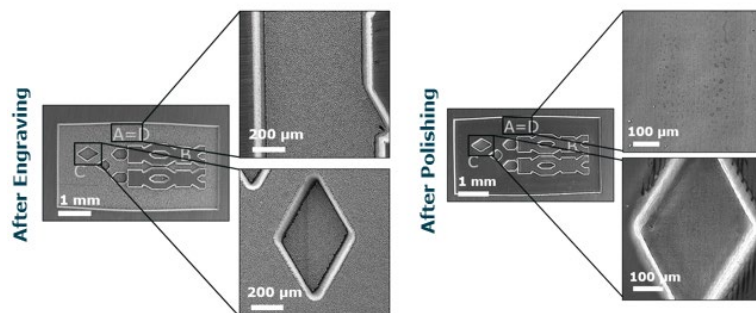


Figure 1: SEM images of a 1.2083 ESU stainless steel mould after engraving (left-hand side) and polishing (right-hand side) by fs GHz burst laser processing [1].

For 3D parts, the transmission of high-power femtosecond laser radiation through optical fibers remains a major technological limitation. Looking ahead, thanks to the low pulse energy inherent in GHz burst operation, this regime offers reduced sensitivity to beam instabilities and fiber damage, making it highly attractive for fibre-based beam delivery. A GHz-burst fs laser was successfully transmitted through a GLO Photonics hollow-core fibre mounted on a robotic arm, achieving up to 20 W of average power. Various surface treatments were performed on a three-dimensional stainless-steel component to assess power and polarisation stability during dynamic fibre motion.

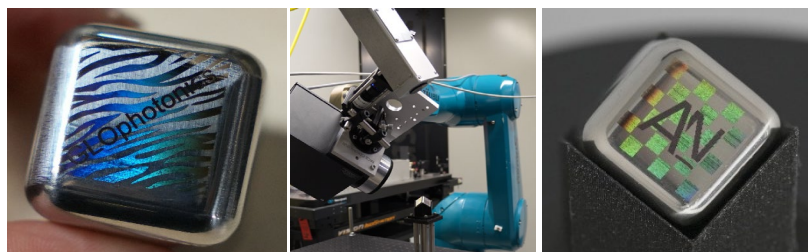


Figure 2: Photos of surface treatment by fibre-delivered fs laser in GHz regime.

[1] I. V. Leniz, T. Bakouche, M. Astigarraga, F. Husson, A. M. Zaldua, L. Gemini, J. L. Vilas-Vilela, and L. Etxeberria, *Polymers*, 17, 1289, 2025

# Laser–Coating Hybridization for Functional Surface Architectures

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Industrial processing based on pulsed laser sources has now entered an early phase of clear technological maturity. While further improvements are expected in photonics, in artificial intelligence and in data-driven process control, to cite a few domains, the most impactful next step for industrial laser processing will likely come from deeper hybridization with materials science. This is where new knowledge, new technologies and significant economic gains are expected to emerge. As physical and industrial limits stabilize, value creation increasingly shifts toward interfaces and the functional design of surfaces.

Within this context, short-pulse laser sources enable highly selective, mask-free thin-film patterning and cleaning strategies that can replace conventional fine masking approaches—often costly, complex, and difficult to scale. Beyond material removal, laser processing enables surface functionalization and preparation prior to coating, including nano-microstructuring, activation, decontamination and cleaning, controlled oxidation and smoothing or polishing. Conversely, laser processing performed after coating also unlocks new possibilities [1]. Post-coating laser treatments on the right coating enables surface functionalities that are typically material-dependent such as laser coloration. By depositing a thin metallic layer prior to laser structuring, processes initially limited to specific metals can be extended to a much wider range of materials while maintaining industrial relevance.

Because industrial performance is strongly driven by cost and process integration, these capabilities naturally lead to hybrid process chains in which multiple preparation and coating steps must be combined and sequenced within the same equipment [2]. In parallel, laser processing performed in controlled environments (vacuum, inert and reactive atmospheres) offers particularly promising opportunities for the control of surface chemistry.

Through selected prototypes and industrial case studies, this presentation aims to illustrate how hybridization of laser and coating technologies could pave the way for the next decade of developments in the field.

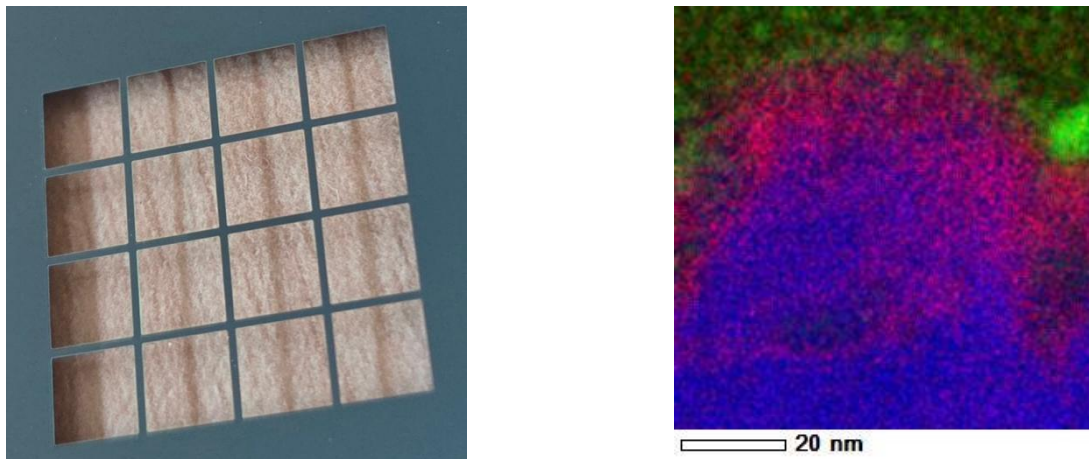


Figure 1. (Left) Laser decoating of a black coating on a glass substrate without loss of transparency. (Right) EDX mapping of a single LIPSS structure on titanium fabricated in a controlled atmosphere.

[1] J. Bonse and J. Krüger, “Structuring of thin films by ultrashort laser pulses,” *Appl. Phys. A*, vol. 129, art. no. 14, (2023)

[2] C. Héau, P. Maurin-Perrier, F. Garrelie, J-P. Colombier, and F. Pigeon, “Machine and method for treating parts of different shapes,” European Patent EP 4175745 A1, May 10, 2023

## “Ultrashort-Pulse Laser Shaping of Diffuser Cooling Holes in TBC-Coated Turbine Blades”

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The continuous pursuit of higher efficiency, lower fuel consumption, and enhanced performance in modern aerospace propulsion and industrial gas turbine systems has driven turbine inlet temperatures to unprecedented levels. Turbine components operating in these harsh thermal environments require advanced cooling architectures incorporating internal air-cooling channels and diffuser-shaped film-cooling holes, along with thermal barrier coatings (TBCs) that shield components from extreme combustion-zone temperatures. Diffuser cooling holes are essential for achieving effective film cooling of the external surfaces in turbine blades, thus decreasing their surface temperature. However, their precise fabrication remains a major industrial challenge. Conventional EDM drilling with orbiting techniques provides reliable control for metering-hole creation but lacks the capability to accurately machine diffuser geometries, particularly through TBC layers and on non-conductive substrates such as ceramic matrix composites (CMCs).

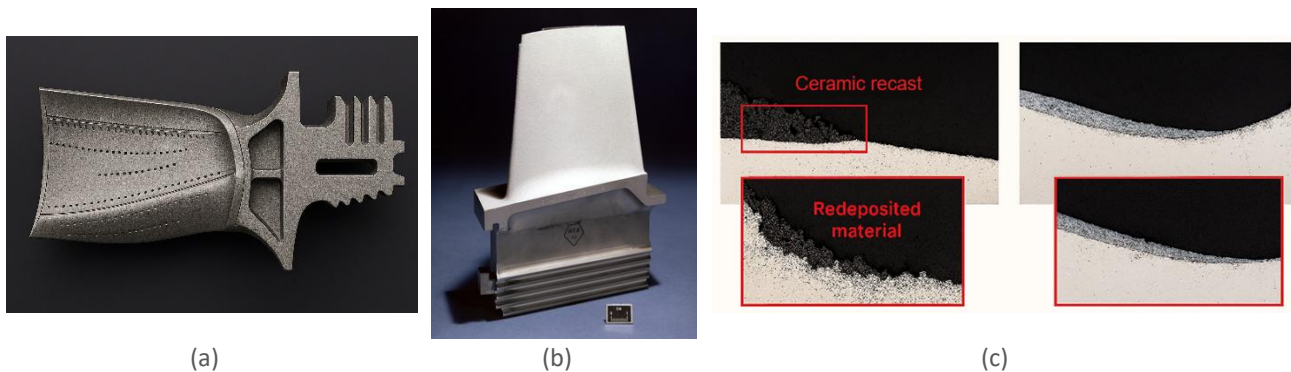


Figure 1: (a) A turbine blade with diffuser-shape cooling holes; (b) a turbine blade protected with a ceramic thermal barrier coating (TBC); (c) cross-sections of diffusers machined by laser in the nanosecond regime (left), displaying recast and redeposition defects, and the same diffusers machined with a femtosecond laser source (right).

Leveraging the high-precision 5-axis platform of the LASER S 500 U, combined with ultrafast laser technology and the deterministic layered-cutting strategies enabled by LaserSUITE360 CAM software, CHARMILLES aims to deliver a fully integrated laser-based manufacturing workflow. This approach targets three key capabilities: controlled layered ablation for accurate diffuser shaping, highly efficient ceramic coating removal with minimal thermal damage, and robust machining of both metallic alloys and non-conductive materials including CMCs.

This presentation outlines the laser-based workflow for diffuser-shaped cooling hole fabrication and highlights internal experimental results. Controlled laser angles of incidence enable highly uniform diffuser morphologies, while femtosecond-pulse processing significantly reduces recast, microcracking, and delamination compared with nanosecond regimes. These advances produce notable improvements in geometric fidelity, coating-removal efficiency, and overall shaping quality, offering a promising path toward next-generation cooling architectures for high-temperature turbine applications.

# Laser Based Surface Preparation – Cleaning and Structuring of Gigacast parts and other materials

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TRUMPF Laser & Systemtechnik SE is a high-tech company with a broad product portfolio ranging from industrial laser sources and system solutions to novel products based on quantum technology. In particular, our industrial laser portfolio addresses solutions for various industries such as mobility and e-mobility, aerospace, medical technology, consumer electronics, energy, and data storage.

Pulsed nanosecond and picosecond laser sources are becoming increasingly important for laser-based surface treatment applications, including cleaning, ablation, and structuring. One of the key advantages of laser processing as a surface treatment tool is its contact-free nature, enabling highly selective and precise surface modification with excellent reproducibility. In addition, laser processing allows manufacturers to comply with increasingly stringent environmental regulations by avoiding the use of chemical additives. Laser processing is often used as a pre-treatment step for subsequent processes such as bonding, welding, coating, sealing, or painting, for example to increase adhesive strength or improve welding quality. Furthermore, laser surface structuring can significantly modify or enhance material properties, such as hydrophilicity or hydrophobicity, by creating micro- and nanoscale patterns.

In this contribution, we present the principles, mechanisms, and recent developments in laser cleaning, ablation, and structuring. By introducing application data and illustrative examples, we demonstrate their potential for industrial applications, with a particular focus on e-mobility, including adhesive and welding preparation as well as the joining preparation of gigacast parts. Depending on the productivity requirements, different laser models can be applied to address these applications. Correspondingly, tailored solutions by TRUMPF will be presented.

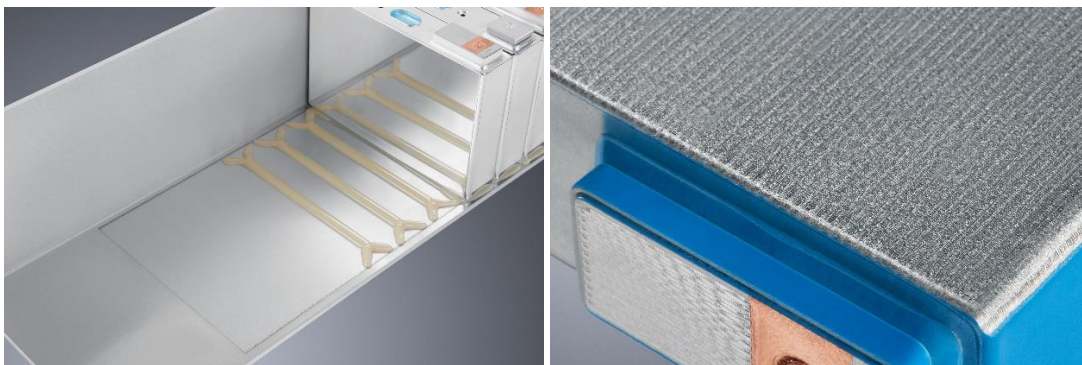


Figure 1 left: Cleaning of the battery pack for adhesive preparation (cell-to-pack technology).

Figure 2 right: Cleaning of a prismatic battery cell as surface preparation for (a) coating and (b) welding (terminals).

# Burst mode in dielectric material laser welding: from glass to SiC

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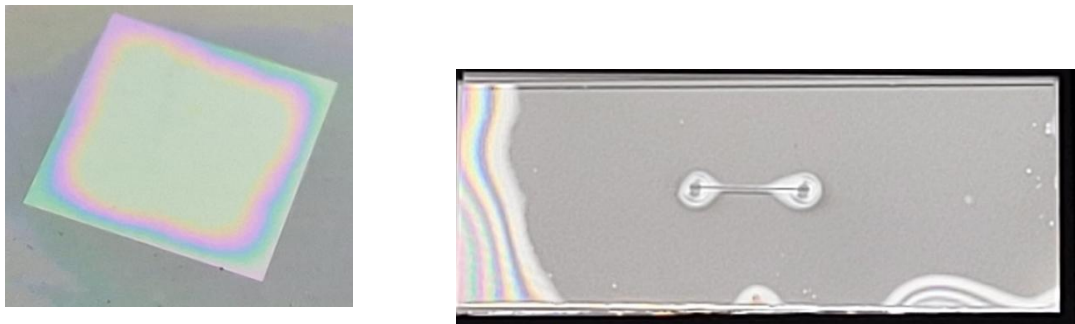
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Transparent materials, especially glass and dielectric materials are key materials in modern technologies. They combine high mechanical resistance, chemical stability, low conductivity and high transparency across select spectral ranges. They are used in photonics technologies, biotechnology, aerospace applications-- from diode packaging and microfluidic to the next generation of quantum optical circuits [1]. Being able to accurately micromachine these materials is therefore a requirement. Our work is focused on their assembly by ultrashort laser welding. By spatially concentrating the laser at the interface of the transparent dielectric materials to assemble, a non-linear absorption takes place creating a localized energy deposition leading to a temperature increase. In our case a long focal (50 mm) and high frequencies are used to benefit of thermal accumulation with a high positioning robustness, making it possible to reach welding speeds of around 1 m/s [2]. However, burst mode opens now possibility to reach higher frequency [3].

Based on a finite element model of the thermo-optical effect, high repetition frequencies have been compared to burst modes. Guided by the simulations, we will show experimentally, how MHz burst mode can be used to enhance the energy deposition in borosilicate glass, and how GHz burst mode is naturally more adapted for glass on aluminium welding. As we will show, the welding of silicon carbide (SiC) monocrystal is also better in burst mode. Finally, to illustrate possible concrete application of the technique, a fully manufactured microfluidic system in borosilicate glass by femtosecond laser will be presented. The channel ablation, hole drilling and welding have been micromachined using a 1030 nm 400 fs ultra-short laser.



*Figure 1 (a) SiC weld on Si-c with a 1030 nm 400 fs laser in burst mode. (b) Glass microfluidic system. The channel ablation, hole drilling and welding have been micromachined using the same laser at 500 kHz.*

## References

- [1] R. Osellame, G. Cerullo, et R. Ramponi, Femtosecond Laser Micromachining: Photonic and Microfluidic Devices in Transparent Materials, vol. 123. in Topics in Applied Physics, vol. 123. (2012)
- [2] M. Gstalter, G. Chabrol, A. Bahouka, K.-D. Dorkenoo, J.-L. Rehspringer, et S. Lecler, Long focal length high repetition rate femtosecond laser glass welding, *Appl. Opt.*, vol. 58, no 32, p. 8858, (2019)
- [3] M. Lafargue, T. Guilberteau, P. Balage, B. Gavory, J. Lopez, et I. Manek-Hönninger, « In-Volume Glass Modification Using a Femtosecond Laser: Comparison Between Repetitive Single-Pulse, MHz Burst, and GHz Burst Regimes », *Materials*, vol. 18, no 1, p. 78, déc. 2024, doi: 10.3390/ma18010078.

# Type-A volume Bragg Gratings inscribed by femtosecond laser using phase-mask and burst-mode exposure

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Volume Bragg gratings (VBGs) are optical devices exhibiting a periodic refractive index structure inside bulk glass, used in a wide range of applications. Traditionally fabricated with UV interference pattern [1], VBGs can now be created in diverse materials using femtosecond (fs) laser inscription [2]. However, achieving fabrication processes compatible with industrial requirements remains challenging. This motivates the development of highly photosensitive glass matrices capable of larger refractive index changes and faster inscription. Glasses containing high concentrations of silver ions are promising, as fs irradiation at high repetition rates (MHz range) forms silver clusters responsible for a distinctive strong Type-A refractive index modification ("A" for Argentum) [3]. Such a high refractive index change allows for high diffraction efficiencies with thinner and more confined gratings. In this context, we investigate phase-mask method [4] to increase Type-A VBG throughput, enabling large-scale parallelization and precise grating control.

In our setup, a 5 cm cylindrical lens focuses the beam in one direction while the phase mask diffracts it perpendicularly, creating a periodic inscription. The resulting light sheet provides a large interaction area requiring a high-power laser to maintain consistent local irradiance for glass modification. For this purpose, a Tangor laser source (Amplitude system, 1030 nm, up to 40 MHz, pulses  $\sim$  430 fs, up to 100 W) was used to achieve the peak intensities and repetition rate suitable for Type-A modifications. Careful selection of the repetition rate is crucial to ensure adequate irradiance for Type-A modification while limiting thermal accumulation. Subsequently, the laser operated in burst mode at 100 kHz, with each burst containing three pulses separated by 25 ns. With 80,000 accumulated pulses, the irradiation generates a light-sheet with lateral dimensions of 850  $\mu$ m along the x-axis and a depth of 500  $\mu$ m along the z-axis (Fig.1 (a)), allowing sample translation along the y-axis for VBG inscription (Fig. 1(a)). The first Type-A VBG using this technique was inscribed with a period of 0.995  $\mu$ m over a 900  $\mu$ m length along the y-axis, completed in 4.5 minutes. A transmitted diffraction efficiency of 77% at 632.8 nm was experimentally measured and was well fitted by modelling with an effective grating thickness of 440  $\mu$ m and an index modulation of  $6.7 \times 10^{-4}$  (Fig.1 (b)).

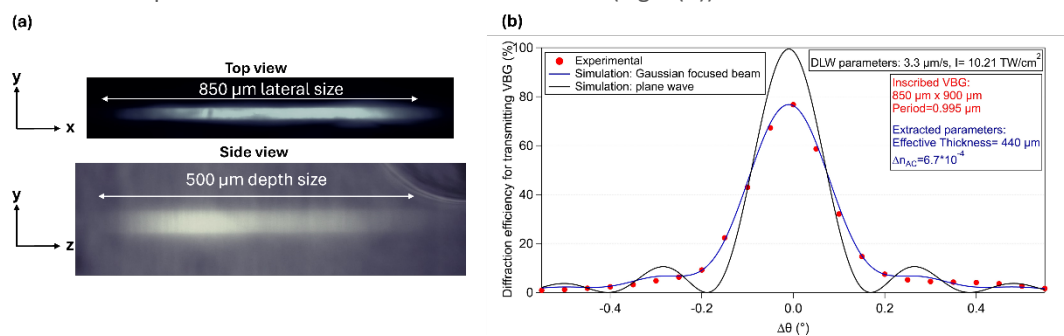


Figure 1: (a) Top view and side view of a fluorescence image (excitation at 365 nm) showing modifications induced using the phase mask (b) Experimental and simulated angular dependence of the diffraction efficiency of the transmitting Bragg grating at 632.8 nm.

In this framework, combining the phase-mask technique with optimized burst-mode processing enables the inscription of a Type-A grating. Burst mode further decouples thermal load from nonlinear interaction via independent control of inter-burst and repetition rates. This breakthrough represents a major step toward scalable industrial fabrication of Type-A VBGs.

[1] L.A. Siiman, J. Lumeau, L. Canioni, L. Glebov. "Non-collinear generation of third harmonic of IR ultrashort laser pulses by PTR glass volume Bragg gratings" Opt. Lett., 34,17 (2009).

[2] C. Voigtländer, D. Richter, J. Thomas, A. Tünnermann, and S. Nolte, "Inscription of high contrast volume Bragg gratings in fused silica with femtosecond laser pulses," Applied Physics A, 102 (2010).

[3] L. Loi, Y. Petit, Y. Petit, and L. Canioni, "High refractive index change in Type A laser modification using a multi-scan approach," Opt. Mater. Express, OME, 12, 6 (2022).

[4] L. Talbot, D. Richter, M. Heck, S. Nolte, and M. Bernier, "Femtosecond-written volume Bragg gratings in fluoride glasses", Opt. Lett., 5,13, (2020).

# Enhanced columnar structuring in silicon via GHz-burst laser processing

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Silicon is a technologically important crystal owing to its exceptional mechanical and thermal properties, including a high Young's modulus ( $27 \times 10^6$  psi), high hardness (Knoop hardness  $\approx 850$ ), high tensile yield strength ( $\sim 10^6$  psi), and excellent thermal conductivity and diffusivity [1-3]. Although silicon processing using ultrashort laser pulses has been extensively studied for applications such as laser-induced periodic surface structure (LIPSS) formation [4] and laser welding [5], controlled in-bulk modification remains challenging. This difficulty primarily arises from the material's high nonlinear refractive index, which results in a low critical power for self-focusing thus leading to adverse effects such as the optical Kerr effect and prefocal absorption, hindering precise energy deposition within the bulk.

In this work, ultrashort laser pulses at a wavelength of  $1.6 \mu\text{m}$  are employed to mitigate these limitations and to achieve uniform backside modifications throughout the bulk of a 1-mm-thick crystalline silicon (c-Si) sample. A systematic comparative investigation is performed between single-pulse irradiation and a two-pulse burst configuration with a temporal separation of 1 ns (2-ppb GHz burst), exploring different parameters including writing speed, pulse duration, repetition rate, and pulse energy to optimize column growth propagating from the rear surface. Moreover, different energy distributions between the two pulses in the burst are also analyzed to assess their influence on the modification probability in silicon. All experiments are carried out under two conditions: (i) with a glass substrate and (ii) in air (floating configuration).

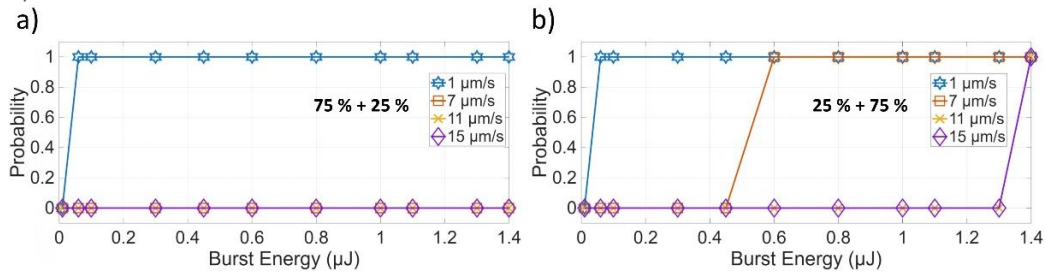


Figure 1. Evolution of modification probability w.r.t burst energy at 1 kHz and 2.5 ps for a) 75 % + 25 % and b) 25 % + 75 % distributions with a glass substrate

The results demonstrate a substantial advantage of the 2-ppb GHz-burst regime over single-pulse for inducing columnar structures in silicon where it's possible to have reproducible modifications over a wide range of laser parameters in the former case than the latter. While 25%–75% (first–second pulse) energy split shows the best performance, a 75%–25% distribution is found to be less effective for fabrication (figure 1). Using the optimized processing parameters, highly repeatable columns are successfully fabricated at writing speeds of up to  $15 \mu\text{m/s}$ .

[1] A. Kelly, Strong Solids, 2nd ed. (Monographs on the Physics and Chemistry of Materials). Oxford, England: Clarendon, 1973

[2] C. J. Glassbrenner, G. A. Slack, "Thermal Conductivity of Silicon and Germanium from 3°K to the Melting Point", Physical Review 134 (1964), A1058.

[3] J. Bonse, T. Seuthe, M. Grehn, M. Eberstein, A. Rosenfeld, A. Mermillod-Blondin, "Time-resolved microscopy of fs-laser-induced heat flows in glasses", Applied Physics A 124, 60 (2018).

[4] L. Gemini, M. Hashida, M. Shimizu et al. "Periodic nanostructures self-formed on silicon and silicon carbide by femtosecond laser irradiation", Applied Physics A 117 (2014), 49-54

[5] A. Hansen, T. Amberla, Y. Okamoto, I. Miyamoto, "Local laser joining of glass and silicon", Proceedings of the ICALEO 2012: 31st International Congress on Laser Materials Processing, Laser Microprocessing and Nanomanufacturing, pp. 372-378

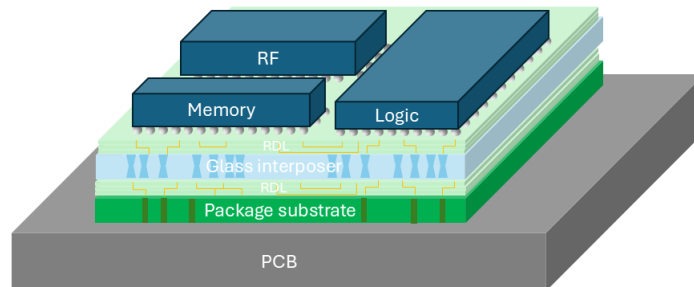
# Lasers ultracourts dans le semi-conducteurs : des procédés aux marchés, opportunités et défis technologiques

Author :Vincent Rouffiange - Quentin Mocaer – Eric Audouard

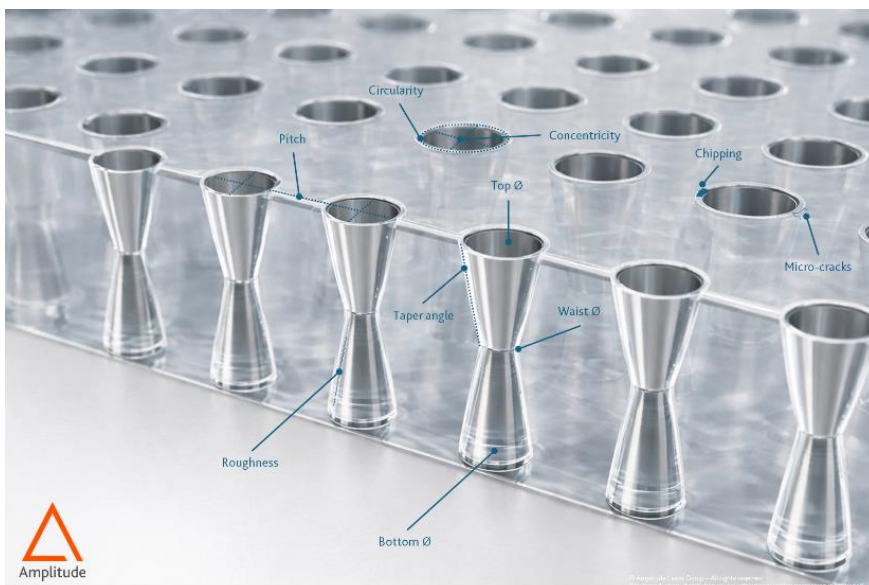
L'évolution rapide des architectures de composants semi-conducteurs, portée par le more-than-Moore, l'advanced packaging et la montée en puissance des applications HPC et IA, fait émerger de nouveaux besoins en procédés de fabrication, de structuration et d'intégration. Dans ce contexte, les lasers ultracourts apparaissent comme une technologie clé pour adresser certaines de ces exigences, en particulier lorsque la précision, la flexibilité matériaux et la maîtrise des effets thermiques deviennent critiques.

Cette présentation propose une cartographie technique des opportunités offertes par les lasers ultracourts dans le domaine du semi-conducteur. À travers un panorama d'applications couvrant l'usinage de substrats PCB HDI avancés, la fabrication des interposeurs en verre, la découpe de wafers en matériaux avancés et fragiles (SiC, GaN, Saphir...), la métrologie avancée, la photonique co-packagée, la présentation analyse les exigences procédés et les contraintes physiques associées à l'utilisation des lasers ultracourts.

L'objectif est de fournir une lecture structurée des domaines d'application des lasers ultracourts dans le semi-conducteur, en identifiant les facteurs limitants dominants pour chaque classe de procédés.



Architecture 2.5D IC



TGV Criteria

# How laser process monitoring enhances manufacturing

*Boubakar Sehili, Area Sales Manager*

*Precitec*

The increasing demand for zero-defect manufacturing and fully digitalized production environments has significantly elevated the role of laser process monitoring in industrial material processing in the last years. While laser-based processes such as welding, cutting, and cleaning offer high precision and productivity, their sensitivity to parameter variations, material inconsistencies, and dynamic process instabilities necessitates robust in-situ monitoring solutions.

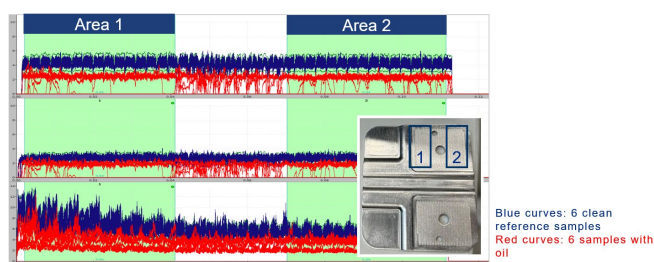
This contribution describes use cases of a high-bandwidth photodiode-based monitoring system (LWM) for in-situ observation of laser welding and cutting processes. Coaxially integrated photodiodes capture broadband optical emissions originating from the melt pool, keyhole dynamics, plasma formation, and material ejection. The temporal characteristics of the emitted radiation are analysed in both time and frequency domains to extract process-relevant features associated with penetration depth variations, keyhole instabilities, pore formation, spatter activity, and cutting front fluctuations.

For laser welding, characteristic signal signatures are correlated with weld penetration states (conduction vs. keyhole mode), incomplete fusion, and pore formation. In laser cutting, emission intensity modulations and high-frequency components are linked to cut front stability, dross formation, and process interruptions. In laser cleaning, the residues presence has a clear impact on the sensor signals, as shown in Figure 1.

New generation of sensor, with more wavelengths enable more precise detection and focus on key aspects of the process tailored to the targeted application.

Experimental validation under industrial conditions demonstrates that photodiode signals provide high sensitivity to process instabilities while maintaining robustness against harsh environmental influences. The results confirm the suitability of compact photodiode systems as cost-efficient and scalable solutions for real-time quality monitoring and as key enablers for closed-loop control strategies in laser material processing.

Finally recent advancements in in-process monitoring and sensor technologies have enhanced the ability to collect real-time data during laser operations. These highly valuable data, when processed with AI Models, are transforming the approach from basic curves analysis to real life physical quantities.



[1] Dr. Daniel Weller, Florian Hermann, Volkan Yavuz (2025)

# Online Multimodal Sensing and Machine Learning for Silicon Laser Thinning

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Laser fault analysis investigates active integrated circuits under operation with optical techniques, such as photoemission microscopy. It requires access to the backside of the circuit through controlled thinning of the silicon substrate. Laser ablation must terminate close to the active layer, without degrading the surface roughness. Ultrafast laser ablation processing is ideal for this application. A practical difficulty is that the thinning process provides no material transition or intrinsic endpoint, making depth control difficult during processing.

This contribution focuses on the use of online diagnostics to monitor ultrafast laser thinning of silicon for fault analysis applications. Rather than introducing complex in-situ metrology into the workstation, the approach relies on simple sensors integrated directly on the laser processing platform. The experimental setup combines an infrared photodiode, an acoustic microphone, a fiber-coupled spectrometer, and a camera, all operating synchronously during ablation. The objective is to determine what information relevant to thinning depth and process state can be extracted from signals available during processing, and how this information evolves from individual sensors to integrated multimodal use.

Experimental results are presented on a dataset of 129 silicon ablation experiments, with ablation depth measured offline using a confocal profilometer. The analysis proceeds in two stages. First, individual sensor channels are considered independently. Using random forest classification, single-sensor signals are shown to encode process parameter information, such as repetition rate and scan speed, indicating that each diagnostic captures information on the operating conditions. Random forest regression applied to individual sensor channels further enables quantitative depth estimation.

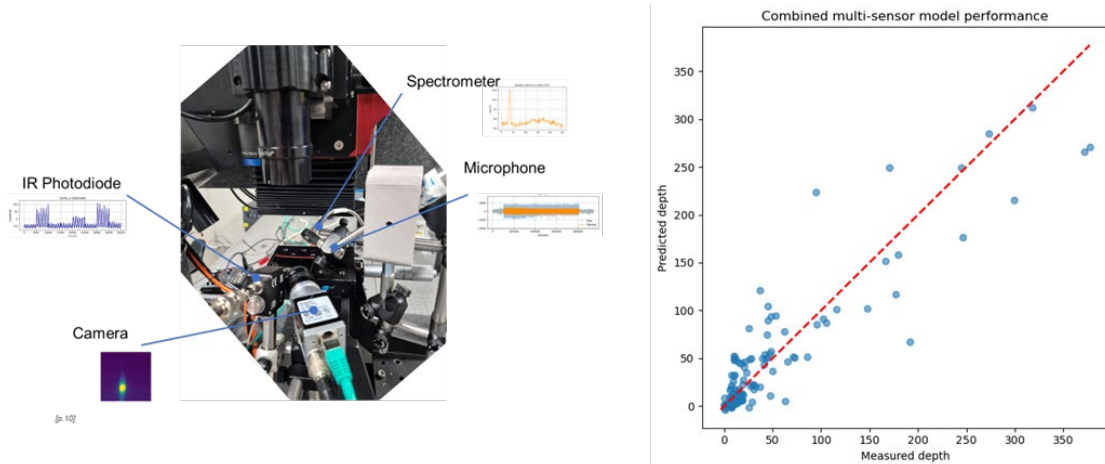


Figure 1 (a) Multimodal micro-processing set-up. (b) Predicted vs measured ablation depths from combined model.

In this configuration, coefficients of determination reach up to  $R^2 \approx 0.8$ , with mean absolute errors on the order of 20  $\mu\text{m}$  across the full thinning range (0–350  $\mu\text{m}$ ), using a dataset of 129 samples. These results show that useful depth information can be obtained from individual online diagnostics, even with limited data.

In a second stage, sensor signals are combined into integrated multimodal models. Multimodal inputs achieve depth prediction performance comparable to the best individual sensor while improving robustness to variations in signal quality and sensor availability. This progression highlights the respective roles of single-sensor diagnostics, which already provide quantitative process information, and multimodal integration, which supports more reliable operation.

Overall, the results demonstrate that simple online diagnostics can enable quantitative monitoring of ultrafast silicon thinning for laser fault analysis. The transition from individual sensor models to integrated multimodal approaches provides a practical basis for monitoring thinning close to the wafer and supports the development of adaptive processing strategies driven by live process signals.

# AI-driven optimization of femtosecond laser micromachining parameters

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In laser micromachining, the complex and non-linear laser-matter interaction prevents theoretical models from predicting optimal engraving parameters to meet time and quality criteria, often requiring numerous experimental tests for each new process to be developed. These traditional approaches are resource-intensive, requiring substantial machine and personnel time. To address these challenges, we propose an innovative methodology leveraging artificial intelligence (AI) to streamline the parameter optimization process. By combining a robust experimental database with advanced AI techniques, such as machine learning models and optimization algorithms, our approach enables the prediction of optimal laser parameters to meet dimensional and quality criteria without relying on exhaustive empirical testing for each new process.

Our latest results on this methodology will be presented, demonstrating its capacity to predict key parameters such as energy per pulse, speed, frequency, and pitch. This approach reduces resource consumption and accelerates process development, offering a transformative step forward in the field.

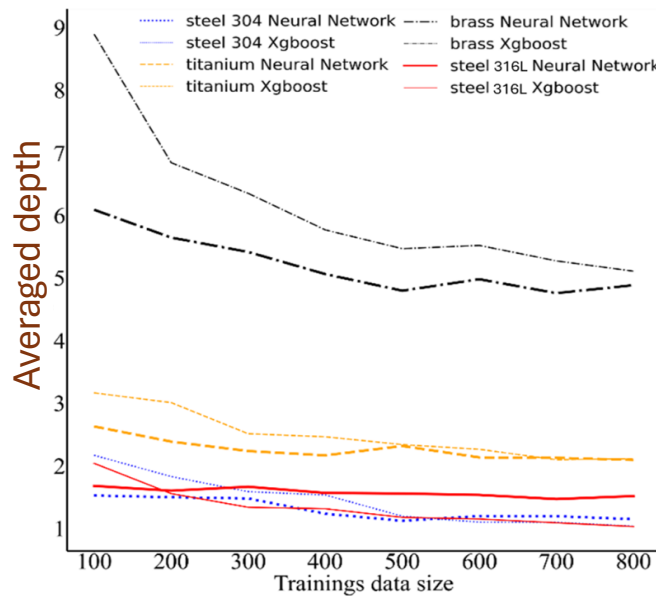


Figure 1 : Performance of each model (Xgboost and pretrained NN + transfer learning) versus training data for each tested material

# AI-aided autonomous laser process development with multi-objective optimization and computer vision

Nicolas Dalloz\*<sup>1</sup>, Sebastian Cucerca<sup>1</sup>, Vahid Babaei<sup>1</sup>, Omid Alizadeh-Mousavi<sup>1</sup>

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Laser process development, traditionally reliant on time-consuming manual trial-and-error, demands significant expert time for parameter tuning across new applications and materials. This expertise requirement, extending beyond laser processing to include application-specific characterization, combined with a shortage of photonics-trained personnel, severely impedes the adoption of laser processing in manufacturing.

Integrating AI and algorithmic optimization can substantially reduce development time and enhance performance, increasing the Return-on-Investment (ROI) of laser processing. However, deep-learning approaches often require thousands of measurements and extensive initial data gathering[1], meaning the trial-and-error phase must still be completed to generate the necessary datasets.

Alternatively, embedding machine learning directly into the experimentation phase yields higher quality datasets and superior outcomes. As an example, our team achieved autonomous tuning for laser color marking by combining a custom multi-objective genetic algorithm with deep-learning-based vision automation. This optimization framework provides enhanced performance and repeatability, enabling advanced applications such as full-color image and true-color reproduction (Figure 1 demonstrates examples on Titanium and Stainless Steel).

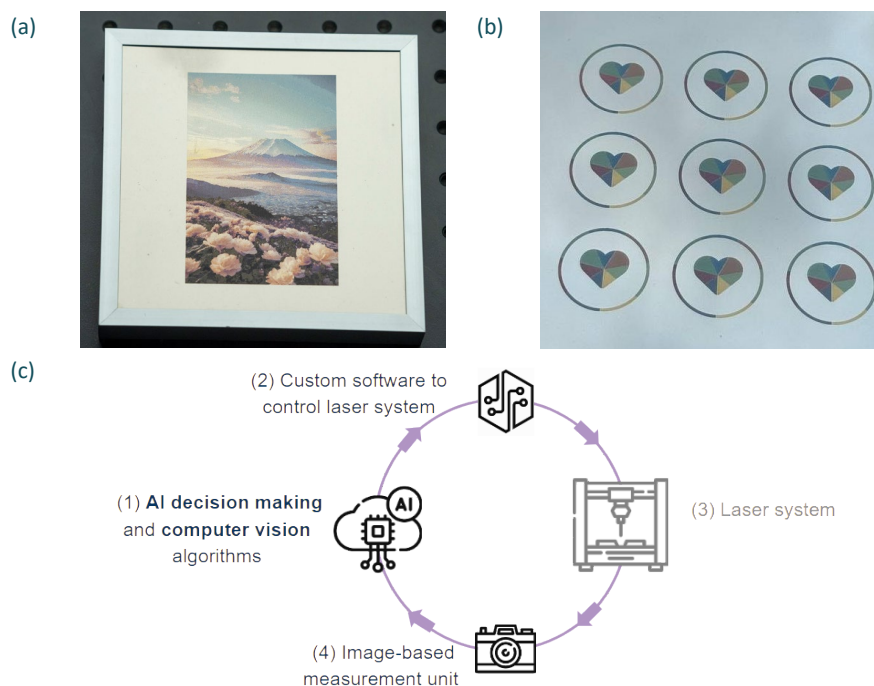


Figure 1 (a) Photograph of a 13 x 13 cm titanium plate marked with an artistic view of mount fuji with saturated and high-resolution colors found with the method (b) 9 highly-saturated color logos reproduced on stainless steel with high reproducibility above usual industrial printing standards (c) schematics of the iterative optimization system where a multi-objective decision making algorithm directly communicates with the laser and results are fed back into the loop by an automated vision unit.

This systematic approach can be carried out exactly in the same way on any laser system and for other laser processes, reducing the need for human intervention. The main blocking point of data collection is overcome through intelligent automation. This framework has potential to overcome the current limitations of laser process development.

[1] Ma, H., Dalloz, N., Habrard, A., Sebban, M., Sterl, F., Giessen, H., Hebert, M. and Destouches, N., "Predicting Laser-Induced Colors of Random Plasmonic Metasurfaces and Optimizing Image Multiplexing Using Deep Learning," ACS Nano 16(6), 9410–9419 (2022).

[2] Cucerca, S., Didyk, P., Seidel, H.-P. and Babaei, V., "Computational Image Marking on Metals via Laser Induced Heating," ACM Trans. Graph. 39(4), 12 (2020).

# Blue-Laser PBF-LB to manufacture high-density pure Copper parts

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Laser-based powder bed fusion (PBF-LB) of pure copper remains challenging due to its low absorption of near-infrared (NIR) laser radiation. Consequently, high laser powers are typically required, while only narrow process windows can be achieved to maintain stable melt pool conditions and suppress excessive spatter formation. To mitigate these limitations, copper alloys with reduced thermal and electrical conductivity are often employed in PBF-LB processes. However, this approach compromises the outstanding material properties of pure copper and restricts the performance potential of the manufactured components. In contrast, shorter laser wavelengths used in PBF-LB, such as green [1] and blue [2], exhibit significantly higher absorptivity in copper, resulting in improved energy coupling and enhanced process stability. With such a set-up, it becomes possible to manufacture pure copper parts with high relative density, which is particularly advantageous for applications requiring complex geometries combined with high electrical conductivity, for example inductors.

In this study, a new 445 nm blue-wavelength laser, the Laserline LDFblue 400-wbc was integrated into a modular PBF-LB system controlled by Autodesk Machine Control Framework (AMCF), to investigate its suitability for processing pure copper. The optical scanner system Raylase SS-IV-30 provides a spot diameter of 100  $\mu\text{m}$  on the powder bed. Using a conventional exposure strategy, the system demonstrated stable melting behavior with minimal spatter and enabled the fabrication of complex geometries, including 45° lattice overhangs (Figure 1a)). Density measurements on cubes based on Archimedes' principle revealed relative densities of up to 99.97%, with many parameter sets exceeding 99.5%, indicating a wide and robust process window (Figure 1b)). These results show that blue-wavelength laser radiation enables high-density pure copper parts and provides strong potential for processing other highly reflective metals such as silver and gold.

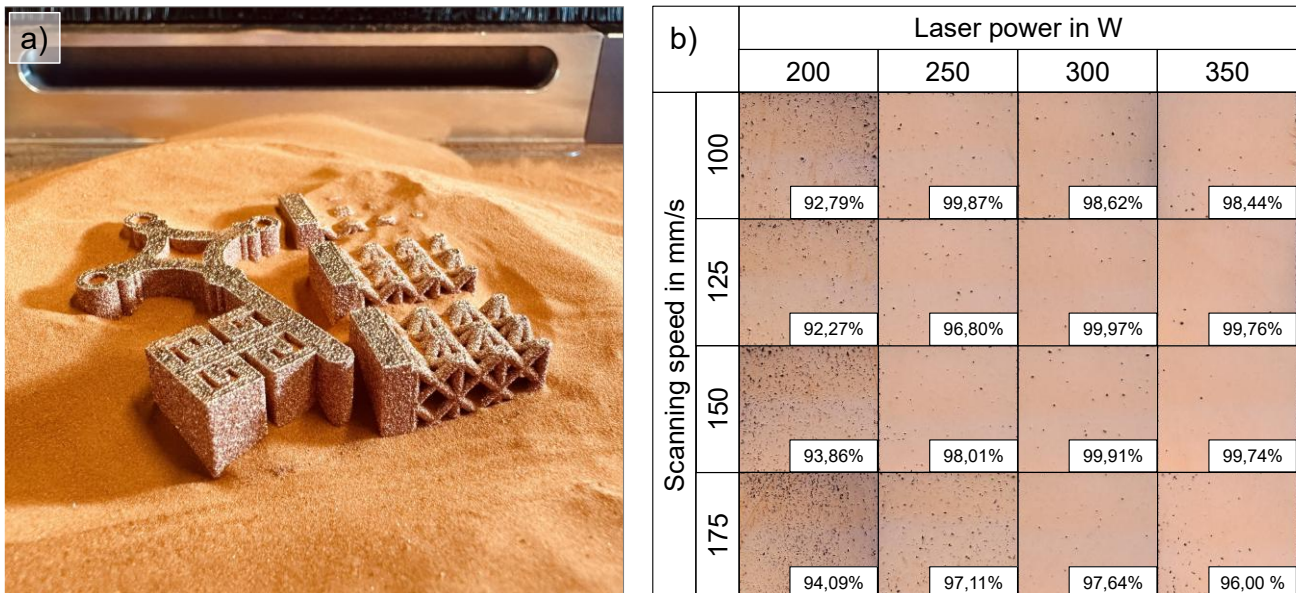


Figure 1 (a) Lattice structures printed from pure copper and part of the city emblem, the “Bremen Key”. (b) Cross-sections of cubes made of pure Copper and the relative density measured based on Archimedes’ principle.

## Acknowledgements

The authors thank Laserline for providing the LDFblue 400-wbc laser for PBF-LB.

[1] I. Günther, B. Zillmann and T. Niendorf, Thomas, Metal powder bed fusion of pure and coated copper for power electronics applications using a green laser, *Journal of Materials Research and Technology*, vol. 38, pp. 5250–526, (2025)

[2] K. Takenaka, Y. Sato, N. Yoshida, M. Yoshitani, M. Heya and M. Tsukamoto, Additive manufactured of pure copper by blue diode laser induced selective laser melting, *Journal of Laser Applications*, vol. 34, 042041, (2022)

## **Optimisation de la qualité en LPBF : Cartographie haute précision des flux gazeux par robotique cartésienne**

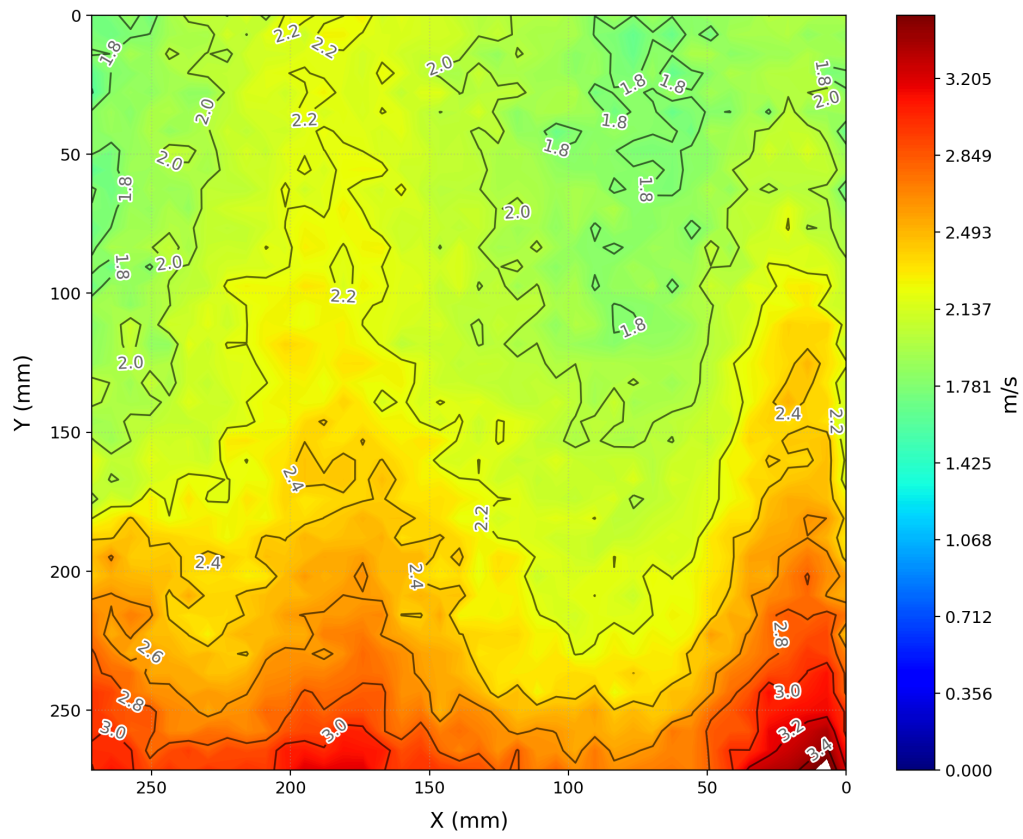
Dans les procédés de fusion laser sur lit de poudre métallique (L-PBF), la maîtrise de l'atmosphère gazeuse est un pilier critique de la performance. Au-delà de la sécurité (prévention du risque d'inflammation) et de la protection chimique contre l'oxydation, le gaz joue également un rôle dynamique crucial : l'évacuation des éjectas et des fumées. Une nappe de gaz homogène et laminaire est la condition sine qua non pour garantir la qualité des pièces produites.

Cette présentation introduit le "Flow Mapping Unit", une innovation développée par Air Liquide depuis 2020. Basé sur un robot cartésien multi-axes, cet outil permet de cartographier avec précision le volume de gaz circulant au-dessus du plateau de fabrication. En couplant ce dispositif à des sondes calibrées selon la nature des gaz utilisés dans les chambres de fabrication (ex : Argon, Azote), il devient possible d'identifier les zones de stagnation ou de turbulence, souvent invisibles mais critiques pour la qualité finale des pièces.

L'intérêt majeur de cette approche réside dans sa capacité de diagnostic et de remédiation :

- Diagnostic précis des lignes d'hétérogénéités de flux sur l'ensemble de la zone de travail à corrélérer avec la qualité des pièces
- Optimisation itérative : les données recueillies permettent, lorsque la conception de la machine le permet, de modifier et de redessiner les buses d'injection.
- Résultats : l'obtention d'un flux dont l'homogénéité est significativement améliorée par rapport à la configuration initiale, garantissant ainsi une évacuation optimale des impuretés.

L'intégration de cet outil dans le cycle de qualification et d'optimisation des machines ouvre de nouvelles perspectives pour l'industrialisation de la fabrication additive, transformant le management du gaz d'une contrainte passive en un levier de qualité active.



## Diode laser cladding: new applications, new cladding head and novel sensor systems

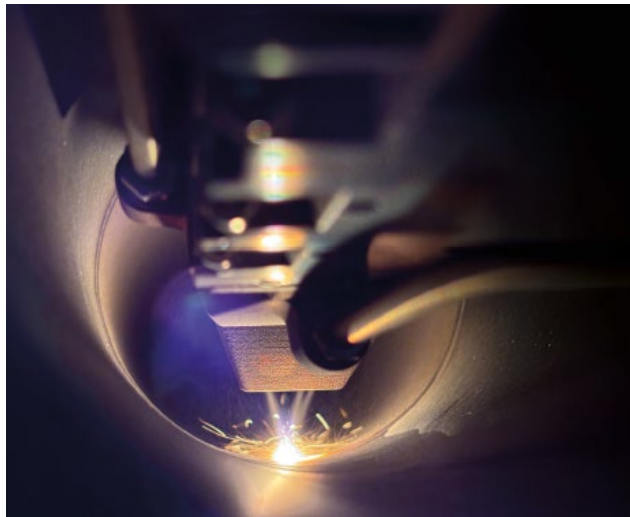
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Diode laser cladding is well established in multiple applications in industry but there are numerous new developments that are worth looking at in more detail.

Diode laser cladding replaces conventional cladding and CO<sub>2</sub>-Laser cladding since the late 1990's/early 2000's and is since long considered established technology in oil and gas industry, maritime, aerospace and various repair applications. New applications include cladding with babbitt, white metal and bronze materials for sliding/simple gears. They are addressed with either wire or powder. Recent approaches show very high deposition rates with almost no pores. At the same time the main advantages of laser cladding remain low heat input, low mixing with the base material and thus very little rework and removal of the clad material. As a result, the procedure is highly effective and finds more and more customers.

Many of the available cladding heads for internal diameter (ID) cladding reach very deep and into very small diameter tubes but are limited to only a few kW laser output power. Because laser cladding reaches to higher and higher deposition rates using more laser power, this limitation has to be overcome. A suitable head and cladding results are presented (Figure 1).



*Figure 1: cladding with 4-jet ID cladding head*

Process monitoring has become an essential tool to ensure quality and stability in laser cladding. Various optical sensors are available today, including pyrometers, photodiodes, and cameras. Their characteristics, limitations, and response times differ significantly and are compared. A particular challenge arises in internal diameter cladding, where space restrictions prevent the integration of conventional sensor adapters on the optics.

# High peak power fibered laser system tailored for the robotization of laser shock applications.

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Since their first laboratory studies in the early 60s [1] laser induced shock waves using nanosecond lasers have shown much promise for applications such as laser cleaning and laser shock peening (LSP). Over the years, these processes have shown their adequation to today's environmental challenges by favouring longer lifetime of parts, recycling and oftentimes being a greener alternative to current techniques such as sandblasting or chemical stripping [2]. Yet, to this day, the adoption of laser shock processes in the industry remains anecdotal, mainly due to high footprint and low flexibility, hindering automation.

This paper presents a fibered laser system capable of delivering unmatched levels of peak power, specifically designed for use with a robotic arm. It is composed of an Nd-YAG laser source optimized for injection in a standard silica fiber, a beam-shaping solution that allows injection of more than 200 mJ @ <10 ns in a single fiber, along with a protected fiber cord. In addition, effectors were designed to address the specific challenges of the target applications, such as water splash-back management in LSP.

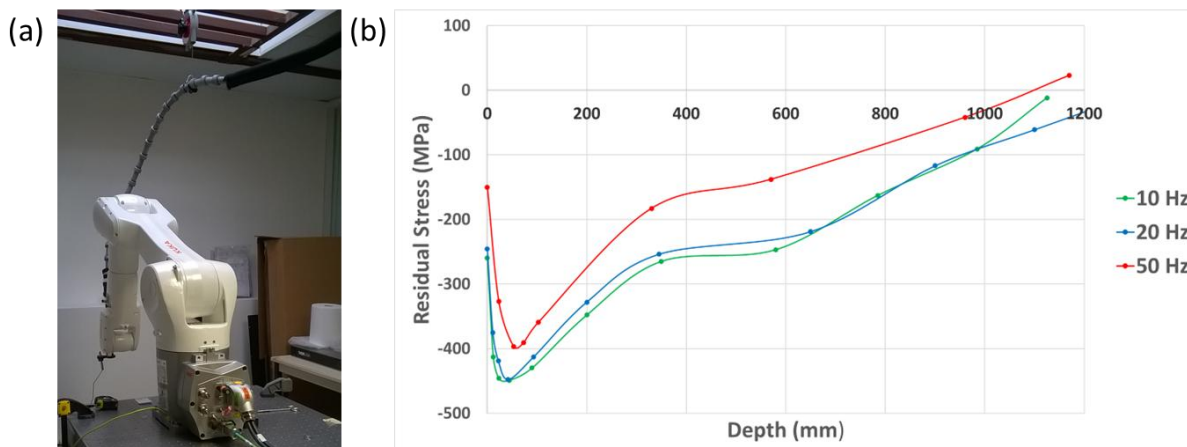


Figure 1 (a) System coupled to a 6-axis robot. (b) Residual stress profile obtained with the system on aluminium 7075

This system has been tested with a traditional 6-axis robot, as well as a cobot for both LSP and laser cleaning applications with excellent results. Good levels of compressive stress were achieved through LSP treatment of Aluminium 7075 at 20 and 50 Hz. Meaning that processing speed was greatly improved compared to previous fibered LSP system that was limited to 10 Hz. Regarding laser cleaning, the great depth of field achieved by the system significantly relaxed the precision constraint for the robot's trajectory, simplifying programming.



Figure 2 laser cleaning, rust on steel. Complex shape treated with no adaptation of the working distance.

[1] Allan H. Clauer, "Laser Shock Peening, the Path to Production," Metals, 9(6), 626 (2019)

[2] Mohammad Khairul Azhar Abdul Razab, An'amt Mohamed Noor, Mohamad Suhaimi Jaafar, Nor Hakim Abdullah, Fatanah Mohamad Suhaimi, Mazlan Mohamed, Noraina Adam, Nik Alnur Auli Nik Yusuf, "A review of incorporating Nd:YAG laser cleaning principal in automotive industry", Journal of Radiation Research and Applied Sciences, Volume 11, Issue 4, 393 (2018)

# Femtosecond laser structuring of Li-Ion batteries electrodes: demonstration and perspective for roll-to-roll production.

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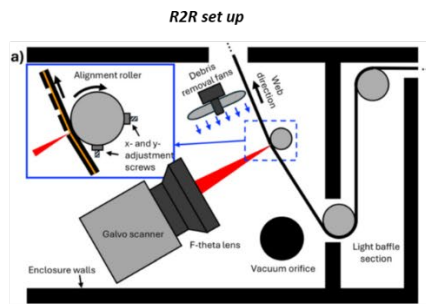
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The automotive industry has initiated a considerable transition by moving from thermal to electric traction. Li-ion batteries are critical to meeting future energy demands for consumer/personal electronic devices, transportation and stationary power storage and stabilization. Li-ion batteries electrodes with engineered microstructures created by ultrafast laser ablation have been shown to provide the next step-change improvement in battery performance, including, charge rate, capacity, and cycle life. However, there remains a lack of R&D work which helps bridge the gap between the laboratory and factory. The laser ablation mechanisms of composite materials used for batteries are not well known, even if they are a key knowledge for the process optimization. For example, the very high value obtained for specific ablation rates of graphite up to 14 mm<sup>3</sup>/min/W is rarely reached in fs ablation of any materials (next to 0.2 mm<sup>3</sup>/min/W for copper, substrate for Lithium Ion anode).[1] Different ablation mechanisms have thus to be considered, that have significative consequences on technical approaches applied to improve the laser structuring process.

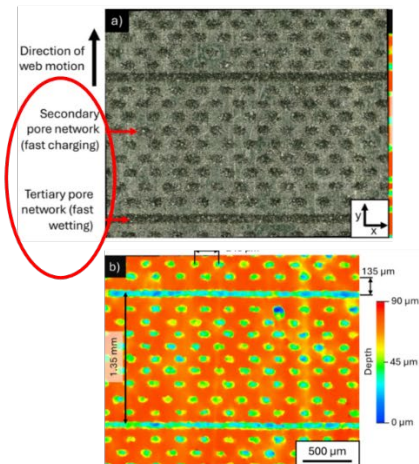
This work contributes towards this effort through demonstrating that an ultrafast laser can easily be integrated into industry standard electrode manufacturing equipment (roll-to-roll manufacturing). Both sides of a double-sided 700 m long graphite anode are laser patterned, and the electrode was subsequently assembled into 27 Ah cells (the largest to date incorporating a structured electrode). Lessons learned from this pilot demonstration are summarized and future recommendations are provided. We additionally provide a techno-economic analysis which concludes that this additional manufacturing step results in a 2% increase to manufacturing costs.[2]

- > For 120 mm large electrode coil
- > R&D set up with low laser power (20 W) laser and low web speed (1-1.5 mm/s)

Laser source Satsuma HP<sup>2</sup>,  
277 fs, 333 kHz, 60.7 μJ (20 W)



Performed Texturation



- > Industrial objective : high laser power (1000 W) laser and high web speed (0.8 m/s)

Figure: R&D roll to roll set up at NREL for anode texturation with fs pulses.

[1] E. Audouard, M. Fleureau, D. Pallarès, J.-M. Romano, F. Mermet (2024), **Characterization of batteries materials ablation by femtosecond pulses**, *Procedia CIRP*124, 57–60 (2024)

[2] Tancin R., Özdoğan B., Sunderlin N., Weddle P. J., Usseglio-Viretta F., Boone D., Mocaer Q., Audouard E., Knehr K., Kubal J., Ahmed S., Finegan D. and Tremolet de Villers B., **Demonstration of and future perspective on scaling ultrafast-laser-ablation microstructuring of Li-ion battery electrodes to roll-to-roll production and large-format cells**, *EES Batteries*, 1, 1522-1543 (2025)

# Optimisation de la productivité par stratégie multi faisceaux : limites et performances

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Les travaux présentés concernent le développement d'applications industrielles de perçage et d'ablation, mettant en œuvre un laser femtoseconde de forte puissance. Le niveau de puissance (300W / 3mJ) doit permettre une productivité élevée. Ces caractéristiques ne peuvent être directement converties en performances process, cela nécessite une certaine maîtrise de la manipulation des faisceaux laser.

Pour cela un système optique SLM Spatial Light Modulator est introduit dans le chemin optique afin de diviser le faisceau en plusieurs points d'interaction, dans le but d'accélérer le procédé.

Sur l'aspect mise en forme du faisceau nous évoquerons les contraintes et limitations que nous avons rencontrées ; autant sur l'étendue de la surface sur laquelle la diffraction est possible ; mais aussi sur l'impact thermique qu'engendre le fait de multiplier les points d'interaction. Nous verrons quelles stratégies ont pu être développées afin de mettre l'impact thermique à profit du procédé, en gagnant du temps et en préservant la qualité.

Seront également abordés les contraintes spécifiques qui ont amené à l'utilisation d'un robot pour couvrir une surface gauche d'environ 1m<sup>2</sup>. Ce choix technologique implique des limitations, particulièrement la précision de positionnement ; nous aborderons les pistes de solutions choisies pour dépasser ces limites.

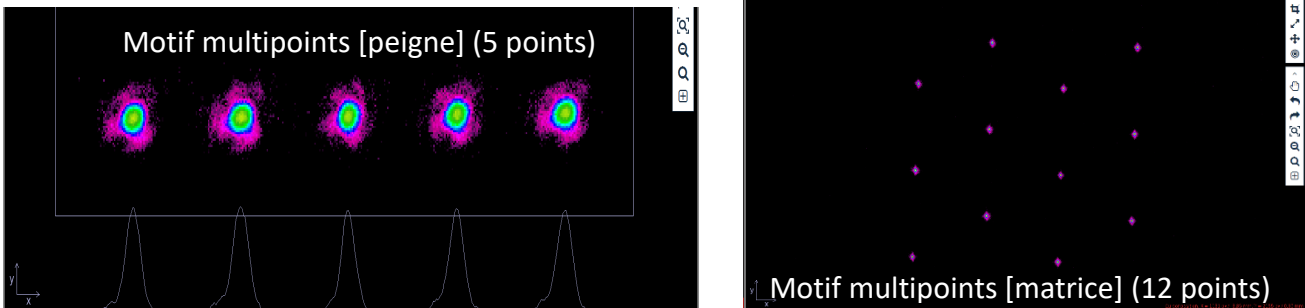


Figure 1 Exemple de mise en forme de faisceau par SLM pour procédé multipoints

# High-Power Femtosecond Laser Processing of Next-Generation Batteries: Cutting and Surface Structuring Performance Evaluation

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Femtosecond laser technology is today considered as a very promising solution for advanced processing of lithium-ion battery electrodes. In particular, it allows burr-free cutting with very high edge quality and almost no thermal damage, which is essential for thin and high-energy-density electrodes. In addition, femtosecond laser processing enables precise micro-surface texturing following the so-called 3D-electrode concept. Such surface structuring can significantly improve the wettability of the electrode, enhance ion transport pathways, and positively influence the electrochemical behavior by increasing the active surface area and reducing diffusion limitations. In this work, we present recent progress achieved in the development of industrial femtosecond laser processes dedicated to cutting and surface structuring of next-generation lithium-ion battery electrodes. The focus is placed on process scalability and compatibility with high-throughput manufacturing. We discuss different beam delivery strategies required to reach industrial productivity, including the use of high-power ultrashort-pulse laser sources, high-speed galvo scanning systems, multibeam machining approaches, and accurate synchronization between laser emission and beam positioning. The optimization of these parameters is essential to maintain high machining quality while increasing the processing speed. A complete Gen3b lithium-ion cell integrating laser-textured electrodes has been manufactured and tested. The electrochemical characterization shows a performance improvement of approximately 25% compared to reference cells, demonstrating the relevance of controlled laser structuring for next-generation battery concepts [1]. Furthermore, we investigate the use of GHz burst-mode operation for electrode processing. The results indicate that, for NMC materials, the material removal rate can be increased by up to a factor of four, while preserving the edge quality and avoiding additional thermal degradation [2]. This approach represents a strong potential for further enhancement of industrial productivity. Finally, we present preliminary results from the French Femtocell project, which aims at the development of a pilot production line dedicated to laser cutting and texturing of Gen4 electrodes [3]. The project focuses on process integration, reliability, and upscaling toward industrial implementation, paving the way for high-performance and cost-effective battery manufacturing based on femtosecond laser technology

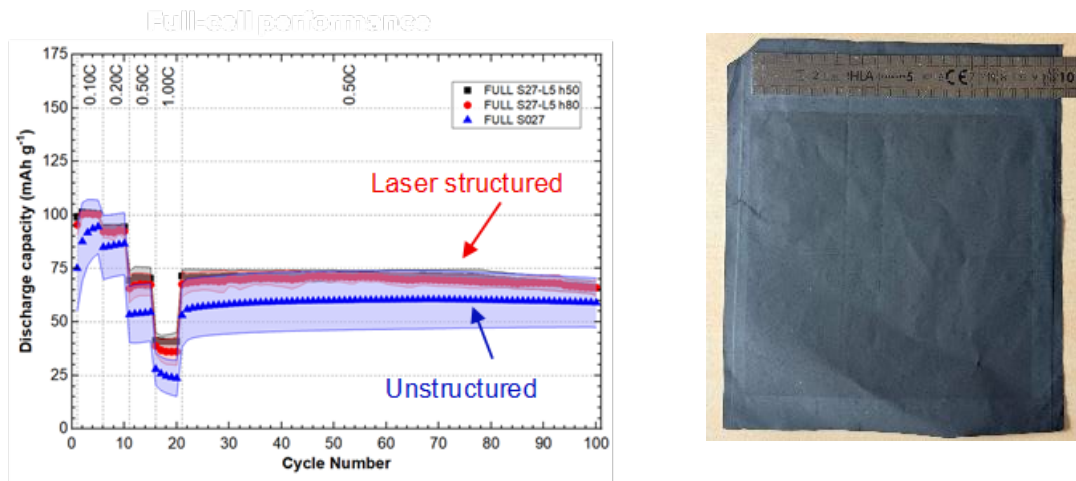


Figure 1 - The figure shows the discharge capacity of a complete laser structured coin cell vs. the Cycle Number (left). On the right a 10 cm×10 cm anode laser structured.

[1] D. Giraldo, P.Tallone, E. Ravesio, G. Montinaro, A. Sikora, M. Faucon, L. Otaegui, G. Mincuzzi: "Extending 3D electrodes concept to the new generation batteries: the case of Gen 3b" Under preparation

[2] A. Sikora, G.Mincuzzi, M.Faucon, L.Gemini : "High throughput manufacturing of micro-structured electrodes by femtosecond laser in MHz and GHz burst regimes" Under final review at Journal of Manufacturing Processes

[3] <https://www.alphanov.com/projets-collaboratifs/femtocell-une-ligne-pilote-pour-les-batteries-de-nouvelle-generation-gen4>

retrieved in data 12/02/2026 s

# 3D Texturing and Characterization of Pre-Patterned Nano-Objects Using a Donut-Shaped Laser Beam

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Three-dimensional texturing of nanostructures by femtosecond laser irradiation has emerged as a powerful tool for functional surface engineering. In contrast to conventional two-dimensional periodic patterns generated by laser–matter interaction, 3D structuring enables volumetric control of morphology at the nanometer scale, allowing precise tuning of optical and mechanical properties for advanced technological applications. Among emerging strategies, the use of structured beams—particularly annular (“donut”) intensity profiles—offers new opportunities for controlled energy deposition and tailored material reshaping. Such approaches pave the way for the development of optoplasmonic sensors in semiconductor and telecommunication technologies, as well as for the design of lab-on-chip platforms for biological applications [1].

In this international collaborative work, three-dimensional nano-objects are first fabricated by focused ion beam (FIB) milling, ensuring accurate and reproducible geometrical definition. These pre-patterned architectures serve as model systems for subsequent femtosecond laser texturing using a donut-shaped beam. The non-Gaussian radial intensity distribution promotes localized interactions along the sidewalls of the nano-objects, enabling controlled surface modification while preserving the global 3D geometry.

The induced modifications are investigated through a multi-scale characterization approach. Scanning electron microscopy (SEM) provides detailed surface analysis, while FIB tomography enables post-process three-dimensional reconstruction with ultra-high spatial resolution. Complementary spectroscopic and optical characterizations are performed to evaluate the functional impact of the laser-induced modifications.

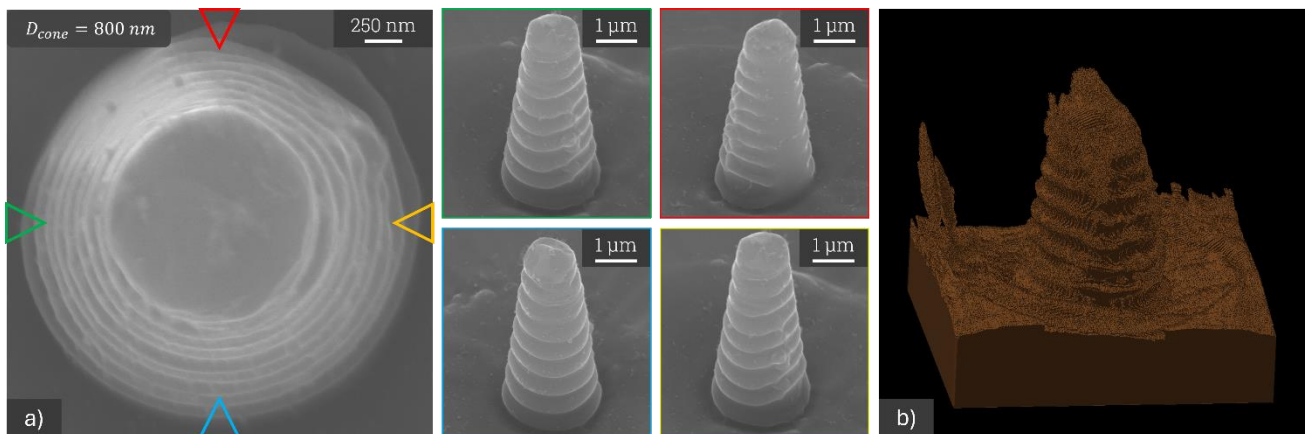


Figure 1: (a) SEM images of laser-textured silicon nanocones: top view (upper left), followed by 45° tilted views acquired at azimuthal rotations of 0°, 90°, 180°, and 270°, highlighting the uniform distribution of the surface texturing along the cone sidewalls. (b) Three-dimensional reconstruction obtained by FIB tomography, providing high-resolution volumetric visualization of the laser-induced morphological modifications.

This study aims to develop and optimize a robust femtosecond laser texturing methodology tailored to three-dimensional nano-architectures, to achieve a comprehensive structural and functional characterization of the resulting 3D surface features, and to deepen the fundamental understanding of laser–matter interaction mechanisms occurring on pre-patterned nanostructures.

[1] J. Xavier, S. Vincent, F. Meder and F. Vollmer, Advances in optoplasmonic sensors – combining optical nano/microcavities and photonic crystals with plasmonic nanostructures and nanoparticles, Nanophotonics, vol.7, pp.1-38, (2018)

## Large-area 3D topographic metrology of DLIP-textured ceramics via super-resolved confocal microscopy

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Direct Laser Interference Patterning (DLIP) is a powerful technique for the high-speed functionalization of bioceramics, enabling the creation of periodic textures that significantly improve cell adhesion and osseointegration [1]. However, the industrial adoption of these surfaces requires fast and non-destructive characterization methods capable of capturing topography across millimetric functional areas. Conventional tools such as Scanning Electron Microscopy (SEM) lack the necessary 3D data, while Atomic Force Microscopy (AFM), though precise, suffers from an extremely limited field of view and slow acquisition rates that make it impractical for large-scale or in-line monitoring. In this work, we propose a scalable metrology solution combining **photon reassignment (PR)** [2-3] **confocal super-resolution** with a **proprietary hybrid axial detection scheme**.

This approach exploits the effective **doubling of the lateral spatial resolution** provided by PR to resolve sub-micron DLIP periods, using long working objectives. To achieve nanometric vertical sensitivity, the system integrates a **phase-sensitive interferometric enhancement** within the confocal architecture. This hybrid configuration allows for the rapid extraction of 3D topographic parameters, such as structure depth  $h$  and fill factor ( $f$ ), across millimetric zones through automated stitching. Preliminary results on DLIP-textured ceramic samples demonstrate the ability to map surface homogeneity over areas 100x larger than conventional AFM scans, effectively bridging the gap between high-resolution laboratory characterization and industrial-scale quality control.

### References

- [1] Fabris, D., Lasagni, A. F., Fredel, M. C., & Henriques, B. (2019). Direct laser interference patterning of bioceramics: A short review. *Ceramics*, 2(4), 578-586.
- [2] Aguilar, A., et al. (2023). "Nondestructive inspection of surface nanostructuring using label-free optical super-resolution imaging". *Scientific Reports*, 13(1), 6008.
- [3] Aguilar, A., et al. (2017). "In-situ high-resolution visualization of laser-induced periodic nanostructures driven by optical feedback". *Scientific Reports*, 7(1), 16509.

# Towards Systematic Characterization of Ring-Shaped Laser Beams

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The state of the art in the field of beam diagnostics in accordance with ISO 11146 includes well-known quantities like 2nd-order moment beam width ( $d_0$ ), Rayleigh length ( $z_R$ ) and beam propagation factor ( $M^2$ ). For beams ranging from gaussian to top-hat shape, this is an established approach. Meanwhile, a multitude of technologies to generate ring-shaped beams found its way into applications – and the above-mentioned quantities struggle to describe those beams with equal accuracy. Therefore, the challenge is, to describe the various new beam shapes and the individual working area more process-related.

The weaknesses for the description of ring beams according to ISO 11146 can be shown: Figure 1 compares the single plane analysis according to 2nd moments method (a) with a new PRIMES parameter set (b). The white circle in figure 1 (a) indicates the beam dimensions according to 2nd moment analysis ( $d_0$ ), the cross shows the principle axes. The dimensions don't correspond to any relevant characteristic of the beam. Figure 1 (b) is evaluated according to PRIMES single mode ring beam analysis. The three circles display the inner and outer diameter of the ring, and the diameter of the core, resulting from gaussian fits to cross sections along several azimuthal angles.

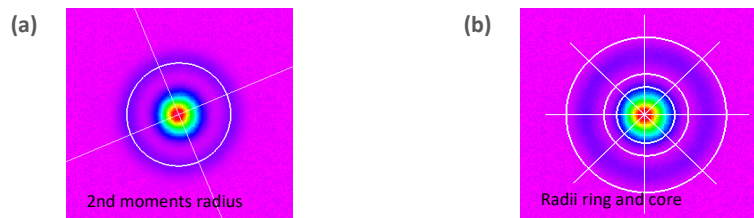


Figure 1 Comparison of a single plane analysis according to 2nd moments method (a) with a new approach according to PRIMES parameters (b)

Doing so, we propose a new set of algorithms for accurately describing arbitrary ring-shaped beams. Key metrics include diameter and power share for core and ring. In case of top-hat shape the algorithm delivers edge steepness, and homogeneity for the ring. Combined parameters like decentering, modulation, and power loss highlight alignment issues and beam quality.

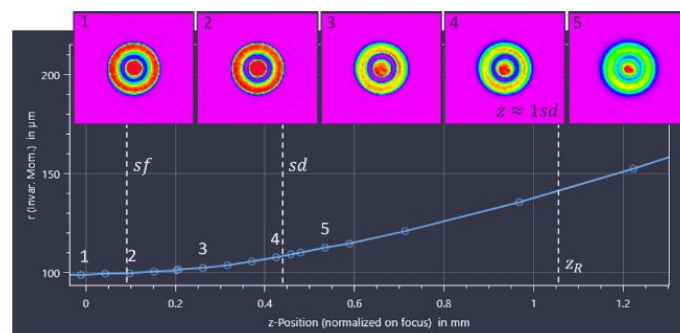


Figure 2 Measurement of a ring beam caustic with increased z-resolution

In order to analyze the beam as a whole, a measured caustic of a ring beam as shown in figure 2 is considered. With a caustic measurement, it is also true that beam parameters such as beam quality, Rayleigh length or waist diameter can even mislead the user into making false assumptions. For example, with typical ring beams, the individual beam parts merge just a few fractions of a Rayleigh length away from the beam waist and any ring-like structure is lost. This requires a much more detailed view in a narrow area around the beam waist. PRIMES therefore established two new caustic parameters, structure depth ( $sd$ ) and ( $sf$ ) structure focus.

Demonstrating a new set of parameters, which are used in the PRIMES software to evaluate ring beams in the focal planes as well as in full caustic measurements, we want to start discussions on an ISO standard for ring beams.

# La mise en forme du faisceau laser comme levier pour le passage à l'échelle de la fabrication additive

*Gwenn Pallier<sup>1</sup>, Nicolas Pernet<sup>1</sup>, Sacha Grelet<sup>1</sup>, Adeline Orieux<sup>1</sup>, Guillaume Labroille<sup>1</sup>*

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La fusion laser sur lit de poudre (LPBF), le dépôt de matière sous énergie concentrée (DED) et le placement automatisé de fibres (AFP) constituent des technologies clés pour la production de composants complexes à haute valeur ajoutée. Toutefois, leur déploiement industriel à grande échelle nécessite encore des améliorations en termes de robustesse, de stabilité et d'adéquation aux exigences industrielles, afin de garantir une production fiable à haut débit. A ce titre, l'augmentation de la puissance laser est souvent envisagée comme un levier majeur pour accroître la productivité. Néanmoins, le fonctionnement à haute puissance engendre généralement des instabilités et des défauts tels que les fissures à chaud, les projections ou la formation de keyholes, limitant ainsi le passage à l'échelle industrielle. Par ailleurs, certains matériaux métalliques, sous forme de poudre ou de fil, demeurent difficiles à mettre en œuvre en raison de leur forte réflectivité et de leur faible absorption du rayonnement laser. Enfin, les contraintes d'intégration industrielle conduisent à rechercher des systèmes toujours plus compacts, compatibles avec des environnements de production contraints.

Dans ce contexte, la mise en forme du faisceau laser apparaît comme une approche prometteuse pour permettre un traitement à haute puissance tout en dépassant ces limitations. Cette présentation mettra en lumière les résultats récents obtenus — en partie en collaboration avec des partenaires industriels et académiques — ainsi que les solutions actuellement en développement en fabrication additive grâce à la mise en forme du faisceau laser :

- **DED-fil** : des stratégies de mise en forme en anneau ont permis de réduire significativement l'encombrement de la tête d'impression (< 5 kg), ouvrant la voie à des systèmes compacts capables de fonctionner à haute puissance (> 12 kW).
- **DED-poudre** : la combinaison de la mise en forme du faisceau et d'un fonctionnement bi-longueur d'onde (infrarouge et vert) montre un fort potentiel pour améliorer la stabilité du procédé et l'efficacité de fusion du cuivre.
- **LPBF** : la vitesse d'impression du Ni625 a pu être multipliée par plus de trois grâce à l'utilisation d'un faisceau en anneau, sans dégradation de la qualité des pièces.
- **AFP** : une mise en forme rectangulaire de type top-hat a permis de réduire d'un facteur 2,5 l'encombrement du système.

In fine, l'adaptation de la distribution d'intensité du laser — via des faisceaux annulaires en LPBF et DED-fil, des motifs ring-dot en DED-poudre ou des profils rectangulaires top-hat en AFP — permet une répartition plus efficace de l'énergie pour répondre aux problématiques rencontrées par l'industrie.

## Laser Beam Shaping for Scalable High-Power Additive Manufacturing

*Gwenn Pallier<sup>1</sup>, Nicolas Pernet<sup>1</sup>, Sacha Grelet<sup>1</sup>, Adeline Orieux<sup>1</sup>, Guillaume Labroille<sup>1</sup>*

La fusion laser sur lit de poudre (LPBF), l'impression par dépôt de matière sous énergie concentrée, le placement automatisé de fibres (AFP) sont des technologies de fabrication clés pour la production de composants complexes et à haute valeur ajoutée. Cependant, leur déploiement industriel à grande échelle nécessite encore des améliorations en termes de robustesse, de stabilité et même d'adéquations avec les besoins de l'industrie, afin de garantir une production fiable à haut débit. A ce titre, l'augmentation de la puissance du laser est souvent considérée comme un levier d'intérêt pour améliorer la productivité. Cependant, un fonctionnement à haute puissance induit généralement des instabilités et des défauts tels que des fissures à chaud, des projections, et la formation de keyholes, limitant ainsi le passage à l'échelle industrielle. En outre, plusieurs matériaux métalliques, sous forme de poudre ou de fil, restent difficiles à traiter en raison de leur réflectivité élevée et de leur absorption laser limitée. Enfin, les contraintes d'intégration industrielle tendent à nécessiter des développements de plus en plus compacts pour matcher les

Dans ce contexte, la mise en forme du faisceau laser représente une approche prometteuse pour permettre un traitement à haute puissance tout en surmontant ces limitations. Cette présentation tend à présenter les récents résultats obtenus (dont une partie en collaboration avec des partenaires industriels ou universitaires) et les solutions en cours de développement en fabrication additive grâce à la mise en forme de faisceau laser :

- En DED-fil, des stratégies de mise en forme du faisceau en anneau ont démontré qu'elles permettaient de réduire considérablement l'encombrement de la tête d'impression (< 5kg), ouvrant de nouvelles perspectives pour l'intégration de systèmes compacts, capables de gérer des hautes puissances (>12 kW).
- En DED-poudre, l'utilisation combinée de la mise en forme du faisceau et du fonctionnement à double longueur d'onde (lasers infrarouge et vert) semble prometteuse pour améliorer à la fois la stabilité du processus et l'efficacité de la fusion du cuivre.
- En LPBF, nous avons démontré que la vitesse d'impression du Ni625 pouvait être multipliée par plus de 3, grâce à l'utilisation d'un faisceau en forme d'anneau sans compromettre la qualité des pièces.
- En AFP, une mise en forme top-hat rectangulaire a permis de réduire de 2,5 fois l'encombrement du système tout en permettant la fabrication de pièces plus complexes.

In fine, en adaptant la distribution de l'intensité du laser (à l'aide de faisceaux en forme d'anneau pour le LPBF et le DED par fil, de motifs en anneaux pour le DED par poudre ou de profils rectangulaires top-hat pour l'AFP), l'énergie peut être distribuée plus efficacement, ce qui améliore la stabilité du bain de fusion et le contrôle global du processus.

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# Procédés DED laser poudre et fil au service de la prévention, réparation et du remanufacturing : retours industriels et perspectives avec le projet RESTORE

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Face à la pression croissante sur les ressources, les délais et les émissions, la capacité à prolonger la vie des composants plutôt qu'à les remplacer devient un enjeu stratégique pour l'industrie. Les procédés de dépôt direct d'énergie (Direct Energy Deposition, DED) par laser, avec apport de poudre ou de fil, offrent pour cela un moyen de mettre ou remettre de la matière exactement où elle est nécessaire, avec des rendements élevés, une maîtrise fine de la dilution et de la géométrie déposée, et des apports thermiques contenus. Ils constituent ainsi une plateforme technologique pour corriger des défauts, renforcer des zones critiques, restaurer des géométries usées ou adapter les propriétés de surface (usure, corrosion, ...), sur un spectre d'applications couvrant les grands secteurs industriels et stratégiques que sont l'énergie, la défense, l'aéronautique, le naval .... La présentation s'attachera à montrer, à partir de cas industriels et du cadre du projet RESTORE, dans quelles conditions le DED peut passer d'une solution opportuniste de réparation à un outil structurant de stratégie de maintenance et de remanufacturing.

Dans une première partie, la présentation mettra en avant l'utilisation industrielle des procédés DED laser poudre et fil comme outils de rechargement et de réparation déjà opérationnels dans différents environnements de production. Les têtes et buses utilisées, développées avec des architectures spécifiques, visent à répondre à des enjeux très concrets de l'industrie : atteindre des taux de dépôt compatibles avec des cadences de production, contrôler finement la dilution pour garantir les performances des revêtements et maintenir une bonne répétabilité sur des géométries parfois complexes. Des exemples d'applications typiques seront présentés, comme la restauration de surfaces fonctionnelles soumises à l'usure ou à la corrosion, la remise à dimension de pièces de production critiques, ou encore le rechargement préventif de têtes de forage utilisées en conditions sévères. Ces cas illustreront la manière dont le DED s'intègre dans une chaîne industrielle existante et permet de sécuriser le retour en service des pièces.

Dans la continuité de ces retours d'expérience, la seconde partie présentera le projet européen RESTORE (<https://restoreeuproject.eu/>) comme un cadre de structuration et d'extension de ces solutions DED vers des scénarios de remanufacturing à plus grande échelle. RESTORE capitalise sur les procédés DED pour adresser des composants de grande dimension issus de secteurs tels que le naval, le ferroviaire, l'automobile, avec des objectifs de performance et une meilleure maîtrise des coûts et des ressources (intégration de matière recyclée dans les matériaux d'apport, optimisation des trajectoires, réduction des opérations manuelles). Les développements s'appuient sur des outils numériques de digitalisation de la chaîne de remanufacturing – de la localisation des zones à réparer jusqu'à la génération et l'optimisation des trajectoires, en passant par la traçabilité et le suivi des réparations – afin de réduire l'incertitude sur les temps d'intervention, les coûts de réparation et la performance des pièces remanufacturées. L'ensemble constitue une démarche cohérente, où les briques technologiques DED sont pensées non seulement comme des procédés innovants, mais comme des solutions de marché pour prolonger la durée de vie des équipements, réduire les déchets et structurer des offres de remanufacturing crédibles à l'échelle industrielle.

Les procédés DED laser ne sont plus de simples procédés de niche : en combinant têtes poudre et fil, contrôle de la dilution et intégration numérique, ils ouvrent un véritable « marché de la seconde vie » pour les composants industriels, en alternative au remplacement systématique. En transformant la prévention, la réparation et le remanufacturing en options compétitives – plus économes en matière, plus flexibles et mieux alignées avec les objectifs de décarbonation – ils renforcent directement la compétitivité et la souveraineté des filières industrielles stratégiques.

# Multi-material 3D parts production by selective laser melting

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New method and SLM machine for 3D multi-material parts production has been elaborated [1,2], where standard recoating systems with roller or blade can be used. The main idea consists in using a narrow fraction of powders of various materials with different medium particle size and special algorithm of powder layer recoating. This not only makes possible three dimensional multi-material parts production, but this method enables to separate the overflow powders of a various materials for reuse. SLM machine concept and concept of the build platform cleaning system is presented and discussed.

When sintering of the multimaterial object with high accuracy, particular attention has been given to shrinkage, dissolution and cross-contamination. Influence of dissolution on the accuracy of the boundaries of various metals is estimated. A system for separating powders by sieving was developed and manufactured. It is shown [3] that this is the only universal method for separating powders of different materials.

The cross-contamination effect has been studied experimentally. Not more than 0.1% cross-contamination are fixed. Special sieving system has been elaborated which provides 100% separation of narrow fractions of spherical powders of two various materials. The experimental Multi 100 SLM machine has been manufactured and is currently being tested.

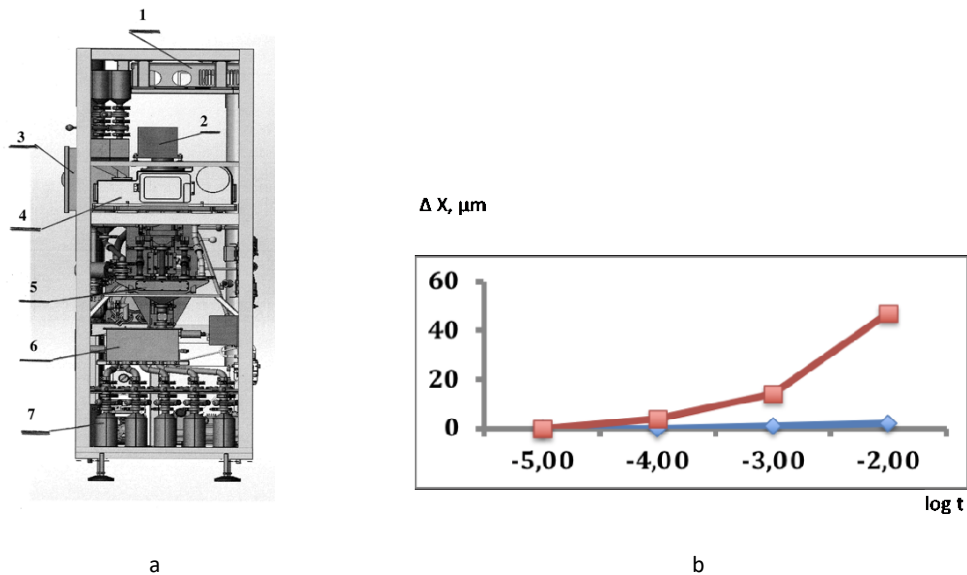


Figure.1. (a) Multi 100 SLM machine, (b) Dissolution of solid in melt versus time:  $\blacksquare - \alpha = 1 \times 10^{-6} \text{ m}^2/\text{s}$ ,  $\blacklozenge - \alpha = 1 \times 10^{-9} \text{ m}^2/\text{s}$

It is obvious that it is necessary to minimize the time of contact of melts of various metals at their boundary. In the developed method, this is ensured, because the powder of one of the metals is melted and sintered to another metal which is in a solid state.

[1] Chivel Yu. Method for producing three-dimensional objects from powder and device for implementing same. WO 201507539, 2014, US Patent 12030253, 2024.

[2] Chivel Yu. New Approach to Multi-material Processing in Selective Laser Melting. Physics Procedia., 83 (2016), 891- 895.

[3] Seidel Ch. Multi-material metal parts by powder bed fusion: New application opportunities. Metal AM., 8 (2022), 149-153.

# Unlocking the next era of fiber lasers – why and how metrology must keep up

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The market for fiber lasers with output powers above 6 kW is expected to grow by 11.3% by 2034 according to a forecast by Global Insights [1]. Today, we are already observing that even lasers exceeding 50 kW are no longer a rarity. In metal processing, falling cost-per-kilowatt figures are creating economically attractive alternatives to traditional machining methods. At the same time, the defense sector is accelerating the development of ultra-high-power laser systems. To operate these powerful laser sources safely, economically, and with consistently high process quality, measurement technology must keep pace.

As the destructive energy of those ultrahigh-power systems is enormous, it is a critical task to develop sensors that are capable of coping with it. Comprehensive cooling technology has to be combined with smart design, as space and weight are critical in some applications. By measuring only a short pulse of the laser power, it is now possible to measure up to 100 kW laser power with a relatively compact device. Dedicated ultra-high-power sensors measure laser power up to 150 kW continuously. Using non-contact measurement techniques, it is also possible to further analyze the beam and gain valuable information such as spatial profile, caustic, Rayleigh length, M2, BPP or focus shift.

This presentation will explore how high-power lasers can be measured without damaging the sensor, and which laser parameters—beyond mere output power—must be captured to ensure reliable and precise operation. It will address core challenges that arise when measuring high power and ultrahigh-power fiber lasers.

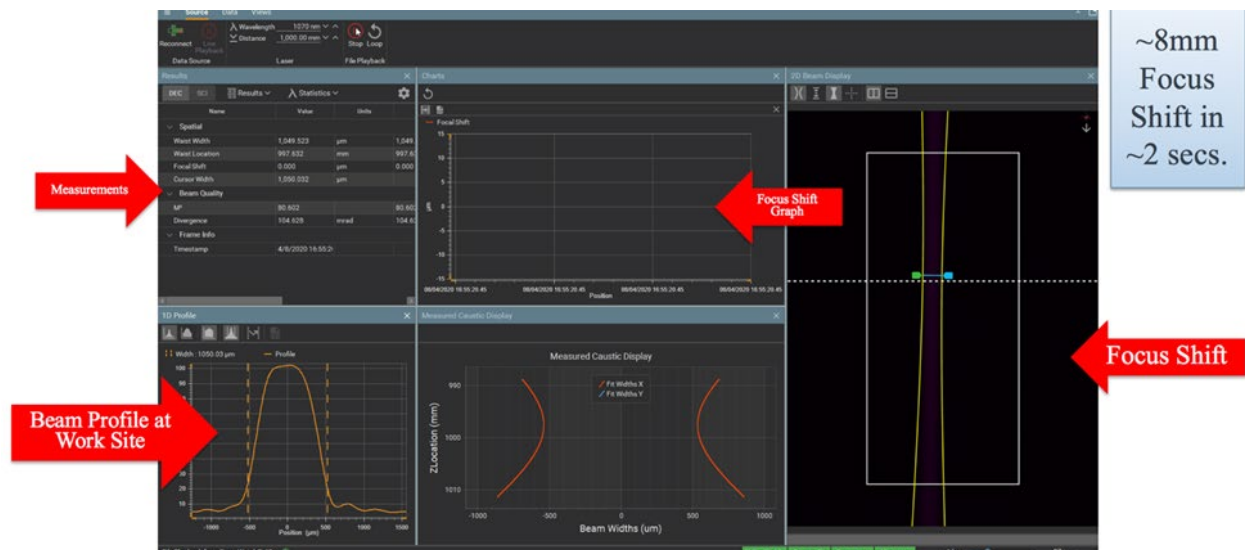


Figure 1. Beam profile of 100kW fiber laser with reflective optics.

[1] Global Market Insights. GMI13873. (2025, May). [Marktgröße, Marktanteil und Prognosebericht für Faserlaser, 2025–2034](#)

## Ouvrir la voie à la prochaine ère des lasers à fibre – pourquoi et comment la métrologie doit suivre

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Le marché des lasers à fibre avec des puissances de sortie supérieures à 6 kW devrait croître de 11,3 % d'ici 2034, selon une prévision de Global Insights [1]. Aujourd'hui, nous observons déjà que même les lasers dépassant 50 kW ne sont plus une rareté. Dans l'usinage des métaux, la baisse du coût par kilowatt crée des alternatives économiquement attractives aux méthodes d'usinage traditionnelles. Parallèlement, le secteur de la défense accélère le développement de systèmes laser de très haute puissance. Pour exploiter ces sources laser puissantes en toute sécurité, de manière économique et avec une qualité de processus constamment élevée, la métrologie doit suivre le rythme.

Étant donné l'énergie destructrice considérable de ces systèmes de très haute puissance, il est essentiel de développer des capteurs capables d'y faire face. Une technologie de refroidissement avancée doit être combinée à une conception intelligente, car l'encombrement et le poids sont critiques dans certaines applications. En ne mesurant qu'une courte impulsion de la puissance laser, il est désormais possible de mesurer jusqu'à 100 kW avec un dispositif relativement compact. Des capteurs dédiés à l'ultra-haute puissance mesurent en continu des puissances laser allant jusqu'à 150 kW. Grâce à des techniques de mesure sans contact, il est également possible d'analyser le faisceau plus en détail et d'obtenir des informations précieuses telles que le profil spatial, la caustique, la longueur de Rayleigh, le  $M^2$ , le BPP ou encore le décalage de la focalisation.

Cette présentation examinera comment mesurer des lasers de très haute puissance sans endommager le capteur, et quels paramètres laser—au-delà de la simple puissance de sortie—doivent être enregistrés pour garantir un fonctionnement fiable et précis. Elle abordera les défis essentiels liés à la mesure de lasers à haute et à ultra-haute puissance.

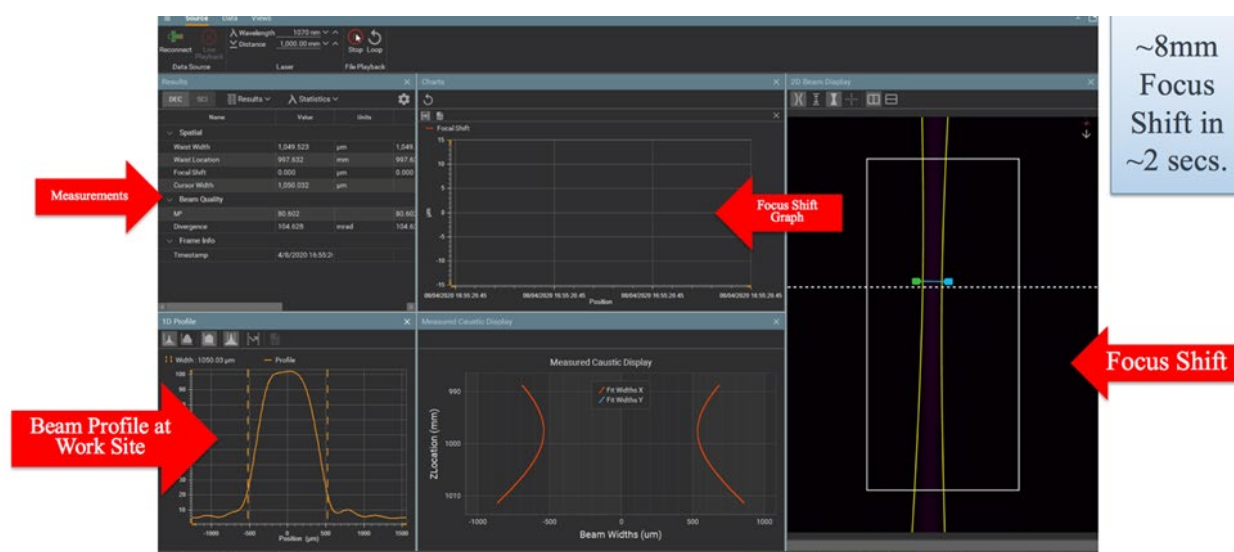


Figure 1. Profil de faisceau d'un laser à fibre de 100 kW utilisant une optique réfléchissante.

[1] Global Market Insights. GMI13873. (2025, May). [Marktgröße, Marktanteil und Prognosebericht für Faserlaser, 2025–2034](#)

## **The Measurement of Time: the cold atom revolution**

**Christophe Salomon**

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Since the dawn of humanity, the passage of time has been measured by the alternation of day and night, sundials, the changing seasons, or the position of the Moon. But none of these methods were very precise, and they were far from useful for navigation. The first precision timepieces were pendulum clocks, invented by Galileo and Huygens in the 17th century, which made it possible to determine longitude for sea navigation.

Today, the most accurate clocks are atomic clocks. Atoms of a given species, such as cesium, are all identical and very well described by quantum physics, the centennial of which we are celebrating this year. Furthermore, when atoms are cooled by laser to a temperature close to absolute zero, atomic fountain clock display an error of less than one second every 300 million years. All these advances in time measurement have led to satellite positioning systems such as GPS and GALILEO, which allow every cell phone user to determine their location to within a meter.

This colloquium will relate how cold atoms have revolutionized time measurements and enabled new tests in fundamental physics such as tests of general relativity, tests of the stability of fundamental physical constants, or search for light dark matter. We will also report first results from the ESA/CNES space mission operating a cold cesium primary clock onboard the International Space Station. In the future, laser-cooled atomic clocks operating in the visible or ultra-violet will lead to a redefinition of the unit of time, the second, with a hundred-fold gain in precision. This is opening up new possibilities in fundamental physics, geophysics, and telecommunications.

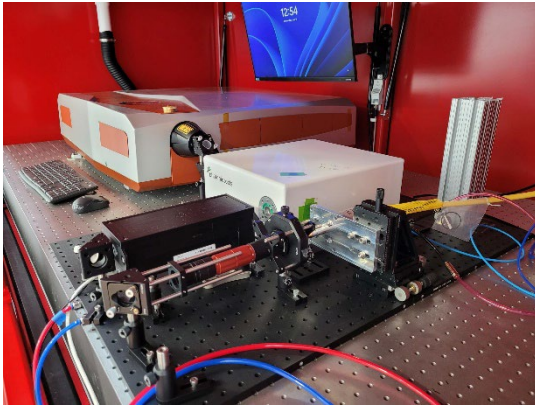
# Methods of Femtosecond Laser Fiber Coupling for Industrial Applications

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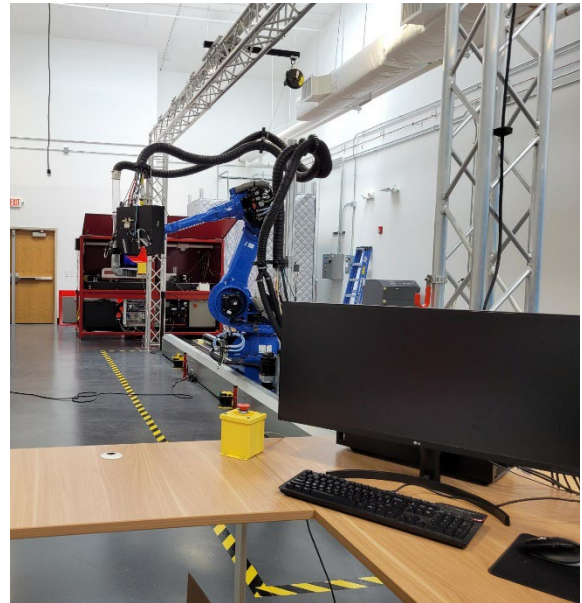
Hollow-core fiber (HCF) delivery is a critical enabling technology for extending femtosecond laser processing to large or immobile components that cannot be brought into conventional femtosecond machining workstations. While HCF delivery of femtosecond sources has been demonstrated at low average powers (<50 W), scaling to industrially relevant power levels—particularly average powers near 300 W and pulse energies approaching 1 mJ—is essential for increasing throughput and unlocking new classes of manufacturing applications. This work investigates high-power coupling strategies using an Amplitude Tangor 300 W femtosecond laser and Photonics Tools LLK-UKP hollow-core fiber in lengths ranging from 3 m to 20 m to represent realistic industrial routing.



*Figure 1 : System configuration of Amplitude T300, Photonics Tools BLS active stabilization, and Cailabs CANUNDA High Power system.*

These advances directly support new large-scale femtosecond laser applications, including precision micromachining, advanced surface functionalization, and high-speed texturing on parts too large or complex for fixed-beam workstations. To demonstrate industrial viability, the optimized coupling architecture is integrated into a custom hollow-core-fiber-fed processing head mounted on a 20'x8'x6' robotic femtosecond laser work cell equipped with a Yaskawa GP-88 robot. This platform enables full-scale processing capability with six-axis motion and high-power femtosecond stability delivered over long fiber lengths. The results highlight a practical pathway for deploying high-power femtosecond laser manufacturing in real industrial environments.

Coupling stability is addressed using two complementary subsystems. The Photonics Tools BLS active stabilization system is used to correct slow and fast beam-pointing fluctuations during long-term operation, while a custom Cailabs CANUNDA mode-cleaning system is implemented to improve spatial mode uniformity at high average power. Each subsystem is evaluated independently and in combination. Measurements of coupling efficiency, transmitted pulse quality, and long-duration power stability are conducted across multiple launch conditions. The highest transmission stability at the full 300 W operating power is achieved when active stabilization and mode cleaning are used in series, providing superior suppression of drift and fluctuations compared to either approach alone.



*Figure 2 : Femtosecond Fiber coupled 20'x8'x6' robotic work cell at the University of Dayton Research Institute*

# Laser-based process and system development for battery manufacturing in electric mobility

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Electrification in mobility, together with its broader societal implications, poses several manufacturing challenges. In the automotive, aviation, naval, and railway sectors, the adoption of electric propulsion requires changes in vehicle design, materials, and manufacturing methods [1]. Laser-based manufacturing stands out as a flexible digital tool that can be adapted to welding, cutting, surface structuring, and heat-treatment applications. The laser industry has evolved rapidly in response to the needs of electric mobility. Recent developments, such as beam-shaping technologies, new wavelengths, and advanced monitoring techniques, have largely been driven by electric mobility applications. Among the key areas requiring further development, battery systems deserve particular attention, as they currently represent the highest cost factor in electric vehicles [2]. Each vehicle contains a battery pack composed of separate modules, which in turn contain multiple cells. From the single cell to the complete battery pack, laser-based manufacturing processes are widely employed.

Accordingly, this work provides an overview of laser-based manufacturing solutions used in the electric mobility industry, with particular emphasis on battery systems. Specifically, it reviews laser cutting solutions for Li-ion battery electrodes and separators using pulsed lasers with ns, ps, and fs pulses, including burst-mode operation, as well as laser welding of electrode current collectors using core/ring beam configurations and wobbling. The work also discusses process development for novel solid-state batteries, with emphasis on free-standing Li-metal and Li-metal on Cu current collectors. The examples are complemented by modelling approaches to provide a deeper understanding of the underlying processing mechanisms as well as process monitoring for process quality assurance.

[1] A.G. Demir, J. Kriegler, A. Fortunato, L. Caprio, C. Geiger, L. Hille, M.K. Kick, A. Ascari, E. Liverani, M.F. Zaeh, Challenges and Opportunities for Laser Applications in Electric Vehicle Manufacturing, in: *Lecture Notes in Mechanical Engineering*, Springer Science and Business Media Deutschland GmbH, 2024: pp. 219–253. [https://doi.org/10.1007/978-3-031-41163-2\\_12](https://doi.org/10.1007/978-3-031-41163-2_12).

[2] A. Fortunato, A. Ascari, L. Orazi, P. Franciosa, A.G. Demir, D. Ceglarek, L. Li, Laser-based manufacturing for the electric powertrain, *CIRP Annals* (2026). <https://doi.org/10.1016/j.cirp.2026.04.116>.

# Micromachining Upscaling from W to kW: increase of Femtosecond Laser relevance in industrial applications

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In today’s world, technologies must be highly efficient and offer cutting-edge capabilities. They also need to be versatile, environmentally responsible, and accurate. In this presentation, LASEA will demonstrate how increasing power in the femtosecond range can enhance laser processing and tackle the related challenges. Boosting laser power involves managing a high-energy beam and controlling its interaction with materials. To optimise processing at kilowatt-level powers, solutions such as beam splitting and beam shaping can be implemented.

LASEA will highlight how beam shaping significantly improves laser processes, particularly in sectors like microfluidics, aeronautics, electronics, batteries and photovoltaics. It is also expected to boost machine productivity in roller, roll-to-roll, and batch production contexts.

Several technologies can be used to manipulate the laser beam, including spatial light modulators (SLMs), dual SLM configurations, diffractive optical elements (DOEs), and multi-plane light conversion (MPLC). These tools enable the generation of various beam profiles—square, circular, triangular, or custom shapes—and even multiple beams such as lines or beam matrices. Direct Laser Interference Patterning (DLIP) is another approach that enables multi-scale processing, including the creation of micro- and submicron structures.

LASEA will present the range of available solutions, their expected impacts, and how to integrate them into laser systems for specific applications. Moreover, beam shaping to generate multiple beams introduces complex challenges in the design and development of laser systems, especially since increased beam counts require higher laser power. This presentation will also cover the hurdles associated with managing multiple beams and high-power sources, and conclude by outlining the potential benefits and advancements enabled by these technologies.

LASEA will present how increasing femtosecond laser power can enhance processing efficiency while addressing related challenges. Techniques like beam shaping and splitting help optimise performance, particularly in microfluidics, aerospace, batteries, electronics and photovoltaics. Technologies such as SLMs, DOEs, MPLCs, and DLIP enable the creation of custom beam shapes and patterns. The presentation also covers the complexities of managing multiple beams and high-power sources, and highlights the expected improvements in machine productivity and process precision across various applications.

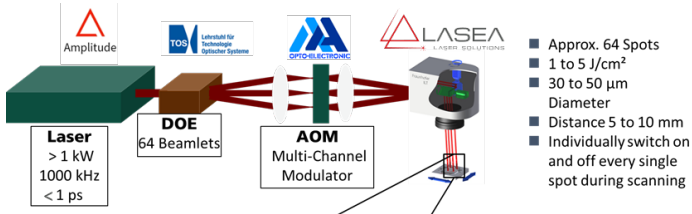
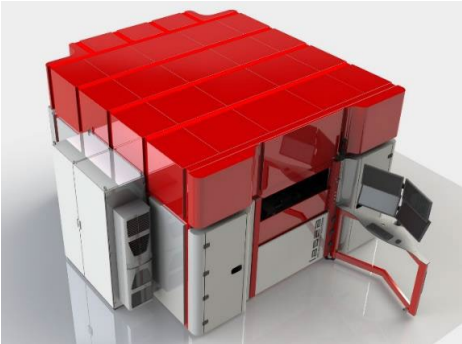


Figure 1 an example of results of high power results with in (a) Illustration of the kW machine developed by LASEA in the MULTIFLEX project. (b) Schematic of the optical principle to generate and manage the beam, using a DOE for splitting the beam followed by as stacked AOMs to gate each individual sub-beams, which are then focused on the workpiece through a single scanner head

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Structuration de la lumière à travers une fibre multimode à cœur creux modélisée par un réseau de neurones

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Dans ce poster, nous étudions la mise en forme de faisceaux à travers des fibres multimodes à cœur creux (HC-MMF) comme moyen de transport de faisceaux spatialement structurés. La capacité à reconfigurer dynamiquement la forme du faisceau ouvre la voie à un contrôle avancé du transport d'impulsions lumineuses. Cette approche présente un fort potentiel pour élargir les fonctionnalités des systèmes actuels de transmission de puissance par fibre optique, en particulier dans les applications nécessitant une grande précision ou une adaptabilité comme les machines de procédés laser, ainsi qu'en optique quantique pour le piégeage de particules.

Nous avons ici en particulier développé un réseau de neurones pour modéliser la transmission d'un rayonnement cohérent à travers une fibre multimode à cœur creux ayant environ 80 modes et nous démontrons, la focalisation dynamique de faisceaux et la projection d'images à travers cette HC-MMF en utilisant le modèle entraîné.

## CLI – Session Poster Doctorant 2026 – Nicolas Jacquot

Etude structurale d'un multicouche type Fabry-Perot asymétrique après insolation laser offrant des couleurs saturées et complémentaires

*Description (français) (anglais pas demandé):*

La conception de résonateurs Fabry-Pérot asymétriques (AFPR) permettant de générer des couleurs structurales hautement chromatiques a fait l'objet de nombreux travaux au cours de la dernière décennie. Leur traitement post-dépôt par laser pour étendre la palette de couleur constitue une orientation plus récente, avec des résultats émergents pour l'anticontrafaçon et l'impression couleur à haute résolution.

Dans ce travail, nous étudions l'inscription laser d'un empilement à base d'argent, déposé par pulvérisation magnétron et irradié par laser nanoseconde. Le multicouche est conçu à la fois pour délivrer des couleurs réfléchies fortement saturées et pour absorber efficacement à la longueur d'onde du laser ( $\approx 532$  nm). Nous montrons que l'irradiation entraîne la délamination du miroir métallique supérieur et déclenche la formation induite par laser de nanopores et de creux au sein de la cavité. Cette transformation structurale conduit à une propriété optique remarquable : l'apparition de couleurs quasi complémentaires entre les composantes spéculaire et diffuse, dans un large gamut de haute chromaticité.

L'évolution structurale avec l'énergie par pulse est mise en évidence par des analyses en coupe (FIB-MEB ; STEM-HAADF), complétées par une caractérisation de la topographie de surface par AFM. Les observations sont corrélées à l'évolution spectrale en réflexion diffuse et spéculaire, mesurées par spectrophotométrie, afin de relier les modifications microstructurales aux signatures optiques. Nous formulons l'hypothèse que la formation des nanopores et leur redistribution dans la cavité pourraient être gouvernées par un fort gradient de température, menant à la nucléation de pores, et l'apparition d'écoulements thermocapillaires, permettant la formation des cavités sphériques observées, contribuant ainsi à la réponse spectrale observée. Ces résultats ouvrent une voie originale pour l'inscription laser de motifs de sécurité, renforçant la résistance à la contrefaçon.

**Remerciements** — Ce travail a été financé par l'ANR dans le cadre du projet **SLICID (ANR-23-CE39-0006)**

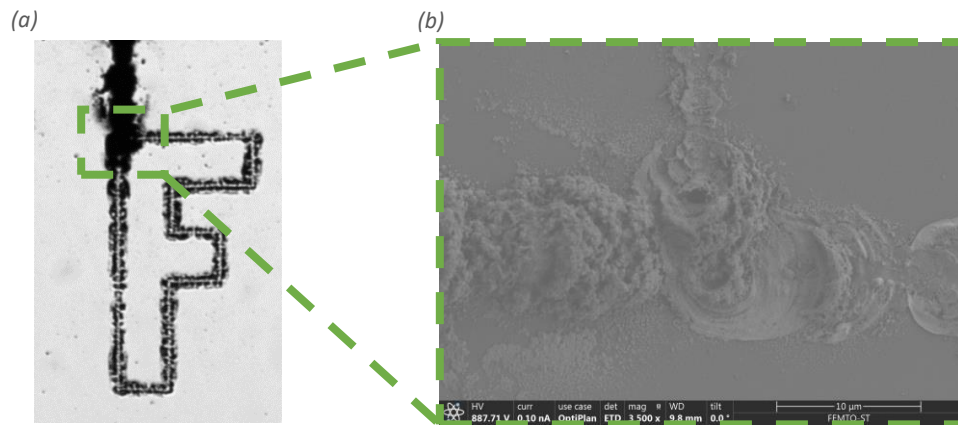
# Laser-assisted 3D deposition techniques of functional materials

*Elliott Crevon, Remi Meyer, Luca Furfaro, Ausrine Bartasyte, François Courvoisier*

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The manufacturing of 3D structures is highly needed for a number of applications in micro and nanotechnologies. Two-photon photopolymerization is particularly successful to fabricate complex devices, but remains limited to material that can accommodate being generated via a polymer ink [1]. To overcome these problems, there are ultrafast laser-assisted deposition techniques allowing the formation of functional material structures. Here, we report on two different manufacturing techniques which are photolytic deposition and pyrolytic deposition of functional materials.

Photolytic deposition is based on the nonlinear effect of bi-photon absorption. This process occurs when an aqueous solution is irradiated with femtosecond pulses. The non-linear absorption induces a chemical reduction process, which dissociates the precursors from the solution in order to reduce the desired particles [2]. The particles will then aggregate and form structures. The location of the deposition is controlled in the 3 dimensions by translating the focal volume of the laser. We demonstrate the deposition of platinum on a transparent substrate placed in liquid solution via nonlinear photolysis [3]. As shown in Fig 1(a) it is possible to produce controlled platinum (Pt) structures. It is apparent that the sintering of the Pt nanoparticles led to the melting of the metal, and displacements of material. In addition, when the beam crosses an already deposited structure, a strong reabsorption takes place (left of Fig.1(b)) and the thickness of the deposit increases, as well as additional texturing, leading to the degradation of the film towards a 3D structure presenting cavities.



*Figure 1 (a) Microscope image of a Pt deposit on a glass substrate for a fluence of 0.3J/cm<sup>2</sup>. (b) Scanning electron microscope (SEM) image of Pt deposition highlighting the Pt formation process during crossing.*

The second technique to study is pyrolytic deposition. Pyrolytic deposition can occur in a gaseous medium or in a gel and is based on thermal decomposition by local heating induced by nanosecond pulses [4]. The laser beam focused at the substrate-reactive medium interface deposits locally a high density of thermal energy which dissociates the precursor molecules from the indium tin oxide (ITO) that we want to deposit. This type of deposition makes it possible to go beyond the usual procedures such as the use of chemical vapor deposition (CVD) machines which cannot produce localized and controlled structures.

The effectiveness of these two techniques, despite the fact that their physical principles are different, both strongly depend on the laser parameters (fluence, repetition rate, scanning speed). Polarization and focusing distance also play a crucial role in these manufacturing processes. Our results open interesting perspectives toward the printing of functional materials on non-planar substrates at micro- or nano- metric scales.

[1] L. Yang et al., "Multi-material multi-photon 3d laser micro- and nanoprinting.", *Light adv. manuf.*, 2, (2021).

[2] L. Yang et al., "Laser printed microelectronics.", *Nat. Commun.*, 14, 12 (2023).

[3] L. Yang et al., "In situ diagnostics and role of light-induced forces in metal laser nanoprinting.", *Laser and Photonics Rev.*, 16, 3 (2022).

[4] Y. Van De Burgt et al., "Laser-assisted growth of carbon nanotubes.", *J. Laser Appl.*, 26:18, 4 (2014).

# Optimization of MHz Pulsed Laser Micro-machining for Graphite Sample Preparation

V.Sanchez<sup>1</sup> ; C.E Cifuentes Quintal<sup>1</sup> ; T. Doualle<sup>2</sup> ; Y. Pontillon<sup>2</sup> ; L. Gallais<sup>1</sup>

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Abstract PLI :

In order to accelerate the characterization of heat-sensitive materials, one of a crucial aspect is the ability to prepare a high number of samples with fine control over the heat-affected zone (HAZ) on the sample. Micro-machining using short-pulsed lasers is a promising technique to meet this challenge. Indeed, the extend of the HAZ depends on the pulse duration, leading to differences of up to three orders of magnitude between the sub-picosecond and nanosecond regimes.

However, while this distinction holds for single-shot processes, using high repetition rates introduces various physical phenomena, such as incubation, plasma shielding, or thermal accumulation, thus complicating the choice of the optimal pulse duration to achieve an efficient and non-damaging process.

We therefore propose a study of laser cutting and engraving to compare process efficiency and the heat-affected zone regarding the scanning speed and the fluence, using two commercial laser sources. These sources emit at 515nm, operate from single-shot up to 2 MHz, delivering average powers from 1 W to 50 W with pulse duration of 700 fs and 2–10 ns, respectively. The material used is EDM3-graphite, a polycrystalline graphite with well-known thermo-physical properties.

Experiments were conducted first to determine ablation characteristics, such as the ablation threshold, incubation parameter, and penetration depth, in order to identify the optimal machining parameters that maximize efficiency while minimizing the heat-affected zone. Laser parameters ranged from 0.1 to 2 MHz, with fluences from 1 to 100 J/cm<sup>2</sup>, and typical scanning speeds between 0.1 and 5 m/s.

## **Caractérisations microstructurales et mécaniques d'alliage de titane texturé par laser nanoseconde**

La texturation laser de surface est un procédé permettant de générer une rugosité morphologiquement contrôlée. Dans le cadre de l'élaboration de revêtements par projection thermique, cette préparation de surface assure un meilleur ancrage mécanique des particules fondues et garantit l'adhérence à l'interface. Toutefois, les gradients thermiques induits par le faisceau laser altèrent la microstructure et les propriétés physico-chimiques de la zone affectée thermiquement (ZAT), pouvant ainsi modifier la tenue en fatigue du système.

Ce travail caractérise l'impact des paramètres de texturation (densité d'énergie, durée et nombre d'impulsions) d'un laser nanoseconde ( $\lambda = 1064 \text{ nm}$ ) sur un alliage Ti-6Al-4V.

Afin de comprendre l'influence de ces paramètres sur l'intégrité de surface, une approche combinée a été mise en œuvre. La microscopie électronique à balayage (MEB) a permis d'identifier les changements microstructuraux et la profondeur de la ZAT sous les cavités. Cette caractérisation est complétée par de la nanoindentation, afin d'établir une corrélation directe entre l'évolution microstructurale et les variations de propriétés mécaniques locales. Enfin, l'état mécanique est évalué par diffraction des rayons X (DRX) pour les contraintes macroscopiques, et par microscopie micro-ondes à balayage (SMM) pour l'étude de la distribution locale des contraintes.

Les analyses révèlent une zone affectée thermiquement de l'ordre de quelques micromètres. Les observations au MEB mettent en évidence une modification microstructurale majeure : la structure équiaxe initiale du matériau massif évolue vers une microstructure lamellaire en sous-surface. Cette transformation est corrélée aux profils de nanoindentation qui indiquent un durcissement significatif, atteignant 4,5 GPa (+12 % par rapport au cœur).

En parallèle, les mesures par DRX révèlent des contraintes résiduelles de traction, dont l'intensité croît avec la densité d'énergie et le nombre d'impulsions. Les mesures par SMM montrent une variation du signal d'amplitude localisée au niveau des cavités, mettant en évidence l'hétérogénéité de la distribution des contraintes à l'échelle locale. Afin de pallier les risques de fragilisation et de chute de la tenue en fatigue induits par ces contraintes, des recuits de détente sous argon ont été réalisés. Ces traitements thermiques ont permis une relaxation majeure des contraintes, avec des baisses significatives allant de 60 à 80 %. Ces résultats démontrent la faisabilité de la texturation laser comme préparation de surface, à condition d'y associer un post-traitement thermique adapté pour restaurer l'intégrité mécanique.

Ces résultats offrent une solution robuste pour préparer les surfaces avant projection thermique, en conciliant une forte adhérence à l'interface et une relaxation efficace des contraintes de traction.

## **Décapage et texturation laser nanoseconde de l'alliage AA2024 : préparation de surface pour une conversion chimique sans Cr(VI)**

La conversion chimique constitue un traitement de surface stratégique pour les pièces en alliages d'aluminium, car elle permet de concilier la protection contre la corrosion et le maintien de la continuité électrique. L'enjeu industriel majeur réside aujourd'hui dans la substitution du procédé actuel contenant du chrome hexavalent, dont l'usage est désormais visé et restreint par la réglementation européenne REACh. Cette transition s'avère particulièrement complexe pour les alliages d'aluminium riches en cuivre, tel que l'AA2024, sur lesquels les solutions de conversion alternatives manquent encore de robustesse. Sur ces matériaux, la présence de particules intermétalliques riches en cuivre, notamment en surface, favorise l'apparition d'amorces de corrosion locales.

Les travaux présentés concernent l'utilisation d'une préparation de surface contrôlée, réalisée par décapage laser nanoseconde en amont de la conversion chimique. L'objectif n'est pas uniquement d'enlever une couche superficielle, mais de reconfigurer l'état initial de surface de l'AA2024 de manière reproductible : limiter les hétérogénéités locales associées aux zones Cu-riches, contrôler la rugosité générée et ajuster la nature des espèces oxydées formées lors du traitement. En maîtrisant ces paramètres, on vise à fournir à la conversion alternative un substrat plus "favorable", conduisant à une couche formée de façon plus uniforme et donc à une performance anticorrosion plus robuste, tout en respectant les contraintes fonctionnelles de continuité électrique et de finition de surface.

À la date de la conférence, le poster présentera la stratégie de recherche mise en place, depuis la définition d'une matrice d'essais de décapage laser jusqu'au choix des moyens de caractérisation mobilisés pour relier paramètres procédé, état de surface et performance après conversion. Il montrera également les premiers résultats portant sur l'état de surface de l'AA2024 après traitement laser.

## Micro drilling of thin glass with GHz-bursts of femtosecond pulses for flat panel displays and microelectronics manufacturing

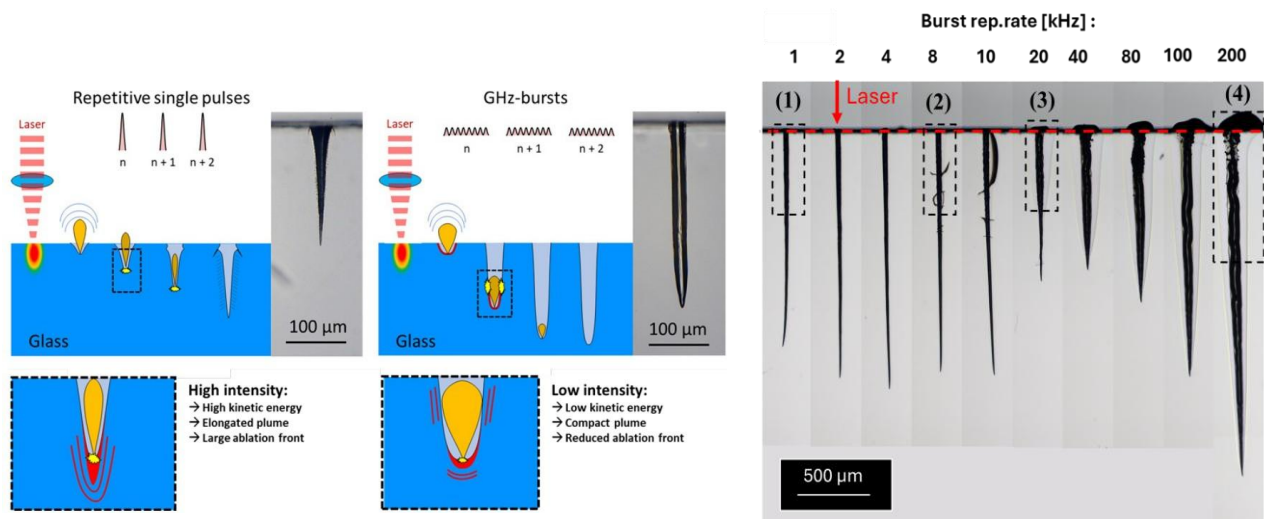
Urruty<sup>1\*</sup>, A., Guilberteaud, T.<sup>1,2</sup>; Lafargue, M.<sup>1,3</sup>; Fillez<sup>1</sup>, T.; Lopez, J.<sup>1</sup>; Manek-Hönninger, I.<sup>1</sup>

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### Abstract

Over the past few years, the use of GHz-bursts of femtosecond pulses emerged as an efficient technique for crack-free and chemical-free high aspect ratio micro drilling of transparent dielectrics materials [1,2]. Indeed, the inter-pulse delay within the burst (0.8 ns) is shorter than the heat relaxation time of the target material, so a gentle heat accumulation occurs during each burst, improving the local ductility of the material and leading to a highly efficient drilling mechanism. In this study, we investigate the potential of this innovative technique for blind and through hole drilling in Corning<sup>®</sup> Eagle XG glass (Alkaline earth boro-aluminosilicate). This glass is considered as the most widely used and trusted glass for thin, light and large-size display panel manufacturing. The glass composition includes no added heavy metals, reducing the environmental impact and health hazards of manufacturing and thinning. Eagle XG glass presents also a high interest for interposers in microelectronics. These devices are used as interconnecting layers between components in 3D printed board chip manufacturing. Our motivation is to develop and optimize a new technique for through glass via (TGV) of Eagle XG glass. Investigated parameters are the burst repetition rate, the fluence, the number of pulses in the burst and the temporal intensity profile of the burst. The role of sacrificial layers for both surface quality and large output diameter is also highlighted for matrix drilling of through holes.



**Fig. 1** (left) Schematic representation of the drilling process in the repetitive single pulse regime and in the GHz-burst mode [3]. (right) Micro drilling of Eagle XG glass at 1.28 GHz, heat affected zone and crack appearance with increasing burst repetition rate.

### References

- [1] Lopez, J., Niane, S., Bonamis, G., Balage, P., Audouard, E., Hönninger, C., Mottay, E., & Manek-Hönninger, I. (2022). Percussion drilling in glasses and process dynamics with femtosecond laser GHz-bursts. *Optics Express*, 30(8), 12533–12544. <https://doi.org/10.1364/OE.455553>.
- [2] Balage, P., Lopez, J., Bonamis, G., Hönninger, C., & Manek-hönninger, I. (2023). Crack-free high-aspect ratio holes in glasses by top – down percussion drilling with infrared femtosecond laser GHz-bursts. *International Journal of Extreme Manufacturing*, 5, 015002. <https://doi.org/https://doi.org/10.1088/2631-7990/aca14>
- [3] Balage, P., Lopez, J., Guilberteaud, T., Lafargue, M., Bonamis, G., & Hönninger, C. (2024). Through Glass Via Drilling Using GHz-bursts of Femtosecond Pulses: Challenges and Implementation. *Journal of Laser Micro Nanoengineering*, 19(3), 2–8. <https://doi.org/10.2961/jlmn.2024.03.2007>

# **From Single Pulses to GHz-Bursts: Optimising Column Growth in Silicon**

Silicon is a fundamental material for modern microelectronic devices and computer chips. In silicon photonics, the direct integration of optical elements onto silicon wafers enables optical and electronic components to coexist on a single platform leading to more compact and energy-efficient systems. While ultrafast laser processing of silicon has been extensively investigated for surface applications such as laser welding and the formation of Laser-Induced Periodic Surface Structures (LIPSS), achieving precise and controlled modifications within the bulk of silicon remains a major challenge. Nevertheless, such three-dimensional bulk modifications are essential for the development of advanced silicon photonics devices including embedded waveguides, and therefore remain a significant technological hurdle.

The primary difficulty in bulk laser processing of silicon originates from its interaction with high-intensity laser beam. Silicon possesses a high nonlinear refractive index, which gives rise to strong nonlinear optical effects under ultrashort pulse irradiation. In particular, the optical Kerr effect induces self-focusing of the laser beam, resulting in prefocal energy deposition before the intended focal region. This behavior prevents controlled and localized energy delivery within the bulk material and often leads to unstable or undesirable modification regimes. One effective strategy to mitigate these nonlinear effects is to lower the laser peak intensity while preserving the total deposited energy by distributing a single pulse into a burst of temporally separated pulses. Consequently, femtosecond laser micromachining in burst mode has attracted considerable attention in recent years and has demonstrated significant advantages for laser-based material processing.

In this study, bottom-up columnar modifications in the bulk of 1 mm-thick crystalline silicon (c-Si) samples are investigated using single-pulse and GHz-burst laser irradiation at a wavelength of approximately 1.6  $\mu\text{m}$ . The experimental approach includes both repetitive single-pulse irradiation and double-pulse configurations with an interpulse delay of 1 ns. A detailed comparative analysis is conducted for pulse durations ranging from 550 fs to 2.5 ps. In addition, preliminary experiments employing a four-pulse GHz-burst are also performed to further explore the benefits of burst-mode processing.

The influence of processing parameters on column growth probability is systematically examined by varying pulse energy, pulse duration, laser repetition rate between 1 and 10 kHz, and writing speed from 1  $\mu\text{m/s}$  to 15 mm/s. The resulting columnar structures are analyzed morphologically to assess the stability and reproducibility of the modifications across different pulse configurations. The experimental results demonstrate that the four-pulse burst regime enables reproducible column growth at the same total burst energy while achieving writing speeds up to five times higher than those obtained using two pulses, provided that the energy of each pulse exceeds the silicon damage threshold. Using optimized processing conditions, highly repeatable columns are successfully fabricated at writing speeds of up to 15 mm/s.

# Femtosecond laser micromachining of glass Lab-on-Chip devices for neural connectivity studies

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Investigating the connectome, the brain's wiring diagram, presents a significant challenge due to its structural and functional complexity. To study network formation in vitro, it is essential to create a microenvironment where neuronal organoids can survive and mature. In addition, organoids need to be capable of growing axons toward neighboring organoids and transmitting action potentials to establish functional connectivity. For connectome classification it is necessary to be able to electrically stimulate and record electrophysiological activity. Microfluidic or Lab-on-chip (LOC) devices provide a versatile platform for such research [1]. These platforms allow controlled studies of pharmacological treatments and electrical stimulation parameters to investigate their influence on neural connectivity [2][3].

The LOCs need to be made from thin, optically transparent materials due to imaging demands (e.g. confocal fluorescence microscopy). Glass presents itself as an excellent substrate material due to its high optical transparency, low thermal conductivity, high electrical isolation and biocompatibility. Compared to traditional lithography techniques, laser processing offers several advantages, including minimal chemical usage, rapid design changes and reduced reliance on cleanroom facilities. However, laser microfabrication of different glasses presents a significant challenge due to their brittleness and hardness. Femtosecond laser processing has proven to be a powerful tool for glass micromachining. The ultrashort interaction between a femtosecond laser pulse and the material is predominantly non-thermal. This reduces the chance for crack formation and enables structuring with a high degree of precision which avoids the need for photoresist or aggressive chemicals.

We designed and fabricated LOC devices incorporating different topographical and galvanotropic elements to investigate neural connectivity. Thin (<1 mm) borosilicate and fused silica glasses were processed using femtosecond laser writing, cutting and welding [4]. A glass microstructure consisting of two reservoirs connected by 5 μm wide trenches was fabricated. The trench geometry was designed to promote directed axonal outgrowth between reservoirs, thus enabling the formation of functional connections between organoids while keeping them physically separated. Surface topology was characterized by using optical profilometry, contact profilometry and scanning electron microscopy (SEM).

Organic electrolytic photocapacitors (OEPCs) were integrated into the LOC design for capacitive neurostimulation. OEPCs are optoelectronic stimulators based on a p-n bilayer of organic semiconductors. Previous studies have demonstrated their ability to generate sufficient electrical charge to modulate neural tissue both *in vitro*[5] and *in vivo*[6]. Fabrication begins by evaporating a 30 nm layer of gold onto a glass substrate, followed by OTS surface treatment to prevent delamination and improve adhesion. Gold is then selectively patterned using femtosecond laser writing, after which the p-n bilayer is deposited by thermal vacuum evaporation. The photocapacitors are electrically characterized by measuring the transient electric potential under optical stimulation.

- [1] R. Van De Wijdeven *et al.*, “A novel lab-on-chip platform enabling axotomy and neuromodulation in a multi-nodal network,” *Biosensors and Bioelectronics*, vol. 140, p. 111329, Sep. 2019, doi: 10.1016/j.bios.2019.111329.
- [2] X. Yang *et al.*, “Kirigami electronics for long-term electrophysiological recording of human neural organoids and assembloids,” *Nat Biotechnol*, vol. 42, no. 12, pp. 1836–1843, Dec. 2024, doi: 10.1038/s41587-023-02081-3.
- [3] L. Mou *et al.*, “Integrated biosensors for monitoring microphysiological systems,” *Lab Chip*, vol. 22, no. 20, pp. 3801–3816, 2022, doi: 10.1039/D2LC00262K.
- [4] M. Lafargue, T. Guilberteau, P. Balage, B. Gavory, J. Lopez, and I. Manek-Hönninger, “In-Volume Glass Modification Using a Femtosecond Laser: Comparison Between Repetitive Single-Pulse, MHz Burst, and GHz Burst Regimes,” *Materials*, vol. 18, no. 1, p. 78, Dec. 2024, doi: 10.3390/ma18010078.
- [5] T. Schmidt *et al.*, “Light Stimulation of Neurons on Organic Photocapacitors Induces Action Potentials with Millisecond Precision,” *Adv Materials Technologies*, vol. 7, no. 9, p. 2101159, Sep. 2022, doi: 10.1002/admt.202101159.
- [6] M. Silverå Ejneby *et al.*, “Chronic electrical stimulation of peripheral nerves via deep-red light transduced by an implanted organic photocapacitor,” *Nat. Biomed. Eng.*, vol. 6, no. 6, pp. 741–753, Dec. 2021, doi: 10.1038/s41551-021-00817-7.

# Une alternative « toute fibrée » au CPA pour la génération et le déport par fibre d'impulsions picosecondes mégawatts.

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Depuis quelques années, les applications biomédicales faisant appel aux sources lasers femtosecondes sont en expansion, et en particulier dans le domaine de la chirurgie ophtalmologique [1]. Ces procédés chirurgicaux nécessitent de fortes puissances crêtes pour atteindre les seuils de claquage optique. Une architecture classique comme l'Amplification d'Impulsion Chirpée (CPA) [2] permet d'atteindre ces puissances mais souffre d'un encombrement conséquent et l'acheminement des impulsions vers le patient pose problème. Nous proposons ici une architecture qui, à l'inverse du CPA, vient mettre à profit l'auto modulation de phase (SPM) [3] dans les fibres. La SPM amène un élargissement spectral de l'impulsion et induit un « gazouillis » temporel qui peut nuire à la qualité de la compression dans le cas d'un pulse gaussien, en particulier pour compresser à l'aide d'un composant à dispersion fixe tel qu'un réseau de bragg chirpé (CVBG). Nous proposons ici une mise en forme parabolique [4] de manière à compenser la phase du CVBG par celle de l'impulsion et obtenir de hautes puissances crêtes à forts contrastes. L'intérêt de cette architecture est la compacité et cette capacité à déporter les impulsions jusqu'à l'application donnée de par l'utilisation de fibres souples.

Dans ce poster, nous présentons un banc entièrement fibré permettant la génération d'impulsion picosecondes à fort contraste en partant d'impulsions gaussiennes d'une durée de l'ordre de 55 ps. Afin d'apporter un meilleur contrôle de la SPM lors de la montée en puissance, une fibre active maison dopée Ytterbium a été réalisée par la méthode du « stack » et « draw » avec pour objectif une fibre monomode même sous la contrainte de rayons de courbures aléatoires. Un cœur de 20  $\mu\text{m}$ , dopé Ytterbium, est entouré d'une première gaine dopée Aluminium pour conserver une faible différence d'indice cœur-gaine ( $\Delta n = 6.10^{-4}$ ) et assurer une émission transversalement monomode. La pompe est guidée à l'aide d'une seconde gaine en silice de plus faible indice. Afin d'améliorer l'efficacité de la fibre, 4 barreaux dopés fluor sont placés dans la première gaine. Enfin 2 barreaux dopés Bore assurent le maintien de polarisation dans la fibre.

Après une mise en forme parabolique dans 500 m de fibre passive, on obtient des impulsions de 1 ps, fortement contrastées, avec des puissances crêtes supérieures à 10 mégawatts.

[1] S. F. Barrett, et al, in Medical Applications of Lasers, Boston, MA : Springer US, 2002.

[2] D. Strickland, et al, Optics Communications, vol. 56, pp. 219–221, Dec. 1985.

[3] Agrawal, G. (2013) Nonlinear Fiber Optics. 5th Edition, Academic Press, Oxford.

[4] C. Finot, et al, Opt. Express 15, 852-864 (2007)

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