PLI

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CONFÉRENCES

June 18 & 19, 2024

Palais de la Bourse - Bordeaux

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MARDI 18 JUIN

▶ SESSION PLÉNIÈRE D'OUVERTURE / PLENARY OPENING SESSION

Amphithéâtre Jean Touton / Modérateur : John Lopez

08:30	Accueil café / Welcoming coffee	
09:00	Ouverture / Opening talk	
09:20	Aiko NARAZAKI AIST *(Japan)*	Traitement laser à impulsions ultracourtes basé sur des données et son application aux matériaux en verre *Data-driven ultrashort pulse laser processing and its application to glass materials*
09:50	Inka MANEK-HÖNNINGER CELIA / BORDEAUX UNIVERSITY *(France)*	Traitement laser ultrarapide avec des rafales de GHz *Ultrafast laser processing with GHz-bursts*
10:20	Minlin ZHONG TSINGHUA UNIVERSITY *(China)*	Micro-nano-structuration laser ultra-rapide d'une chambre à vapeur ultra-mince pour un refroidissement très efficace en microélectronique *Ultrafast laser micro-nano structuring of ultra-thin vapor chamber for high efficient cooling in microelectronics*
10:50	Pause-café / Coffee break	
11:20	Jan-Philipp WEBERPALS AUDI *(Germany)*	Applications améliorées du faisceau laser dans la construction de carrosseries automobiles sur des composants en aluminium *Enhanced laser beam applications in car body construction on aluminum components*
11:50	Andreas MICHALOWSKI IFSW *(Germany)*	Apprentissage automatique dans les applications laser *Machine learning in laser applications*
12:20	Pause déjeuner / Lunch break	

▶ SESSION MICRO-USINAGE / MICRO MACHINING SESSION

Amphithéâtre Jean Touton / Modérateurs : Julien GRANIER & Florent THIBAULT

14:00	Floriane CRESTEY IRT SAINT EXUPERY *(France)*	Maîtrise du procédé laser pour la préparation de surface avant collage *Towards a reliable laser process for surface preparation before bonding*
14:20	Théo GUILBERTEAU CELIA / ALPHANOV *(France)*	Polissage d'acier inoxydable par impulsion laser femtosecond en burst-GHz *Polishing of stainless steel with femtosecond GHz-burst laser*
14:40	Pauline JULLIAN MANUTECH USD *(France)*	Traitement laser femtoseconde à 515 nm avec un module de mise en forme du faisceau top hat *Femtosecond laser processing at 515 nm with a top hat beam shaping module*
15:00	Sara Maria VIDAL AIMEN *(Spain)*	Texturation d'outils avec laser de femtosecondes pour la réplication via R2R *Femtosecond laser tooling texturing for replication through R2R process*
15:20	Laurent GALLAIS INSTITUT FRESNEL *(France)*	Étude du traitement au laser en tant qu'approche prometteuse pour la préparation d'échantillons de céramique de combustible nucléaire en environnement hostile *Investigation of laser processing as a promising approach for the preparation of nuclear fuel ceramic samples in harsh environment*
15:40	Pause-café / Coffee break	
16:20	Marie FLEUREAU AMPLITUDE *(France)*	Débit amélioré dans le traitement laser à impulsions ultracourtes : stratégies et implications pour l'industrie automobile *Enhanced throughput in ultrashort pulse laser processing: strategies and implications for automotive industry*

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16:40	Guillaume SZYMCZAK LASEA *(France)*	Le traitement laser ultracourt de designs complexes, d'une lunette de montre à un roll-to-roll, grâce à la synchronisation avancée des paramètres optiques et mécaniques *Ultrashort pulse laser processing of complex designs, from Bazel ring to a roll to roll thanks to advanced synchronization of optical and mechanical parameters*
17:00	Jean-François POISSON LIGHT CONVERSION *(Lithuania)*	Micro-usinage de précision utilisant une source laser femtoseconde UV en faisceau "flat-top" *Precision micromachining using a femtosecond flat-top deep UV laser*
17:20	Valentin GARTISER ALPHANOV *(France)*	Projet Newskin : solutions industrielles pour la fonctionnalisation de surfaces par laser *The Newskin project: industrial solutions for laser-enabled surfaces*
17:40	Bryan GERMANN AEROTECH *(USA)*	Progrès des systèmes de positionnement laser et impact sur la fabrication électronique et l'emballage des semi-conducteurs *Advances in laser positioning systems and impact on electronic manufacturing and semiconductor packaging*
18:00	Fin de journée / End of the day	

▶ SESSION SOUDAGE & FABICATION ADDITIVE / WELDING & ADDITIVE MANUFACTURING SESSION

Salle Gabriel / Modérateurs : Frédérique MACHI & Laurent MENUAT

14:00	Anika LANGEBECK BIAS *(Germany)*	Cartographie de la température couche-par-couche pour un meilleur contrôle du processus lors de la fusion laser sur lit de poudre *Layer by layer temperature mapping for enhanced process control in laser powder bed fusion*
14:20	Andre ELTZE LASERLINE *(Germany)*	Revêtement par laser à diode pour des produits plus durables : roulements, disques de frein, pistons *Diode laser cladding for more sustainable products: bearings, brake discs, pistons*
14:40	Victor HAYOT ICAM / IREPA LASER *(France)*	Amélioration de la prédiction de la pénétration du cordon en soudage laser par une intelligence artificielle *Improving prediction of laser welding penetration in metals using artificial intelligence*
15:00	Peter KALLAGE COHERENT *(France)*	Relever les défis de la fabrication des batteries avec des lasers à fibre à haute brillance et à mode central *Overcoming challenges in battery manufacturing with high brightness center mode fiber lasers*
15:20	Nathan HAGLON ICB / LASER RHONE ALPES *(France)*	Soudage dissimilaire entre l'alliage constantan Cu55Ni45 et l'alliage de titane Ti-6Al-4V avec des lasers Ytterbium YAG aux longueurs d'onde 1030 nm et 515 nm *Dissimilar welding between Cu55Ni45 constantan alloy to Ti-6Al-4V titanium alloy with 1030 nm and 515 nm Ytterbium YAG lasers*
15:40	Pause-café / Coffee break	
16:20	Andrey ANDREEV TRUMPF *(France)*	Vision Line OCT *Vision Line OTC*
16:40	Wilfried VOGEL MKS / OPHIR *(France)*	Comment s'assurer de la qualité du faisceau de lasers haute puissance dans les procédés de fabrication additive par laser ? *How to ensure the beam quality of high-power Lasers in laser additive manufacturing process?*
17:00	Gwenn PALLIER CAILABS *(France)*	Renforcer les procédés de soudure laser du cuivre et de l'aluminium grâce à la mise en forme de faisceau avec la conversion multiplans de la lumière *Strengthening copper and aluminum laser welding processes through beam shaping with multi-plane light conversion*
17:20	Tugay KURTAY OPTOPRIM *(Italy)*	Exemples de solutions sur mesure en soudage laser *Examples of tailored solutions in laser welding*

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17:40	Stephan HOLESCH PRIMES *(Germany)*	Maximiser la rentabilité et le rendement en production à travers l'analyse des faisceaux laser *Maximizing cost efficiency and production uptime through laser beam diagnostics*
18:00	Fin de journée / End of the day	

▶ SOIRÉE NETWORKING / NETWORKING EVENING

18:45	Départ en bus de Bordeaux Centre - Allée de Tourny / Bus transfer from Bordeaux center - Tourny path
19:15	**Arrivée aux Bassins des Lumières** / Arrival at Bassin des Lumières
19:30	**Apéritif** / Aperitif
20:30	**Dîner** / Dinner
23:00	Départ en bus vers Bordeaux Centre / Bus transfer to Bordeaux center
23:15	Arrivée Bordeaux Centre / Arrival at Bordeaux center

MERCREDI 19 JUIN

▶ SESSION MICRO-USINAGE / MICRO MACHINING SESSION

Amphithéâtre Jean Touton / Modérateur : Marc FAUCON

8:40	Manon LAFARGUE CELIA / AMPLITUDE *(France)*	Soudage de verre par transparence avec un laser ultrabref en régime mono-impulsion ou rafale *Femtosecond laser glass welding with repetitive single pulses and in burst mode*
9:00	Daniela SERIEN AIST *(Japan)*	Microstructures 3D protéiques pures par écriture directe au laser femtoseconde de forme libre *Pure proteinaceous 3D microstructures by free-form femtosecond laser direct write*
9:20	Baptiste DE AZEVEDO INSA STRASBOURG *(France)*	Modélisation multiphysique du soudage verre-silicium par laser ultrabref *Multiphysics modelling of glass-silicon welding using ultrafast laser*
9:40	Hansjoerg ROHDE LASER COMPONENTS *(Germany)*	Miroirs de diagnostic pour le contrôle du processus de fabrication des matériaux par laser *Diagnostic mirrors for monitoring the laser material process*
10:00	Luis Alonso VAZQUEZ-ZUNIGA INSTITUT FRESNEL *(France)*	Réparation des optiques LMJ par usinage Laser CO2: optimisation du processus par simulation numérique *CO2 laser processing for laser induced-damage mitigation of fused silica optics. Process development based on numerical simulation*
10:20	Pause-café / Coffee break	

▶ SESSION MICRO-USINAGE & SÉCURITE LASER / MICRO MACHINING & LASER SAFETY SESSION

Salle Gabriel / Modérateur : Guillaume SZYMCZAK

8:40	Franck RIGOLET IREPA LASER *(France)*	Soudage laser manuel : une révolution dangereuse ? *Manual laser welding: a dangerous revolution?*
9:00	Julien BRIBET ALPHANOV *(France)*	Comment améliorer le comportement en matière de sécurité laser dans l'industrie ? *How to improve laser safety behaviour in industry?*

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9:20	Emric VERWAERDE LASER CHEVAL *(France)*	Micro-usinage laser, décoration : quels enjeux ? *Laser micromachining, decoration: what are the challenges ?*
9:40	Florent THIBAULT QIOVA *(France)*	Mise en forme dynamique du faisceau : des performances de traitement laser supérieures pour booster l'adoption du micro-usinage laser dans l'industrie *Dynamic beam shaping: delivering superior efficiency and capabilities to boost adoption of laser micro processing across industries*
10:00	Romain DUBREUIL GF MACHINING SOLUTIONS *(France)*	Redéfinir les signatures lumineuses automobiles grâce à la gravure laser de précision *Redefining automotive light signatures through precision laser engraving*
10:20	Pause-café / Coffee break	

▶ TABLE-RONDE / PANEL SESSION

Amphithéâtre Jean Touton / Animatrice : Gwenn PALLIER

11:00 Table ronde sur la mobilité aérienne / Panel session on air mobility
- Clémentine GALLET, CEO de Coriolis, Présidente du GIFAS
- Denis DESCHEEMAEKER, Senior Manager Airbus, CEO IRT St Exupéry
- Sébastien DEVROE, CTO de Add-Up

12:20 Pause déjeuner / Lunch break

▶ SESSION PLÉNIÈRE DE CLOTURE / PLENARY CLOSING SESSION

Amphithéâtre Jean Touton / Modératrice : Inka MANEK-HÖNNINGER

14:00	Markus KOGEL HOLLACHER PRECITEC *(Germany)*	Les défis du soudage laser dans l'e-mobilité : quelles innovations sont à l'origine des tendances ? *The challenging aspects of laser welding in e-mobility: which innovations are setting trends?*
14:30	Christian HAGENLOCHER IFSW *(Germany)*	Potentiels des stratégies de mise en forme du faisceau dans le soudage laser *Potentials of beam shaping strategies in laser welding*
15:00	Jiri MARTAN WEST BOHEMIA UNIVERSITY *(Czech Republic)*	Surveillance à grande vitesse de la température d'accumulation de chaleur dans le micro-traitement de surface laser à haut productivité *High-speed heat accumulation temperature monitoring in high-throughput laser surface micro-processing*
15:30	Roberto OCAÑA TEKNIKER *(Spain)*	Micro-perçage laser à haut débit pour le contrôle du flux laminaire hybride *High Throughput Laser Micro-Drilling for Hybrid Laminar Flow Control*
16:00	Richard CARTER HERIOT WATT University *(Scotland)*	Soudage laser pulsé ultra-court de cristaux, verres, métaux et plus encore *Ultra-short pulsed laser welding of crystals, glasses, metals and more*
16:30	Johan BOULLET NAQUIDIS *(France)*	Les technologies laser pour le quantique *Laser technologies for quantum*
17:00	Discours de cloture / Closing talk	

Data-driven ultrashort pulse laser processing and its application to glass materials

Traitement laser à impulsions ultracourtes basé sur des données et son application aux matériaux en verre

Data-driven ultrashort pulse laser processing and its application to glass materials

Aiko Narazaki*[1], Takemichi Miyoshi[1,2], Daisuke Nagai[1,2], Hideyuki Takada[1], Dai Yoshitomi[1], Ryunosuke Kuroda[1], Masato Tanaka[1], Hiroshi Ogawa[1], Daisuke Sato[1], Naoyuki Nakamura[3], Junichi Nishimae[3], Keisuke Furuta[3], Toshio Otsu[4], Tomoharu Nakazato[4], Yohei Kobayashi[4], Kinji Takiguchi[5], Yumi Yamahara[5], Keiichi Asami[5], Godai Miyaji[2]

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Ultrashort pulse (USP) laser processing is highly flexible and promising for precise microfabrication. However, due to its high degree of freedom, it is necessary to optimize multiple process parameters that are intricately correlated, and the process optimization generally requires a lot of effort and time. Therefore, we have developed a new technology, which we call data-driven USP laser processing and is based on three core technologies of in-process monitoring, machine learning, and high-speed laser modulation. In this talk, its application to laser-induced periodic surface structures (LIPSS) and micro-drilling of glass materials is introduced.

Figure 1 shows our concept of the data-driven USP laser processing and its application to the LIPSS formation on brittle transparent materials like glasses. Since the LIPSS formation is sensitive to process parameters as well as material surface conditions, forming the LIPSS stably over a large area is still challenging. Therefore, a process control based on in-process monitoring is vital to make nanostructures more stably. However, it is difficult to monitor the nanostructure formation in-process, because the nanostructures are much smaller than visible light wavelengths. To overcome this issue, a new in-process monitoring technique was developed for identifying the nanostructure formation by using the anti-reflective property of the periodic nanostructure [1]. It has been reported that the periodic nanostructure much smaller than the light wavelength occurs an anti-reflection effect, which decreases the reflectance at the nanostructured surface and increases the transmittance [2]. As a result, we could determine whether a periodic nanostructure has been formed in real-time by monitoring the reflectance and transmittance due to the ani-reflection effect. Finally, we succeeded in stable LIPSS formation with less defects on glass by feedback control of USP laser intensity based on the in-process monitoring data. In the future, the data-driven USP laser processing will create more flexible, more precise, and more productive machining technology.

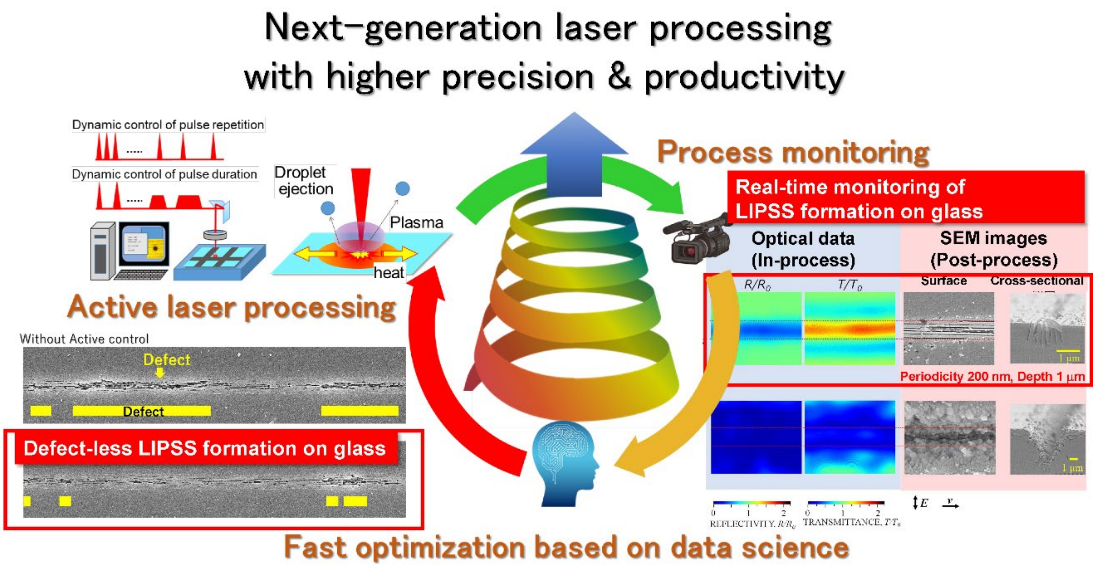

Figure 1 Concept of data-driven ultrashort pulse laser processing.

[1] D. Nagai, H. Takada, A. Narazaki, and G. Miyaji, In-process monitoring of femtosecond laser-induced periodic nanostructures on glass by using anti-reflective property, Proc of SPIE LAMOM, 12408, 124080O, (2023).

[2] E. B. Grann, M. G. Moharam, and D. A. Pommet, Optimal design for antireflective tapered two- dimensional subwavelength grating structures, Journal of the Optical Society of America A, 12, pp.333- 339, (1995).

Ultrafast laser processing with GHz-bursts

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Micromachining with femtosecond lasers operating in the GHz-burst regime has recently attracted increasing attention. Indeed, this temporal beam-shaping technique is a powerful tool for microprocessing of various materials as the time interval between the individual pulses within a burst is typically shorter than the heat diffusion time. Enhanced ablation rates of metals and silicon have been reported [1,2]. For these applications, long GHz-bursts are more advantageous than short ones, and the right choice of burst parameters is crucial [3].

In this contribution, we will present our advances on drilling and cutting of dielectrics with an ultrafast laser source which can operate either in the MHz- or in the GHz-burst regime. A comparison of top-down percussion drilling in glasses with a Gaussian beam in both burst regimes will be given. In contrast to standard drilling with repetitive single pulses (see Fig. 1, left part), the GHz-burst mode allows for obtaining crack-free holes with an outstanding surface quality of the inner walls and featuring an almost cylindrical shape (see Fig. 1, right part) without shifting the beam focus nor the sample [4].

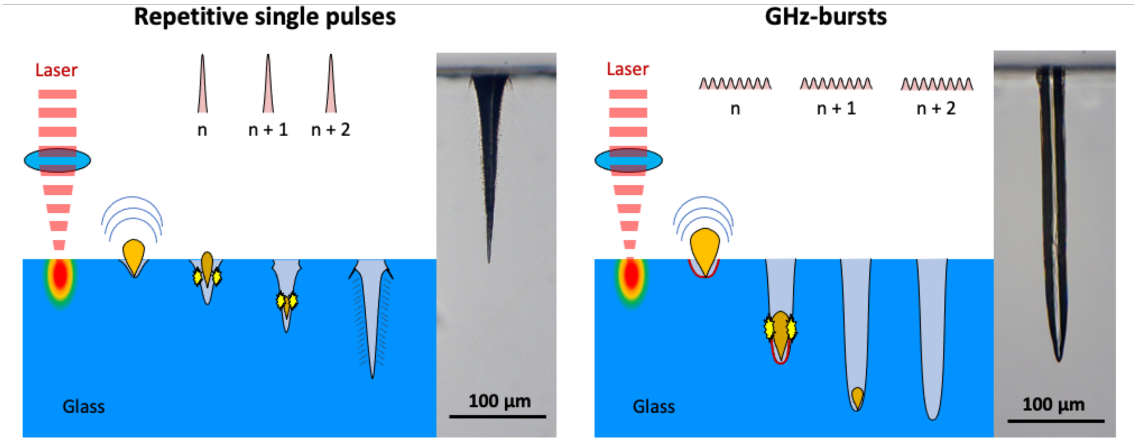

Figure 1 (left) Schematic of drilling with standard repetitive single femtosecond pulses and microscope image of a drilled hole. (right) Schematic of the drilling in GHz-burst mode and corresponding microscope image of a drilled hole.

Moreover, combining temporal and spatial beam shaping allows for cutting of transparent dielectric materials with a Bessel beam. A comparison of the cutting results in both burst operation regimes will be shown illustrating the influence of the laser beam parameters on the machining quality of the cutting plane. In both regimes, dust- and chipping-free cutting has been achieved for glass samples of up to 1 mm thickness. However, the best cutting plane quality in terms of surface roughness is obtained in the GHz-burst regime [5].

[1] C. Kerse, H. Kalaycoglu, P. Elahi, B. Cetin, D. Kesim, O. Akçaalan, S. Yavas, M. Asik, B. Oktem, H. Hoogland, R. Holzwarth, F.O. Ilday, Ablation-cooled material removal with ultrafast bursts of pulses. Nature 537, 84–88, (2016)
[2] P. Elahi, O. Akçaalan, C. Ertek, K. Eken, F.O. Ilday, H. Kalaycoglu, High-power Yb-doped all-fiber laser delivering 300 fs pulses for high-speed ablation-cooled materiel removal. Opt. Lett. 43, 535-538, (2018).
[3] G. Bonamis, E. Audouard, C. Hönninger, J. Lopez, K. Mishchik, E, Mottay, and I. Manek-Hönninger, Systematic study of laser ablation with GHz bursts of femtosecond pulses, Opt. Express 28 27702–14 (2020).
[4] P. Balage, J. Lopez, G. Bonamis, C. Hönninger, I. Manek-Hönninger, Crack-free high-aspect ratio holes in glasses by top– down percussion drilling with infrared femtosecond laser GHz-bursts. Int. J. Extrem. Manuf. 5, 015002, (2023)
[5] P. Balage, M. Lafargue, T. Guilberteau, G. Bonamis, C. Hönninger, J. Lopez, I. Manek-Hönninger, Comparative Study of Percussion Drilling in Glasses with a Femtosecond Laser in Single Pulse, MHz-Burst, and GHz-Burst Regimes and Optimization of the Hole Aspect Ratio. Micromachines 14, 1754 (2023)
[6] P. Balage, T. Guilberteau, M. Lafargue, G. Bonamis, C. Hönninger, J. Lopez, I. Manek-Hönninger, Bessel Beam Dielectrics Cutting with Femtosecond Laser in GHz-Burst Mode, Micromachines 14, 1650 (2023)

Ultrafast laser micro-nano structuring of ultra-thin vapor chamber for high efficient cooling in microelectronics

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Efficient thermal management has become a bottleneck for the further development of highly integrated and high-power microelectronics. Vapor chambers (VCs) based on the passive liquid-vapor phase-change process have attracted increasing attention due to their extraordinary thermal management capabilities together with easy-to-assemble advantages. As microelectronics continuously get more compact and miniaturized nowadays, there appears greater demand to develop high-performance ultra-thin VCs (UTVCs). However, when the overall thicknesses of VCs below 0.3 mm, increasingly serious theoretical and technological bottlenecks occur. On the one hand, the liquid flow and phase change inside VCs present many different physical characteristics at the extremely-thin scale, which requires in-depth research and delicate micro-nano structures; on the other hand, traditional fabrication methods turn to be very difficult or even impossible to fabricate qualified UTVCs in mass production, there reliable new methods are urgently needed.

Due to its superior structuring accuracy and flexibility, laser structuring is functioning as an efficient and enabling technique for versatile surface micro-nano structures, which opens the possibility to design and fabricate sophisticated micro-nano structures for high-performance UTVCs. Herein, by employing laser to fabricate controllable micro-structures and in-situ nano-structures, we first performed a systematic research on the basic phenomena of capillarity, evaporation and transport at the extremely-thin scale. Based on that, we fabricated a kind of dual-scale micro-nano grooved wick with a capillary performance K/R_{eff} up to 1.322 μm by applying a pulse laser - DLIP process, and established a corresponding capillary transport model to elucidate the enhancement mechanism. Then, we proposed and fabricated a novel triple-level super-wicking routes surface using a short pulse and ultrashort pulse laser hybrid processing to achieve excellent capillary performance and efficient and continuous thin-film evaporation, with its photothermal evaporation efficiency up to 3.33 $\mathrm{kg \cdot m^{-2} \cdot h^{-1}}$. Finally, we demonstrated an UTVC with a three-region hybrid configuration fabricated via a facile laser micro-nano structuring approach. The synergy of micro-nano cones and micro-nano grooves reduced the overall vapor-liquid transport resistance and facilitated the self-driven circulation inside the VC (i.e., water evaporation, water condensation, and water/vapor transportation), rendering the UTVC a remarkable effective thermal conductivity to be 12032 W/(m·K) with an overall thickness of only ~0.22 mm, as shown in Figure (1).

We have developed a set of laser based micro-nano structure fabricating approaches for providing theoretical basis and technical support for the internal structure design and large-scale manufacturing of high-performance UTVCs for high efficient cooling in microelectronics.

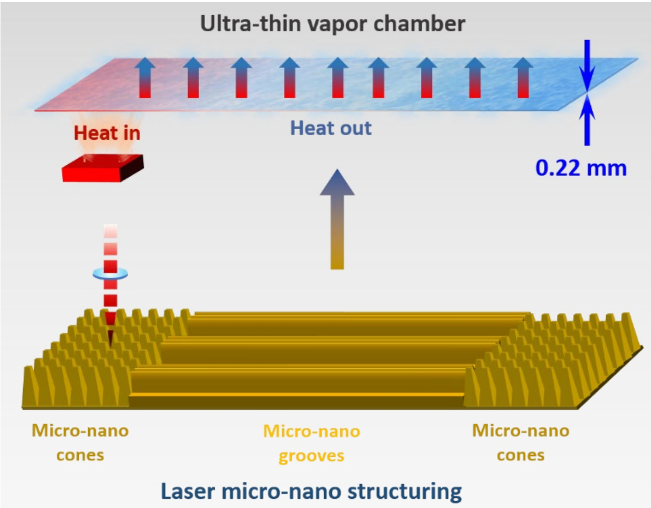

Figure 1 The design and laser micro-nano structuring of ultra-thin vapor chamber for high efficient cooling in microelectronics

Enhanced laser beam applications in car body construction on aluminum components

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The core of future automotive designs is a flexible and at the same time stable joining technology of lightweight materials. A new approach in particular is laser beam remote welding of aluminum. The method enables controlled heat management in the part. Exact positioning of the laser beam in relation to the edge reduces susceptibility to hot cracking. In addition, the gap dimension between the parts can be determined during the joining process and can be effectively bridged by controlled adjustments of the process parameters. Therewith, the amount of heat input to the part is reduced by nearly one-half, which has beneficial effects in terms of reducing heat-related distortion. The increased feed rate and the lower power required by the welding process reduce CO2 emissions by a quarter. Finally, the development of laser beam remote welding compared to tactile laser welding enables significant savings in series production running costs. The elimination of filler wire and protective gas, and all wear components for management of the process media, is a significant adjusting factor. In addition, due to the larger working distance of the processing optics from the interaction zone, it is better protected from contamination like spatters and process emissions, which is why protective glass consumption is significantly reduced. Accordingly, running costs can be reduced by 95% through the use of laser-remote welding. All of these advantages pay off, especially the ability to implement lightweight designs with smaller flanges. As a result, the joining peripheries in the door frame of the Audi A8 are an example to significantly increase field of view for the driver and reduce weight of automotive hang-on parts by using the latest joining technologies. The extension of laser beam remote welding to other areas of the company, affects, for example, door production of the complete Audi A6 family with all derivatives, as well as the first use on the tailgate of the Audi A7. Follow-up operations with this novel technology are the doors, the tailgate and the underrun protection of the Audi e-tron. This clearly shows the importance of this technology for Audi, as design and product- driven concepts can otherwise no longer be implemented. Audi as the first premium manufacturer has thus achieved a unique selling proposition, in that the company uses laser beam remote welding on wrought aluminum alloys [1, 2].

Furthermore, an in-situ sensor concept for this novel welding process enhances the usability for quality assurance. This enables a significant reduction of quality control loop in series production, an absolute measurement of underlying process results, deriving connection properties from the weld seam topography and at last the reduction of investment costs for plant technology. The quality assurance during laser beam remote welding enables high-quality products with a minimum of rework. The direct measurement of seam topography leads to a reduction of complexity using one system platform for tracking, welding and quality assurance. All imperfections are component-specific visualized and determined according to test specification. The resultant significant reduction of closed loop in series production can be reflected in the reduced investment costs by 26 % [3].

In addition to the innovative further development of laser beam remote welding of aluminum components, the process technology for tactile manufacturing processes is also being further developed through the use of adapted beam shaping. By combining the advantages of the process regimes of heat conduction welding and deep penetration welding with small beam diameters, existing process limits can be exceeded. With the help of beam shaping elements, the process and weld seam quality is improved to such an extent that the feed rate can be increased by up to 40%. In addition, beam shaping optimizes the appearance of the weld seam, and the use of argon as a shielding gas has reduced shielding gas costs by 98% [4].

[1] J.-P. Weberpals, D. Böhm, S. Müller: Laser Beam Remote Welding of Aluminum Hang-On Parts. In European Automotive Laser Applications 2015, Bad Nauheim (2015).
[2] J.-P. Weberpals: Laser Processing in Lightweight Production in Automotive Industry. In: International Laser Technology Congress AKL 2018, Aachen (2018).
[3] J.-P. Weberpals and D. Böhm, In-situ Sensor Concept to Ensure the Process Quality for Laser Beam Remote Welding of Aluminum. In European Automotive Laser Applications 2016, Bad Nauheim (2016).
[4] J.-P. Weberpals and D. Böhm, Laser beam welding of aluminum: Improving performance by means of adapted beam shaping. In European Automotive Laser Applications 2021, Bad Nauheim (2021).

Rapid optimization of process parameters through machine learning and automation

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Lasers in material processing are highly versatile tools, capable of executing a wide range of tasks. However, determining optimal process parameters for specific tasks is extremely challenging due to the high-dimensional nature of the parameter space, often referred to as the "curse of dimensionality" [1]. Machine learning algorithms can be very powerful tools for addressing this problem.

One notable black-box optimization method often used in noisy conditions and when fewer than about 20 parameters need optimization is Bayesian optimization (BO) [2]. This paper investigates the broader applicability of Bayesian optimization to real-world problems, highlighting its general utility for laser process developers in practical scenarios. We provide a concise introduction to Bayesian optimization and evaluate its practical use in laser cutting, laser polishing, and laser welding. Our research demonstrates that sophisticated optimization frameworks, coupled with modest expertise from process developers, can identify suitable process parameters within just a few experimental iterations [3]. Additionally, the advantages of automation are highlighted, which ideally complement Bayesian optimization and significantly reduce the time required for parameter identification [4].

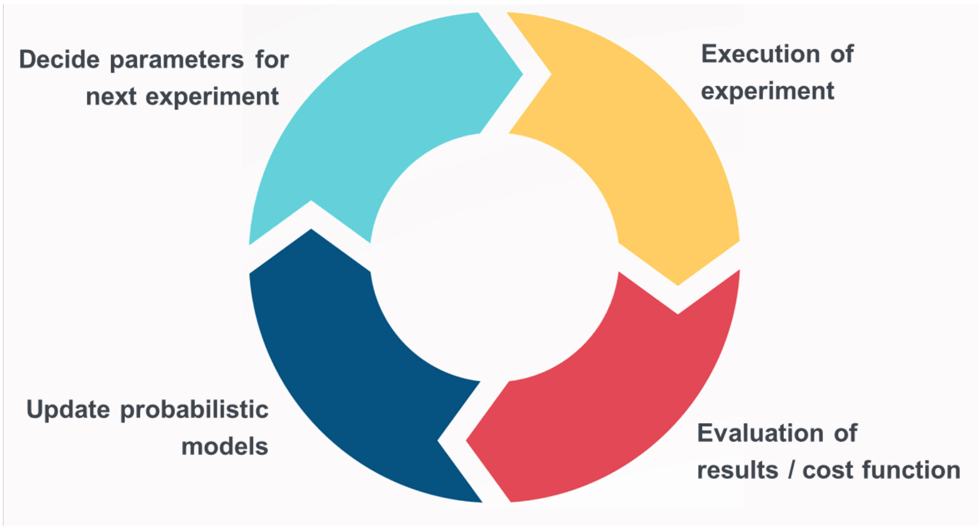

Figure 1 An iterative process for automatic parameter optimization utilizing active learning is implemented including a fully automated workflow. The algorithm develops a surrogate model to determine the next set of test parameters. Often, this method identifies highly suitable parameters with significantly fewer experiments compared to a traditional design of experiments approach.

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Towards a reliable laser process for surface preparation before bonding

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In both the aeronautical/aerospace industries as well as marine & offshore industry, the replacement of riveted and screwed connections with adhesive bonding plays a decisive role in lightening the structure and components. Bonding presents also a high potential for multi-material assembly and ensures a better distribution of stress. Surface preparation before bonding is crucial to guarantee the mechanical performance of these structural bonds. Laser surface preparations are potential alternatives to historical cleaning and pickling processes based on the use of chemical baths. These processes enable to equal or even surpass the mechanical performance of bonded assemblies. For several years, IRT Saint Exupéry has, not only been studying the laser surface preparations through the identification and understanding of the relevant process parameters, but also investigated the transfer of the process to automated platforms able to treat representative technological specimens. The analysis of diverse influential factors sensitivity and the implementation of different online control process technologies are the keys to ensure robustness of laser process for bonding.

Firstly, when embedded on a 6-axis robot for the treatment of parts with complex shapes, some intrinsic deviations may occur such as the loss of the laser beam focus, leading to modification of the resulting treatment. In order to avoid defocus, the laser treatment itself is monitored with a specific regulation system allowing to master the working distance with high precision (< 0.5 mm). This regulation system relies on a linear axis to ensure the laser head displacement and a telemeter that measures precisely the working distance and provides mechanical interlock with the linear axis. The effect of regulation system on bonding was tested at low and high scanning speed, showing that the bonding performances were maintained even at high scanning speed.

Secondly, two on-line non destructive testings (NDTs) have been developed in order to monitor laser focus during treatment. A first one is based on the imaging of the laser-induced plasma with subsequent image processing, while the second one is based on plasma spectroscopy. The robustness of both devices have been assessed considering incidence, presence of surface contamination, surface brightness, etc., ensuring the proper completion of laser surface preparation.

Finally, in addition to texturing and functionalizing the surface, the laser also aims to eliminate any surface contamination. Contaminants of different natures exist in production environments : oils, mold release agents or even fingerprints and can affect adhesion for concentrations as low as $\mu g.cm^{-2}$. Achieving a clean surface and characterizing the absence of contamination is imperative to ensure a robust bonding process. In this study, we present an innovative non destructive technique allowing real-time contamination detection during laser treatment. The *in situ* LIBS (Laser Induced Breakdown Spectroscopy) device is used for spectroscopic analysis of the plasma generated during laser treatment for surface preparation before bonding. This technique follows the level of elements characteristic of the contaminants during the laser surface preparation. The *in situ* LIBS capability of detection and quantification is investigated on aluminium and titanium samples contaminated with different categories of contaminating agents representative of those encountered in production facilities, such as silicon based released agent, cutting fluid and artificial handsweat simulating fingerprints.

Polishing of stainless steel with femtosecond GHz-burst laser

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In this contribution, we report on the use of a femtosecond laser operating in GHz burst-mode for metal polishing, with and without ablation, in order to improve the micromachining quality.

Laser polishing has been widely investigated [1,2] as a contact-less and an efficient process compared to mechanical polishing. The principle is to melt the surface so that surface tension forces smooth the surface, therefore the energy deposition over time is a crucial point. It has been shown recently that GHz- bursts of femtosecond pulses can be used for this purpose [3] since the pulse-to-pulse delay is shorter than the mean heat relaxation time of the material. Moreover, the GHz-burst regime has also shown tremendous results in recent drilling and cutting studies [4,5].

For this experiment, we used a Tangor 100 from Amplitude allowing us to study several burst configurations in the GHz-burst regime. We led a comparative study between GHz bursts of 50, 100, 200, 400, 800 pulses at 1.2 GHz intra- burst repetition rate while keeping the same burst energy. The laser beam is focused onto the metal surface with a f- theta lens of 100 mm, resulting in a spot of 12 µm. The process is performed by scanning the flying spot over the metal surface. This study was realised on stainless steel. The results are discussed in terms of surface roughness as a function of the pitch between two spots and lines, respectively, in the materials.

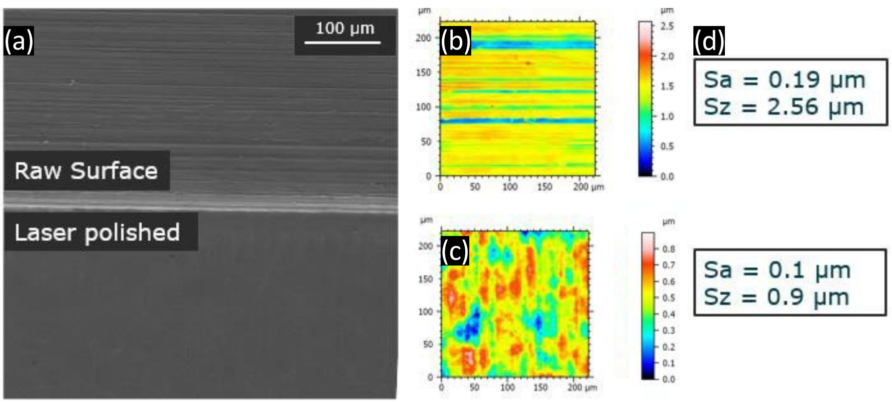

Figure 1: SEM image (a), topography measurements of unpolished (b) and laser-polished stainless steel (c) measured with a Zeiss Profilometer at 50x objective, cut-off wavelength λ_c=80 µm, (d) associated roughness measurements.

Figure 1 (a) shows the SEM image of a stainless steel sample comparing the unpolished (raw surface) and laser-polished surface obtained with bursts of 131 µJ in the GHz-burst regime, with a spot-to-spot pitch of 8 µm and line-to - line pitch of 24 µm leading to an important overlap. Figures 1 (b) and (c) depict the associated profilometer topography measurement obtained with a confocal microscope. These measurements reveal a surface roughness (Sa) of 0.2 µm and 0.1 µm, and a peak-to-valley (Sz) of 2.6 µm and 0.9 µm before and after laser polishing (d), respectively.

During this study, we observed that for the same burst energy, longer bursts allow for a larger process window and a more versatile process.

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Femtosecond laser processing at 515 nm with a top hat beam shaping module

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Femtosecond IR lasers are already well known for material processing because of the many advantages they offer. However, new laser configurations are now industrially available on the market including other wavelengths that could provide new opportunities in terms of throughput, quality and versatility.

Manutech USD, a technological platform specialized in surface functionalization by femtosecond laser processing has collaborated with Cailabs and Luxinar to demonstrate the potential of coupling a 515 nm femtosecond emitting laser with a square top hat beam shaping module.

The set up will be presented, including its specificities and the points of vigilance observed during the installation of the laser environment. The 515 nm Luxinar femtosecond laser provides several operating options such as pulse on demand or burst mode with controlled energies, the latter being studied on different application samples after irradiation. The top hat shaping module provided by Cailabs will also be characterized by a beam analyzer in order to criticize its exploitability at the focal plane : homogeneity, shape stiffness, depth of field…

A comparison will finally be made between the natural gaussian beam from the laser output and the shaped top hat beam for various applications such as decoating and laser engraving. The objectives are to present the interests of such a new tool, in particular for the obtained machining quality : surface roughness, uniformity of the textured patterns, side walls stiffness, machining efficiency and potential processing time saving …

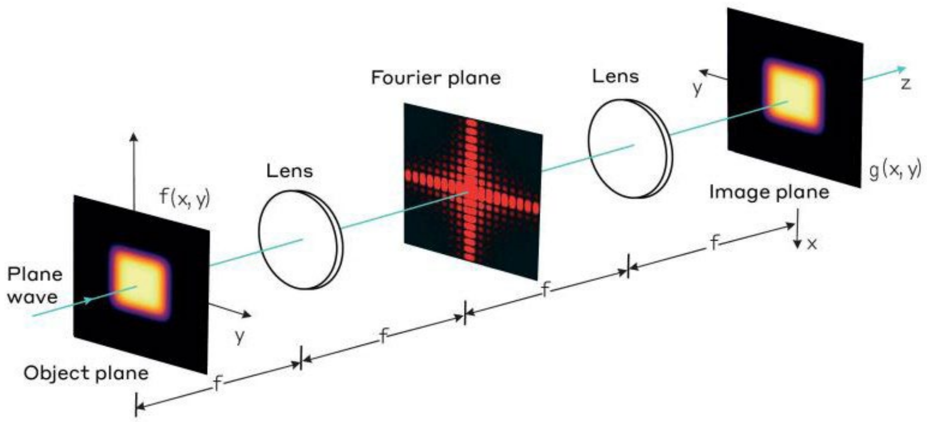

Figure 1 : Transport of the top hat laser beam out of the module to the working plane (Courtesy of Cailabs)

Femtosecond laser tooling texturing for replication through R2R process

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The NewSkin project offers the European Innovation Ecosystem access to innovative manufacturing facilities all over Europe, that provide the tools to create and validate new technologies, to TRL7 and higher, in the field of advanced surface technologies. For this purpose, an OITB (Open Innovation Test Bed) has been created to work as a self-sustainable entity to offer open access services.

In this context, AIMEN offers laser-based surface micromachining and surface functionalization, as well as replication of textures trough Roll-to-roll (R2R). Part of the work done by AIMEN in the NewSkin project is presented here, and includes, on the one side, the procedure to obtain surface texturing with micro and nano features in metallic samples by ultrafast laser; and, on the other side, the procedure for R2R replication of the textures on a polymer film. Finally, a topography analysis will be shown where both textures, laser-textured master and R2R replication, will be compared to assess the effectivity and limits of the whole manufacturing chain.

Laser texturing with Ultra Short Pulsed Lasers (USPL) has been widely proved [[1],[2]] to provide high quality surface modifications with details in the micron size, but also at the nano scale. The main issue of USPL surface texturing is the limited productivity of a spot-wise process, leading to large processing times for industrial purposes whichcan span up to square meters. To reduce this inconvenient, two solutions are investigated here. The fist of them is static parallelization to produce an array of equally distributed beamlets, through the use of diffractive optic elements (DOEs) in the laser setup. In this way, it is possible to process severalzones of the whole area at the same time, what significantly reduces the processing times. The other solution is making a master tool with the negative of the desired texture, and then replicate it as much as needed in a R2R process, so the replications will have the positive texture and it could be applied over almost every kind of material. This second solution is proposed as an alternative for complex geometries where direct laser writing process is difficult to be applied, as well as for those applications, such as wettability control or optical functionalization, where very large areas need to be covered with this small-featured textures.

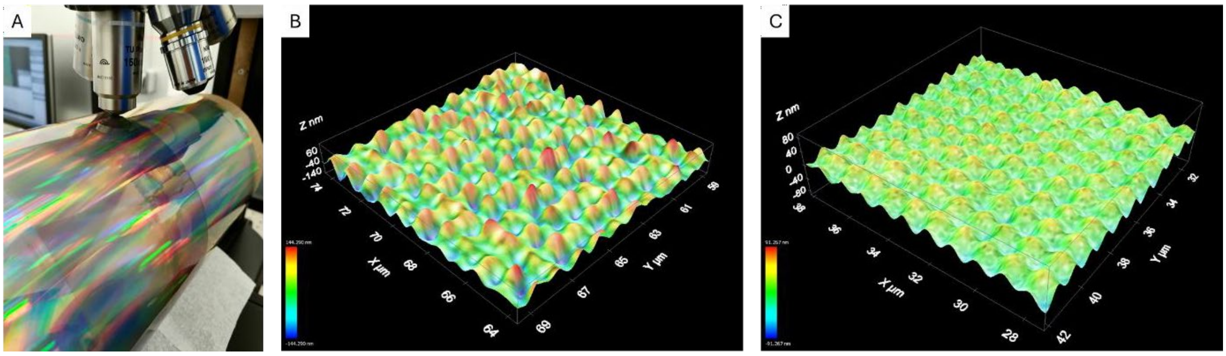

Figure 1 (A) Metallic sleeve textured with micron-scale features. (B) Detail of the topography of the texture (C) Detail of the texture replicated in a cellulose di-acetate film.

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Investigation of Laser Processing as a promising approach for the preparation of nuclear fuel ceramic samples in harsh environment

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In the field of nuclear energy, ongoing advancements and innovations are imperative to ensure the safety and efficacy of reactor technologies. A central challenge lies in the accurate examination of nuclear fuels behavior under both base irradiation and off normal conditions, marking a transformative shift from global to local data within the fuel pellet. The complexities of obtaining appropriately sized samples for in-depth studies, typically ranging from a few hundred microns to a millimetre, pose significant challenges. Conventional approaches in this field involve mechanical machining, with inherent limitations. Laser micromachining is of particular interest for this application because it offers high precision, versatility and it is contactless. However, the laser process needs to be optimized to minimize heat-affected zones, which is important for preserving ceramic properties.

For such application we explore different laser processing approaches, from sub-ps to µs pulses, as a trade-off is required between efficiency, applicability in nuclear environment and thermal impact on samples, as temperature control is essential to safeguard the microstructure and inherent properties of the studied samples. Our approach involves laser processing experiments on selected model materials, including graphite and oxide ceramics, coupled with surface temperature measurements using a high-speed thermal camera and numerical simulation to link the heat affected area to the laser processing parameters [1].

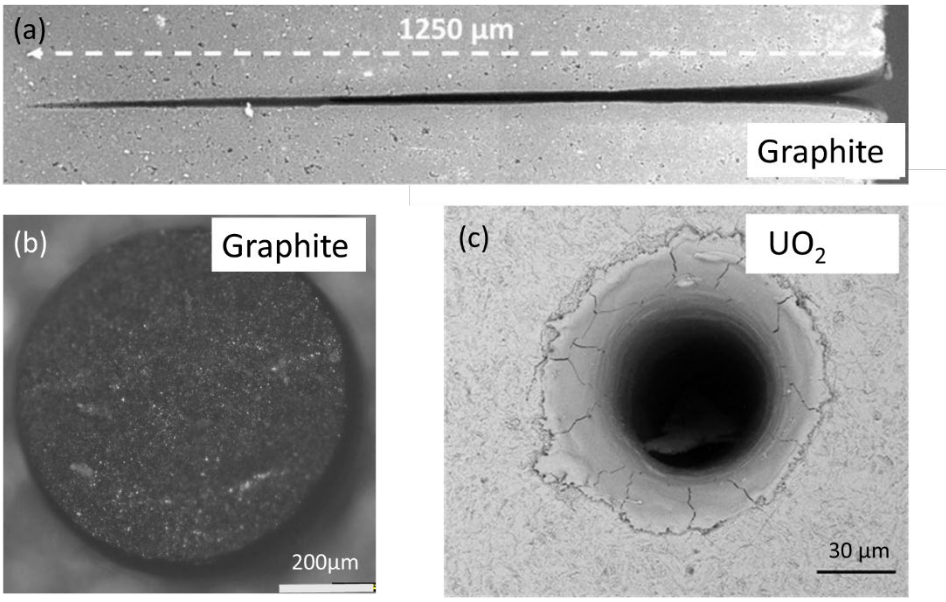

Figure 1 (a) Scanning Electron Microscope (SEM) observation of the cross-section of a laser-processed graphite sample with an Ytterbium Fiber laser (1080 nm, 50 µs pulses). (b) a cylindrical sample (0.5 mm thick, 1 mm diameter) obtained by laser cutting of a graphite plate with a femtosecond laser system (1030 nm, 500 fs pulses). (c) Laser ablation of Uranium dioxide sample (1080 nm, 50 µs pulses).

The application to real nuclear fuel samples is in its early stages, but our work offers a foundational understanding for potential applications in nuclear fuel fabrication. Moreover, the integration of laser systems in a nuclear environment, i.e. hot laboratories to handle highly radioactive materials, poses many challenges that have to be simultaneously addressed to provide a functional solution.

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Enhanced Throughput in Ultrashort Pulse Laser Processing: Strategies and Implications for Automotive Industry

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Ultrashort pulse laser applications have become commonplace in industrial environment, due to their versatility. The consistent and rapid advancement of laser average power, alongside developments in synchronization and temporal pulse shaping witnessed over the last two decades, have unlocked new opportunities to fully leverage femtosecond lasers and cater to the needs of highly demanding industries.

With multi-hundreds of watts femtosecond lasers already present in the market, the pursuit for high average power persists. kW femtoseconds lasers have been demonstrated in several laboratories worldwide, with ongoing development efforts directed towards achieving industrial maturity. The advent of these high-power lasers introduces new challenges in process development, integration, and utilization. Managing multi-hundreds of watts lasers entails complexities beyond those of lower power systems. Effectives strategies for managing and delivering such levels of power will be essential in leveraging these lasers effectively and turning the high power into high productivity.

Temporal pulse shaping may be pivotal in enhancing throughput. Recent investigations indicate a heightened interest in GHz burst patterns, which notably enhance the ablation efficiency of femtosecond lasers. The ability to tailor bursts, encompassing hundreds to thousands of femtoseconds pulses, involves thermal and non-thermal ablation mechanisms, leading to high quality and high throughput material processing.

This presentation will delve into potential process strategies, while highlighting the challenges and practical limitations. Special emphasis will be placed on addressing technological requirements such as pulse-on-demand, rapid scanning or beam division as well as exploring enhancements through methods offering superior ablation efficiency. Femtosecond technologies hold significant promise in the automotive sector, opening a wide array of compelling possibilities. We will examine several instances, including the cutting of battery electrodes.

Ultrashort pulse Laser processing of complex designs, from Bazel ring to a roll to roll thanks to advanced synchronization of optical and mechanical parameters.

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To increase quality and productivity, mechanical and optical axis synchronization is one of the corner stone in USP laser industrial applications. We provide a description of a built-in functionality enabling synchronization of mechanical and optical axis to enhanced cutting, engraving and texturing operation over 2D surfaces on a roll-to-roll.
Before to go on a roll-to-roll scale, demonstration and industrial machine where build up for instense for the luxury market. The target was to synchronize a rotary axis to texture and engrave a watch bazel.

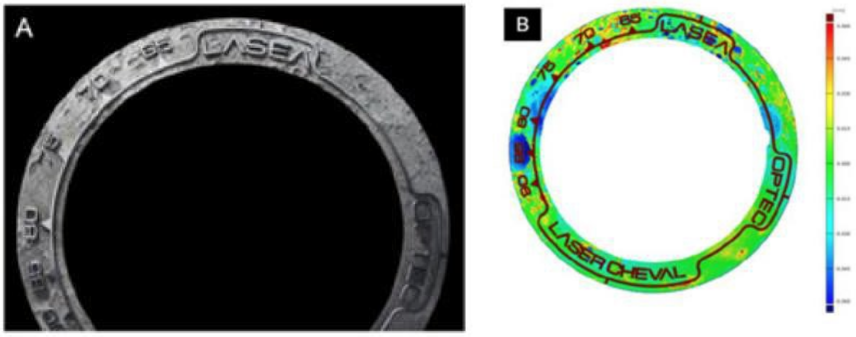

Figure 1: Overview of the machined bezel (A) and its topological analysis (B)

Based on this experience a scale up was made to be able to achieve synchronization with bigger elements like a roll-to-roll. Thanks to a closed loop regulation of the scanner over the roll-to-roll encoder, the energy distribution is maintained constant and homogeneous during machining. The functionality is fully integrated into LASEA KYLA® and LS- CAM™ software allowing us to easily generate complex machining strategies with multiple input formats (DXF, STL, Greyscale). The ability to select the axis to be synchronized enables to cover a large range of machining applications without discontinuities in the pattern, which are known, for instance, to impact the quality and the final product performance. This processing method also optimize the speed of the process especially for cutting application of large surfaces. This important aspect paves the way for increased productivity thanks to the increase of laser power and scanning speeds in industry. We provide a new solution for optimized cycle time and machining quality, demonstrated here onto parts process on a roll to roll.

Keywords: Laser micro processing, digital manufacturing, laser system synchronization, surface functionalization.

Precision micromachining using a novel femtosecond flat-top UV laser

Kamile Kasaciunaite, Jean-François Poisson

Ultrashort pulse laser systems are widely used in fields such as material science and engineering, metrology, medicine, telecommunications, etc. These systems are unparalleled when it comes to producing various components for microelectronics, biomedicine, lithographic applications, optoelectronics, MEMS, etc.

Though non-linear absorption-driven ablation is possible in all types of materials, in some cases, it is preferred to carry out ablation in the linear absorption regime to improve surface roughness characteristics (sub-µm engraving of optically transparent materials) or avoid damage to the underlying layers (laser-lift-off, etc.). In recent years, techniques such as 4-5th harmonic generation from the fundamental IR wavelength (1030 nm) have made significant advancements, opening new possibilities for the stated micromachining applications. Additionally, typically, solid-state lasers emit a Gaussian intensity distribution beam; however, here, we demonstrate a novel type of laser that emits a flat-top intensity distribution beam.

The top-hat intensity distribution can be successfully utilized for homogeneous material removal with sharp edges, such as solar cell patterning, lift-off processes, high aspect ratio hole drilling, glass engraving with surface roughness control, and other marking applications. In this study, we compare two laser beam intensity distributions, namely the Gaussian beam and the flat-top, for their effectiveness in micromachining applications at a UV wavelength of 257 nm (4th harmonic generation).

The Newskin project: industrial solutions for laser-enabled surfaces

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The Newskin project aims to propose innovative solutions for industry in the field of nanotechnology and surface engineering, including surface laser texturing. Here an overview of the main project's results is reported.

a) A pilot line for continuous laser texturing of metallic coils was implemented and upgraded (Figure 1a) [1]. The pilot line is based on a high-power femtosecond laser (either 100 W or 350 W) and a roll-to-roll samples handling. Thanks to this set-up the possibility to nano texture coils as long as tens of meters has been firstly shown. Preliminary tests shown that forming doesn't modify the properties of large surfaces nanotextured with laser induced periodic surface structures (LIPSS) [2]. Moreover, after the implementation of a specific MPLC module, we have shown that the same pilot line can be used to effectively texture large surfaces by direct laser interference patterning (DLIP) technique.

b) The durability of laser textured surfaces was evaluated by carrying preliminary tests to assess how a Hafnium oxide (HfO_2) nanocoating deposited on top of the laser induced structures (Figure 1b) modifies the surface stability in time and the reliability of some key surface properties like wettability (Figure 1c).

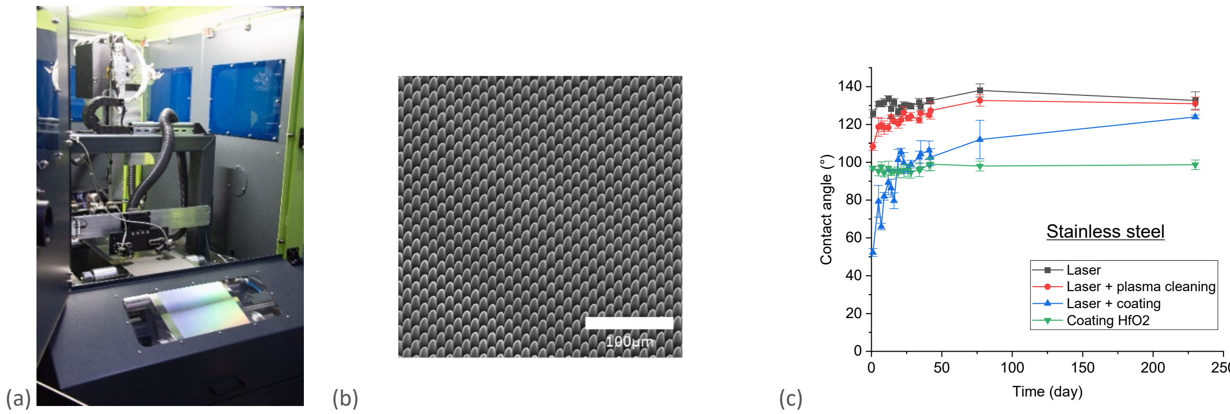

Figure 1: (a) Roll-to-roll pilot line, (b) 14µm DLIP structures on stainless-steel (b) Evolution of the contact angle measurement as a function of days after laser treatment on laser textured stainless steel (black), laser textured and plasma cleaned stainless steel (red); laser textured and coated stainless steel (blue), coated stainless steel (green).

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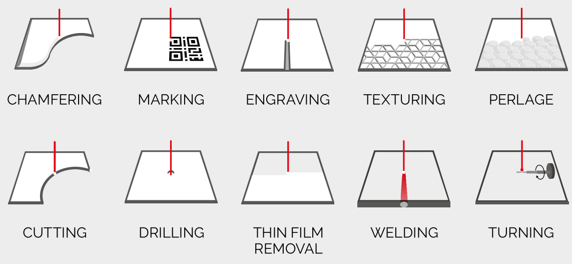

Advancements in Laser Positioning Systems and the Impact on Electronic Manufacturing & Semiconductor Packaging

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The ability to laser process vertical high aspect ratio holes is critical to several key electronics and semiconductor manufacturing technologies. Laser drilled vias in flexible and rigid PCBs are found in most electronic devices that are mass produced today. In recent years, semiconductors have adopted heterogeneous integration techniques with glass interposers requiring high density through glass vias (TGV) manufactured via ablation or laser induced deep etching (LIDE). These technologies are critical to developing advanced electronic components and semiconductor devices.

Both application areas leverage a common motion trajectory primitive — step and settle. Step and settle moves are predicated on the ability of the motion system to move the laser spot from a fixed position to another fixed position as fast as possible and fire the laser only after the motion system has settled to within the desired tolerance. The desired time to move from hole to hole and fire the laser is typically measured in tens or hundreds of microseconds. High-density PCBs or glass interposers have tens of thousands of holes, making drilling time critical to overall production throughput.

As the via diameters and spacing between them decrease for existing and emerging applications, the dynamics and precision for positioning the beam at each hole location become more critical. As the via diameters decrease and via hole density increase for next-generation applications, decreasing step and settle times are vital for viable production processes.

This presentation will discuss a novel real-time motion control feature, Enhanced Scanner Control (ESC), that drastically reduces step and settle times for laser scan heads. Additionally, advancements in scan head motion technology required to maximize via drilling efficiency are covered. Examples of parts with performance data demonstrating the improvement the control feature has on this and other motion primitives will be shared.

Layer by layer temperature mapping for enhanced process control in laser powder bed fusion

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During laser powder bed fusion (PBF-LB), heat accumulations can lead to e.g. annealing colors, increased porosity, worse mechanical properties or protruding edges and are one of the reasons for the necessity of support structures. Using constant manufacturing process parameters, heat accumulations often cannot be avoided due to varying heat dissipation cross sections and gradients or lead to significantly increased process times when printing ghost parts.

To improve the inner and outer quality of additively manufactured PBF-LB parts it is common practice to separate the parts e.g. into different overhang, contour as well as inner volume areas and optimize the process parameters individually. While high part qualities can be achieved, this practice is very time and material and hence cost consuming. Temperature-based process control is a promising approach. However, a conventional process control based on the data recorded one time step before is only suitable to a limited extent due to high scanning speed as well as complex geometries which lead to varying heat dissipation. A process control approach to prevent heat accumulations independently of the part geometry and volume for heat dissipation is needed. This can be realized by using the temperature data of the previous layer directly under the current process zone, which has comparable heat dissipation conditions, as a more reliable process variable.

Such a process control is developed in this work and the suitability of a temperature map based process control to assure high part qualities independently of the part geometry is analyzed. To do so, coaxial two-channel pyrometric measurements are used to generate spatially and temporally highly resolved temperature maps of each layer during the PBF-LB process. These temperature maps are then divided into pixels containing a temperature value representing the mean temperature of that sub-area (Figure 1). By doing so, heat accumulations can be detected and quantified in-situ. The quantified information regarding the present heat accumulations is then used to locally and automatically adapt the laser power in the following layer by a control loop. For this an individual PID control loop corresponding to each pixel calculates the laser power for the corresponding sub-area in the following layer. To individually apply the controlled laser power to each sub-area the scanning vectors are be divided into sub-vectors, where the length of the sub-vector corresponds to the length of the sub-area. By using the sky-writing functionality of the laser scanning system, the sub-vectors are scanned at a constant speed and are therefore identical to the original vector. With this adaption it is possible to apply locally variable laser power within a single vector while remaining the original scanning strategy.

It could be shown that independently of the part geometry uniform temperature maps can be achieved using this temperature map-based process control, resulting in high part qualities without additional parameter optimizations.

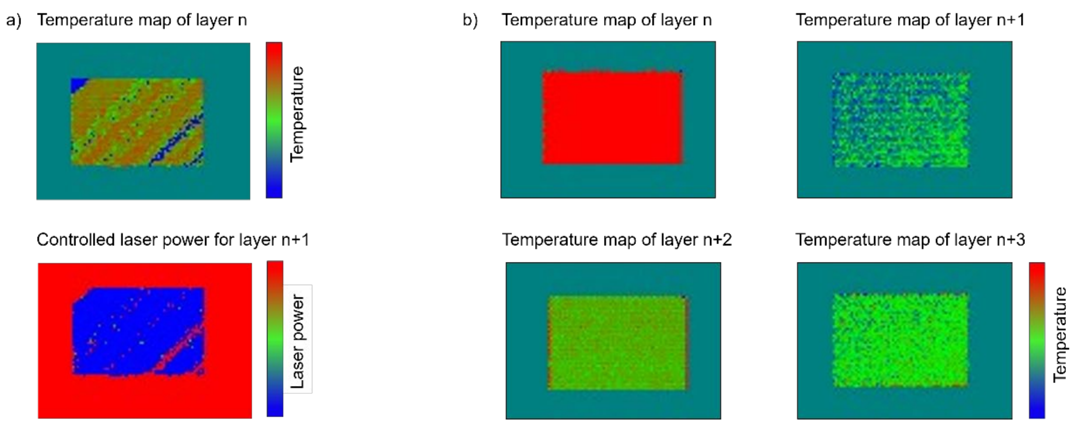

Figure 1 a) In-situ measured temperature map and PID-controlled laser-power map based on temperature map and a) four temperature maps of subsequent layers during PBF-LB with temperature map based process control

Diode laser cladding for more sustainable products: bearings, brake discs, pistons

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Diode lasers are well established in high-power cladding applications for over two decades due to their exceptional characteristics, including high wall-plug efficiency, robustness, and an optimal beam profile with a superior spot intensity distribution. Recent advancements in diode laser technology have resulted in enhancements in product durability, for example in resistance to abrasion, contributing to the development of more sustainable products.

The driving force behind numerous diode laser applications lies in their remarkable wall-plug efficiency, often surpassing 50%, facilitating highly effective heating and drying processes. A good example is in battery manufacturing, where bulky and gas-intensive ovens are replaced with more efficient diode laser systems enabling 85% energy savings.

In cladding applications, the efficient heat generation adds to an equally efficient process. The combination of an optimal beam profile and ideal wavelength enables the creation of ultra-thin layers with minimal mixing and a small heat-affected zone. These metallurgically bonded layers exhibit longevity and withstand thermal or mechanical shocks, ensuring prolonged durability.
An emerging application of diode lasers is in the deposition of bronze or babbit/white metals onto plain bearings used in wind turbines, propulsion systems, or hydraulic components (Figure 1). The ability to deposit thinner, well-defined layers not only reduces energy consumption and material usage but also enhances component lifespan. Processes include powder and wire deposition welding. The high-quality coatings contribute to reduced friction, subsequently lowering energy losses and enhancing overall operational efficiency. For axial piston pumps the process allows replacing lead by more environmentally friendly materials.

Figure 1 (a) deposition of CuSn12Ni2 on a shaft at more than 30 kg/h and (b) high-speed cladding for thin bronze layers on a shaft

The utilization of lasers for cladding vehicle brake discs presents an optimal solution for reducing fine dust emissions in transportation (Figure 2). The high-speed cladding process employed here enables the creation of very thin layers, resulting in material and cost savings. By employing adapted intensity profiles, including multi-spot approaches, laser powers of up to 30 kW can be utilized, leading to reduced machine costs and higher production rates, as production output scales nearly linearly with laser power. Novel approaches also include two-sided cladding for further increased productivity.

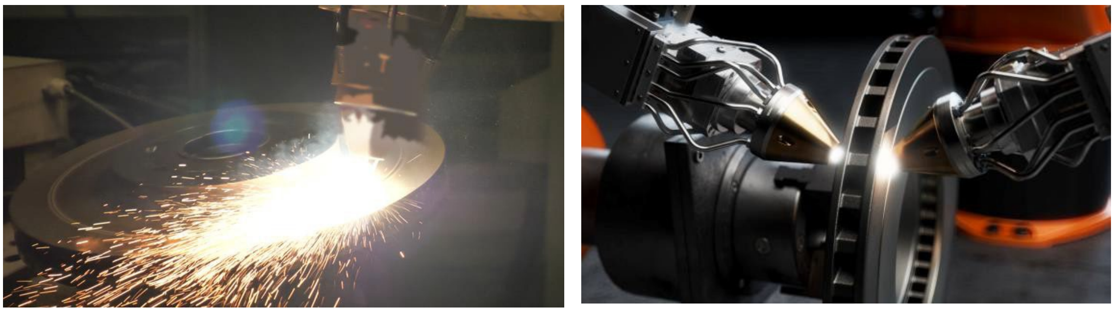

Figure 2 (a) cladding of a brake disc using 30 kW laser power and (b) simultaneous processing of both sides

Improving prediction of laser welding penetration in metals using artificial intelligence

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Laser welding is a reliable tool for the industry. Able to achieve both conduction and keyhole welding, it allows for fast joining of dissimilar materials through a characteristic deep melt pool. As the process involves thermodynamics, laser-matter interactions and fluid mechanics amongst other physical phenomena, the links between the parameters and the quality of the weld is highly non-linear [1]. Due to the large number of interlinked parameters, simulations and efficient Design of Experiment are costly and long to conduct. As a direct consequence, the processing parameters' optimization remains a major challenge.

In that context, Artificial Intelligence (AI) is seen as a powerful answer, thanks to its ability to learn from past experiences–[2]. The literature contains some examples of successful prediction of laser weld penetration using AI [3-5]. Their datasets however, often lack the complexity and the scope of real industry use-case : only one laser wavelength and spot diameter used, and narrow ranges of parameters like welding speed and laser power.

Relying on labelled data collected from years of experience at IREPA LASER, we have built a dataset containing 698 different welds. This dataset covers a wide range of materials such as carbon and stainless steels, aluminium and copper, across different welding speed, laser power, focus shift on straight trajectory with optional vobulations or zigzag. This dataset was used to train an AI using an automated pipeline optimizer [6]. In the most used testing conditions, an 80/20 split of the entire dataset, state-of-the-art performances were achieved with a R2 score of .96, and a Mean Squared Error of 0.22 mm2. Then a set of challenging tests highlighted the model capacity to handle extrapolated welding parameters. In those conditions, the model was able to keep high R2 scores. The model can now be used to draw parameter maps where inputs of the process are linked to the weld penetration, helpful to reduce the search window for optimal parameters.

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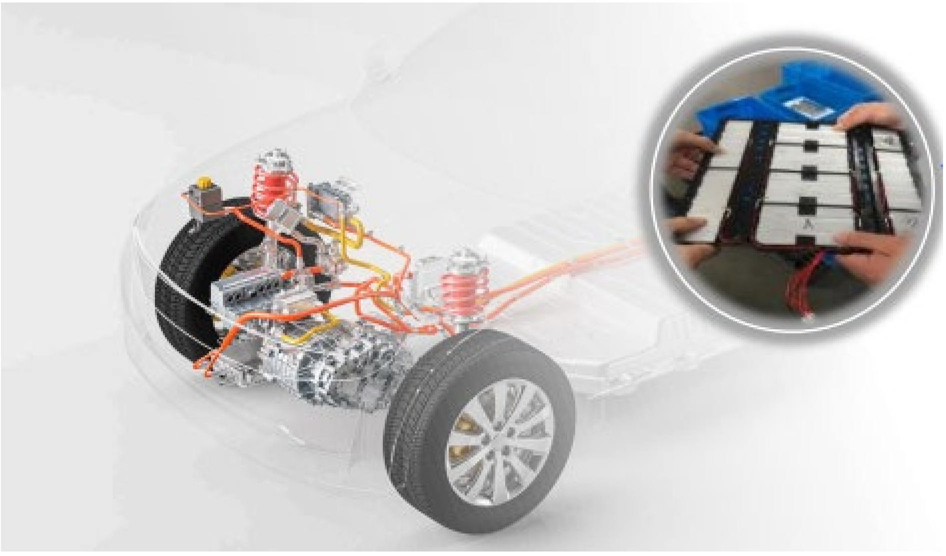
Overcoming challenges in battery manufacturing with high brightness center mode fiber lasers

Speaker: Dr.-Ing Peter Kalage, Manager of the high-power laser application laboratory Coherent Hamburg

The exponential growth of the EV market is driving the demand for laser welding that can accelerate the throughput of battery production while maintaining the quality requirements of the automotive industry. The new HighLight FL-ARM lasers from Coherent feature longer collimated beam lengths and smaller spot sizes that enable high-quality deep welds with greater uniformity over large working areas. Combined with the high degree of weld control that the adjustable center and outer ring mode beams provide independently, the new ARM lasers can complete deep welding tasks with higher speed, resulting in lower cost of ownership.



The electrification of transportation and the rise of industry 4.0 are accelerating the demand for laser processing systems for battery manufacturing that combine state-of-the-art processing performance, extreme versatility, a wide range of sensing options, and machine learning intelligence.

Coherent recently introduced improvements on two processing heads, the HIGHmotion 2D and the PH20 SmartWeld+, both of which work seamlessly with HighLight FL-ARM lasers.

The HIGHmotion 2D is ideally suited to applications where the beam is quickly moved about a stationary workpiece to complete multiple welding tasks. This widely deployed laser processing head is now available with a low-magnification design that enables deep copper welds of more than 3 mm while maintaining a large work area of up to 100 x 140 mm when configured with a lowest magnification.

The PH20 SmartWeld+ is ideal for longer weld seams or weld layouts of individual battery cells. The PH20 SmartWeld+ is now available with up to 6kW of power, enabling precise control of penetration depth. In addition, what differentiates this processing head is its ability to oscillate the laser beam in any desired pattern while moving along the weld path, thanks to its lightweight mirrors and proprietary process control, and such at high oscillation speed.

Finally but not less Coherent makes laser process monitoring easier and more accessible than ever with the introduction of SmartSense+. This accessory enables improved laser processing results and better reproducibility, and also provides traceability and documentation data. The latter is particularly vital in medical device, e-mobility, microelectronics, and other high-precision manufacturing applications.

SmartSense+ is an opto-mechanical accessory which incorporates optical detectors and (optionally) acoustic sensors, and includes all the required data acquisition and signal processing electronics and software. SmartSense+ delivers the same dynamic view of laser processes both on and beneath the surface, but using an inherently less complex and costly approach. The SmartSense+ optical system captures back-reflected laser light, plus light emitted by the process itself. This light is split into its visible, laser wavelength, and near-infrared (NIR) components, and sent to three separate detectors. Together, these signals deliver detailed information about the absorption of the laser light, the characteristics of the plasma (ionized plume) created by the laser process, and the surface temperature of the part. The option for detecting acoustic signals, using piezoelectric contact sensors and microphones, enables acquisition of an even more comprehensive process fingerprint, such as heat cracking in a joint during or even after the welding process.

Dissimilar welding between Cu55Ni45 constantan alloy to Ti-6Al-4V titanium alloy with 1030 nm and 515 nm Ytterbium YAG lasers

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Copper and bronzes have been attracting the attention of research community in quality of an intermediate materials for dissimilar joining of titanium alloys to steels [1]. However, such joints have quite limited plasticity due to the brittleness of Cu-Ti intermetallics. It has been recently reported that the addition of pure nickel in a melted zone between copper to titanium allows obtaining metallurgically sound welds [2]. This motivated us to investigate the laser welding of Cu55Ni45 constantan alloy to Ti-6Al-4V titanium alloy in view of replacing copper in 316L/Ti-6Al-4V joints by more mechanically resistant [3] Cu55Ni45 insert. The present weldability studies between Cu55Ni45 and Ti-6Al-4V were conducted with Ytterbium YAG lasers having λ = 1030 nm (IR range) and λ = 515 nm (green laser).
With respect of a full penetration of 1 mm thick plates, the dilution between two alloys was varied in a high extend (from 10 up to 78 at.% Ti) by offsetting a thin laser spot (∅<100 µm) from either side of the joint line, which allowed exploring the melted zones of various phase content. The obtained welds were quite inhomogeneous due to the mismatch in fusion temperatures and thermal conductivities of the alloys (Figure 1) and showed very random Vickers microhardness going locally from 200 HV up to 900 HV. They contained a complex interplay of intermetallics dominated by the ternary Cu-Ni-Ti phases that was successfully reproduced by a thermodynamic modelling in Thermo-Calc software. Despite the formation of numerous intermetallic phases, no cracks were observed in the melted zones, possibly due to the compensation of local brittleness by surrounding softer phases.

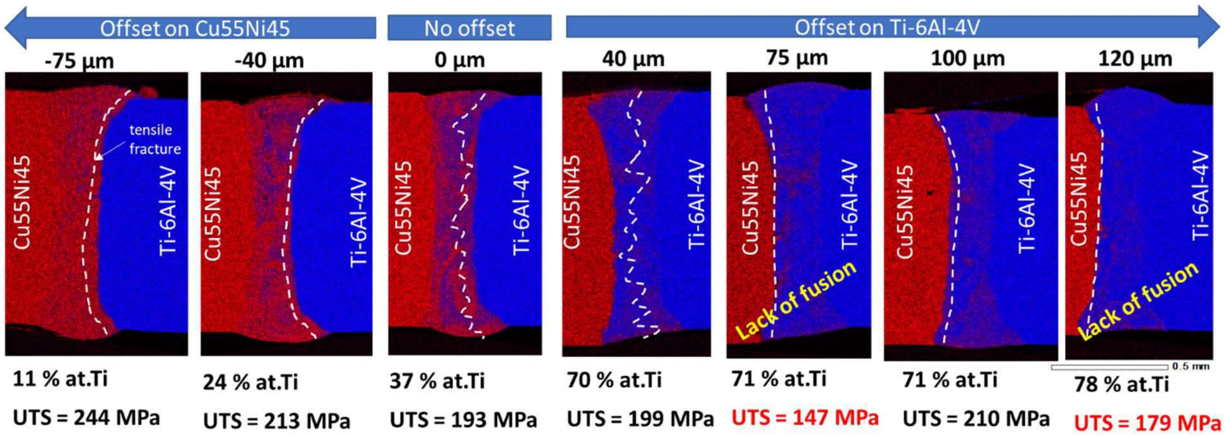

Figure 1 EDX cartography of Ti-6Al-4V/Cu55Ni45 welds obtained with 1030 nm Yb:YAG laser and their tensile properties.

Despite a large variation of dilution between the alloys, the fracture during the tensile test systematically occurred in the locations dominated by the ternary phases (Cu,Ni)Ti and τ_1. The UTS of the joints was maximal (244 MPa) under beam offset towards Cu55Ni45 alloy, with the fracture occurring at the interface between the (Cu,Ni)-based melted zone and Ti-6Al-4V. The beam offset on the opposite Ti-6Al-4V side led to lower UTS values (~200 MPa) with fracture at the interface between the β-Ti-based melted zone and Cu55Ni45 alloy that revealed to be particularly sensible to a local lack of fusion. Low beam offsets produced a transversal fracture of the melted zone, however, UTS also neared 200 MPa. It is noteworthy that the tested joints exhibited rather high ~0.5 cm break deformation.

These results exceed those obtained for the previously studied bronze aluminum alloy Cu-6Al-2Ni/Ti-6Al-4V joints (UTS < 100 MPa). The immediate perspective of this study consists in the creation of double-pass joints Ti-6Al-4V/Cu55Ni45/316L.

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VisionLine OCT from TRUMPF: functionality and process limits of the online (IN) weld depth monitoring

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Many industrial laser welding applications require online monitoring of the weld result to prevent defective parts from further costly processing steps or, in the worst case, from being used in the final product. For example, when battery cells are joined in a complete module, each weld must have a good connection to achieve a good electrical performance. There are many sensor systems available, such as photodiode-based sensors, but they can only provide indirect and relative data, evaluating the weld quality by comparing the signal to a reference value.

OCT technology (optical coherent tomography) can be used to measure and evaluate reliable, close to absolute, values. VisionLine OCT from TRUMPF can be used in various ways: VisionLine OCT Detect is used for offline seam positioning and geometrical characteristics finding before the laser welding process (PRE), while VisionLine OCT Check enables online process monitoring of the penetration depth (IN) and seam surface measurement (POST). Using busbar welding as an example, the feasibility of penetration depth measurements can be demonstrated for three different process strategies: standard process, fast welding process and wobbled beam path. The application and accuracy of VisionLine OCT for copper, aluminum, mild steel and stainless steel are tested in basic research. To measure the penetration depth, the OCT determines the capillary depth during welding. Before running a IN-measurement a suited measurement position must be found. Therefore, a so-called keyhole shape measurement must be performed in the first pass to evaluate the capillary shape and to find its deepest point. In stable welding process the keyhole shape is constant during the whole seam and the measurement position has a fixed relative position to the laser spot or TCP (tool center point). Some processes require coaxial positioning, while others may have the optimum behind or even in front of the laser spot. This depends on the material, welding parameters and penetration. Figure 1 shows an example for a usable keyhole shape. In this picture the keyhole ground is shown by the big number of valid points in the middle. The offset value of the OCT should be set in the middle of this region.

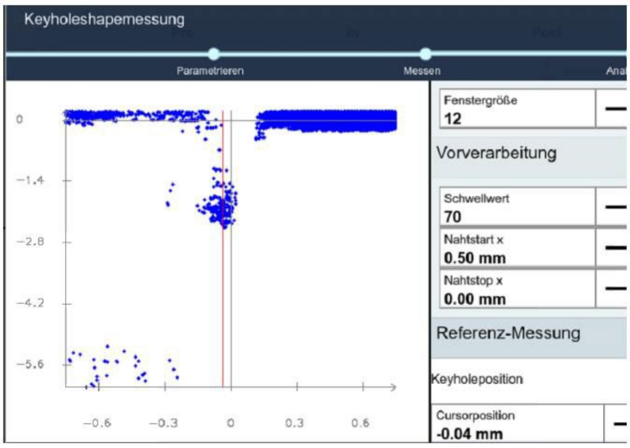

Figure 1 Result of keyhole shape measurement to examinate optimum offset for IN-measurement: Select an offset value in the center of the area with the highest dot density in the estimated penetration depth. Here at cursor position -0.04 mm.

Penetration depths in the range of 0.5 to 4.5 mm were measured with this method. For steel materials, high welding speeds result in lower signal quality, while for copper and aluminum, high speeds the increase measurement stability.

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How to Ensure the Beam Quality of High-power Lasers in Laser Powder Bed Fusion Process

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The most important challenge in laser powder bed fusion additive manufacturing is to ensure the reproducibility of the process. From one layer to another, from one laser source to another and from a machine to the next one, you want to get the same results.

A key factor in the quality of the finished AM product is the condition of the laser and optical components used. To ensure proper operation, to optimize the system performance, and to prevent potential quality problems, the laser together with the optical system require periodical monitoring, especially in an industrial environment.

Among the most common malfunctions are laser power degradation, profile distortion due to contamination of optical components, and thermal lensing, which causes focal shift and focal spot enlargement. All those issues can inhibit fusion between the powder particles, resulting in inferior product quality and diminished reproducibility. However, the traditional laser beam inspection methods cannot necessarily be adapted to AM chambers.

In recent years, manufacturers such as MKS have worked intensively on the development of dedicated measurement devices for use in additive manufacturing environments. Innovations include the simultaneous measurement of the laser beam in combination with power measurements or stand-alone pulse-to-power measurement devices without additional cooling. By integrating the measurement of the high-power laser beam in the production lines, deviations of key laser parameters can be detected and resolved quickly. The presentation will outline key findings on the parameters influencing the additive manufacturing process and explain measurement options enabling its optimization.

Figure 1 : Ariel power meter installed in a SLM additive manufacturing chamber

Strengthening copper and aluminum laser welding processes through beam shaping with Multi-Plane Light Conversion

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The electric vehicle (EV) market is experiencing rapid growth, driven by increasing political, societal, and ecological demands. This surge has led to the rise of gigafactories and a significant push towards innovation to keep pace with the market's evolution. The EV industry's expansion reflects a transformative phase in automotive manufacturing, necessitating advanced technological solutions to meet these burgeoning needs.

One of the critical challenges in EV manufacturing is laser welding. Unlike in traditional combustion engine vehicles, where welding primarily involves simpler materials like steel with a focus on mechanical durability, EVs present a more complex scenario. The materials used in EVs, such as copper for thermal conductivity and aluminum for weight reduction, are inherently more difficult to weld due to their high reflectivity, thermal conductivity, and ductility. Additionally, the welding criteria for EVs are more stringent. It is vital to minimize porosity to optimize weld conductivity and reduce spatter to prevent short circuits, which are significant hazards in electric vehicles.

To address these challenges, advanced laser beam shaping modules have been developed and tested using Multi-Plane Light Conversion (MPLC) technology. The beam shaping is accomplished using two integrated mirrors positioned between the collimation block and either a focusing block or a scanner. This fully reflective implementation allows for potential high-power applications. MPLC technology enables highly flexible beam shaping, with various forms being presented. Notably, this technology offers a depth of field four times greater than dual-core technologies, significantly simplifying its application.

The presentation will showcase the benefits achieved in welding real components, such as battery modules, busbars, and hairpins. Additionally, an X-ray analysis of the welds will be presented. Simulations of numerous beam shapes and their effects on the welding process will also be featured.

MPLC technology is revolutionizing complex welding processes, transforming them into more tolerant processes. This innovation is key to the future of electric vehicle manufacturing, enabling the next generation of EV factories to meet the high standards of efficiency, safety, and reliability required in this rapidly evolving industry.

Figure 1. Left: Welded busbars. Right : Welded hairpins

Examples of tailored solutions in laser welding into the Optoprim's ELAC (European Laser Application Center)

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- Examples of 3 tailored solutions costumer oriented will be presented by the Optoprim Engineering Group
- A standard methodology is used to address each specific problem based on the following points :
- Problem comprehension and industrial contest analysis
- Subsequent solution selection according to the best obtained result

<u>High power blue laser applied to copper welding</u>

- Superb stability and larger process window for conduction welding condition was demonstrated. A comparison was done against NIR lasers using same spot dimensions
- Limited working range for blue laser scanner source was highlighted

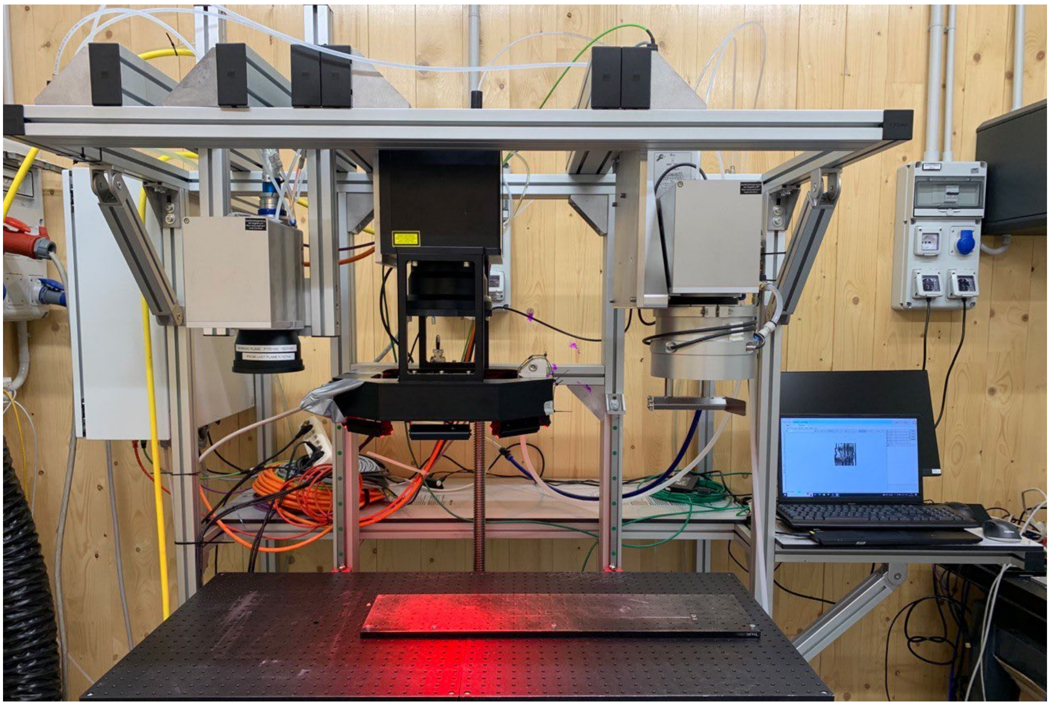
<u>Benefit of single mode lasers in aluminum 6xxx series remote welding</u>

- Identification of stable process parameters for welding of 6xxx series using NIR wobbling strategies was assessed
- Benefit of identified process parameters transferred to single mode laser was assessed

<u>NIR laser beam shaping applied to martensitic stainless steel</u>

- A solution to enhance deformability in subsequent deformation stage of but joint welding in AISI 430 using beam shaping is presented

The following set-up with 3 Scanning heads is used for the different weldings :



Maximizing Cost Efficiency and Production Uptime through Laser Beam Diagnostics

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The laser as one of the most powerful, accurate and versatile tools is key enabler in numerous cutting edge applications. It is known for its precision and reliability whilst working without degradation. A story, too good to be true. The question is, what happens under real world conditions and what is challenging the laser process? The influencing factors are manifold and the weakest link in a chain defines the process quality. Which makes it all the more important to have an eye on relevant beam parameters, to control the system and exclude production errors.

Whether for safety aspects or cost reasons, scrap production is not an option in many areas. If you take applications in battery cell production as an example, both factors come into consideration. The aim is a zero error production at large production volume. For process development, this requires the definition of a stable process window which goes hand in hand with various questions: What does my tool, the focussed laser beam, actually look like? How does it behave under process conditions? For applications in the multi-kilowatt range, heating of beam- guiding components is hard to avoid. Therefore, it is important to determine possible process limitations in advance.

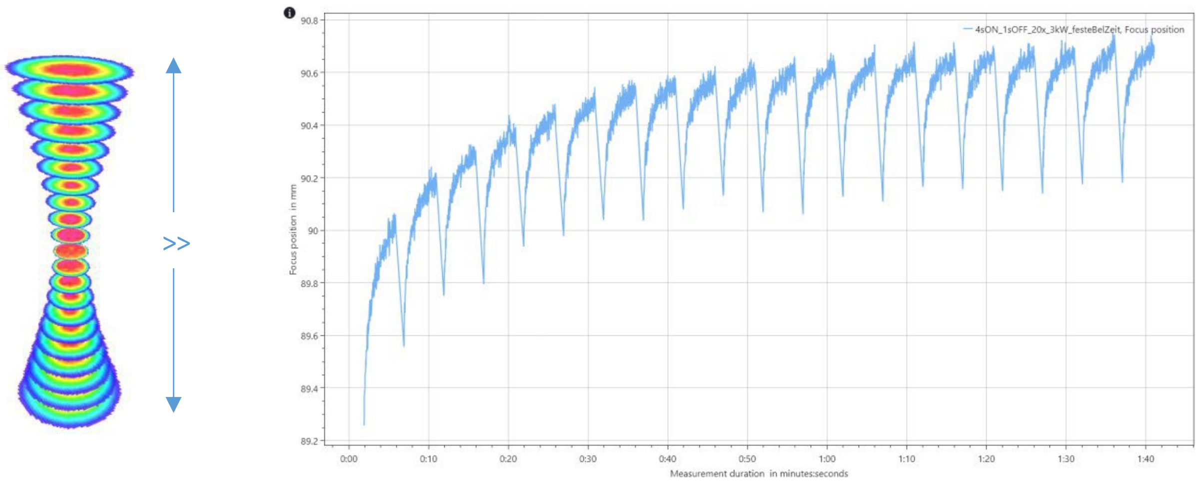

Figure 1 (a) Standard caustic of a focused 3kW fiber laser (b) Focus shift at 3 kW in a processing cycle of 4 sec on- and 1 sec off-time

Figure 1 shows a standard caustic of a focused fiber laser as it looks under lab conditions on the left hand side. The graph on the right shows the focus behaviour in a time scale of 100 seconds, starting with a cold processing head. Under process conditions with 3 kW laser power and a process cycle of 4 sec laser on- and 1 sec laser off-time, the optics heat up during the first 40 seconds. The focus position moves towards the optics, due to thermal effects. [1] Ideally, the process should then run in an equilibrium without any problems and variation. But the influence of contamination and ageing of optical elements must also be taken into account. [2] Thermal effects can cause the focus position to shift slowly over time. Contamination can also cause a rapid change in focal position. In both cases, the process parameters will leave their defined window. Laser beam diagnostics makes it possible to recognise this critical point in time at an early stage. This enables short response times and long-term planning of service activities. Production downtime is thus minimised in favour of cost efficiency. It is therefore crucial that the right parameters and their limits are considered in order to be able to react appropriately. Ultimately, this is where the greatest potential for cost savings is hidden. This presentation aims to analyse and discuss this challenge in the agile field of laser material processing.

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Femtosecond laser glass welding with repetitive single pulses and in burst mode

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In this communication, we show transparent glass welding of sodalime using a femtosecond laser operating in different MHz regimes along with a galvanometric scanner. We demonstrate the possibility to perform large-area and crack-free welding with high scanning velocity without any surface preparation.

Although glass is widely used in a variety of industrial fields, joining glass remains a challenging issue. Laser-based transparent welding emerges as a promising solution for glass bonding due to its ability to provide rapid, high-precision, high-quality, and flexible bonding with minimal heat distortion. In fact, ultrashort laser pulses allow to locally weld transparent materials. Thanks to the ultrashort pulse duration and the well-localized non-linear absorption, melting appears in a very restricted volume nearby the focal region. By positioning the laser focus at the interface of two glass samples and scanning the laser spot, it is possible to produce a welding seam. The dimensions of the welding seam increase with high repetition rate (in the MHz range) owing to heat accumulation between successive repetitive pulses [1]. Moreover, we show that the use of bursts helps to reduce residual stress resulting in high breaking strength [2].

We used a Tangor 100 from Amplitude, allowing us to explore several burst configurations in the MHz regime. The laser beam was focused into the glass samples (sodalime) by a high numerical aperture (0.2) telecentric lens with a focal length of 30 mm resulting in a beam focus diameter of 5.3 µm. A galvanometric scanner allowed to move the spot according to a chosen trajectory to produce a welding seam. Preliminary tests have been conducted to identify the influence of the laser parameters on the interaction zone (energy, burst duration, frequency, velocity…) and on the mechanical resistance. We have identified several kinds of defects that can occur and deduced reasonable operating windows, where it becomes possible to produce uniform and transparent crack-free welding, as shown in Figure 1.

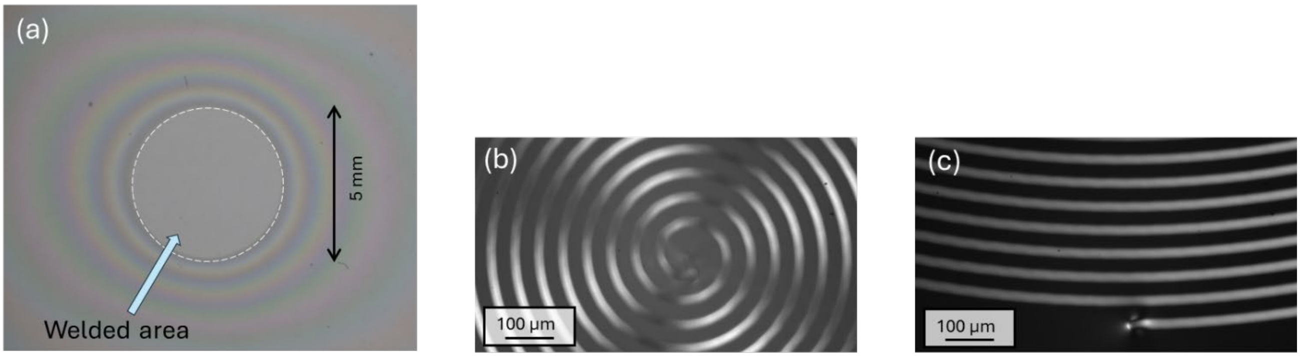

Figure 1: Microscope image of sodalime glass plates welded in single-pulse MHz regime with an energy of 13.7 µJ and a scanning speed of 50 mm/s (a), microscope images under crossed-polarization showing residual stress at the centre (b) and at the end of the spiral (c)

The process is repeatable and does not require any surface preparation. Additional characterizations of the welded samples were conducted, including mechanical tensile tests. These tests reveal that the pressure required to break the weld reaches up to 60 MPa.

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Pure proteinaceous 3D microstructures by free-form femtosecond laser direct write

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Femtosecond laser direct write (fs-LDW) is an attractive 3D printing method with key advantages of high fabrication resolution and nearly arbitrarily free 3D writing capability. These properties result from the two-photon absorption by the precursor material only where the laser intensity exceeds the fabrication threshold within the laser focal volume [1]. Amidst diverse materials, fs-LDW enables 3D printing from protein precursor to fabricate 3D proteinaceous microstructures for various biomimetic and biomedical applications [2]. Importantly, photoactivator-free fabrication from pure protein precursor is feasible [3]. While the fabrication mechanism is not fully understood, we demonstrated that chemical crosslinking plays a role in the fabrication process [3]. Recently, we identified amino acids that are beneficial to the fabrication process [4], and investigated 3D printing of the family of fluorescent protein [5].

Our current research interest is the free-form fabrication, in which fabricated microstructures are unbound to any substrate. Figure 1a shows a simplified setup and schematic of the hypothesis. We use a 520 nm, <400 fs laser to excite UV-bands of protein molecules like bovine serum albumin (BSA). Figure 1b shows a AIST logo mark fabricated without attachment to the substrate within a 400 mg/mL BSA precursor at 5 µm/s stage velocity. Preliminarily, we identified that 100 kHz repetition rate results in a broad fabrication window. We identified two subranges within this fabrication window. While higher pulse energy induces undesired shrinkage in designated design, lower pulse energy nearing the lower fabrication threshold permits to retain the designated design.

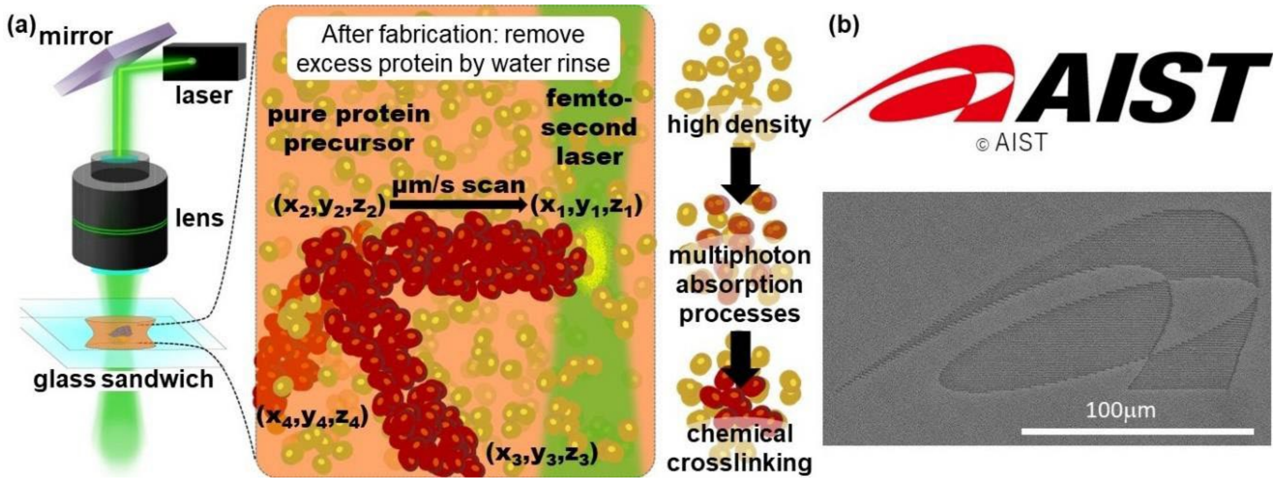

Figure 1 (a) The schematic shows basic setup and hypothesized fabrication mechanism. (b) The mark of the AIST logo is fabricated from bovine serum albumin (BSA) with a line pitch of 1 um. The AIST logo is adapted with permission from AIST 2024.

Because the native protein function is macroscopically retained after fs-LDW fabrication [2], this technology holds great potential for biomimicking applications, biomedical microfluidics or lab-on-a-chip device integrations that utilize native protein functionality to solve specific biological needs such as binding functions or enzymatic activity.

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Multiphysics modelling of glass-silicon welding using ultrafast laser

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Glass is an omnipresent material in everyday life and industry, as its chemical, mechanical and optical properties are particularly interesting. It has applications in architecture, watchmaking, medicine, aerospace, photonics and more [1]. This is why it is essential to be able to combine it with other materials to manufacture more complex mechanical systems. Ultra-short pulse laser welding of glass overcomes some of the problems associated to current assembly processes such as anodic bonding, adhesive bonding or optical contact joining. It provides mechanical strength close to that of the initial material without the need for additional material and with a localized temperature rise, thus eliminating the problem of micro-component damage [2]. This is why the process is particularly well suited to applications in MEMS packaging, micro-fluidics, micro-optics and more.

The partnership between IREPA-LASER and the ICube laboratory has led to the development of an original set-up based on a long-focal length lens to focus the laser's pulses. The long-focal lens creates a longer Rayleigh length which provide numerous advantages such as greater positioning tolerance, increased welding speeds up to one meter per second, and reduced thermal gradients thanks to the larger focal volume [3]. These improvements make the process more suitable for industrial applications.

In order to have a better understanding of the physical phenomena involved during the process, a finite element modelling (FEM) of glass-silicon welding has been developed using the COMSOL Multiphysics software. The model takes into account both electromagnetic and thermal physics to model effects such as beam autofocusing by optical Kerr effect, non-linear multiphoton absorption and thermal accumulation. The model demonstrates that the temperature distribution can vary considerably depending on the pulse energy and on the repetition rate of the laser pulses. The modelling results could also help in forecasting the emergence of various silicon phases and determining the size of the solder joint, in addition of providing insights into the effects of laser and materials parameters. The Figure 1 shows a solder joint visualized by atomic force microscopy and the temperature distribution obtained by electromagnetic modelling after a single laser pulse of 6 µJ.

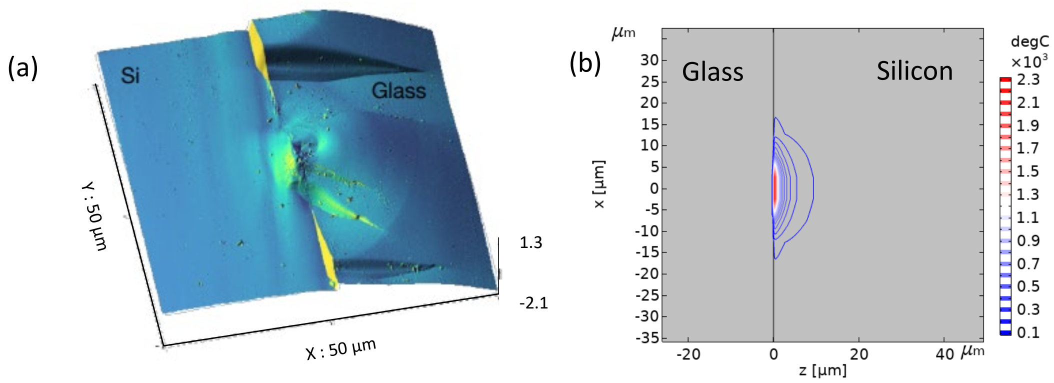

Figure 1 (a) Atomic force microscopy visualization of a welding seam between glass and silicon. (b) Temperature distribution modelling in silicon after one laser pulse (E_{pulse} = 6 µJ, λ = 1030 nm, t_{pulse} = 300 fs).

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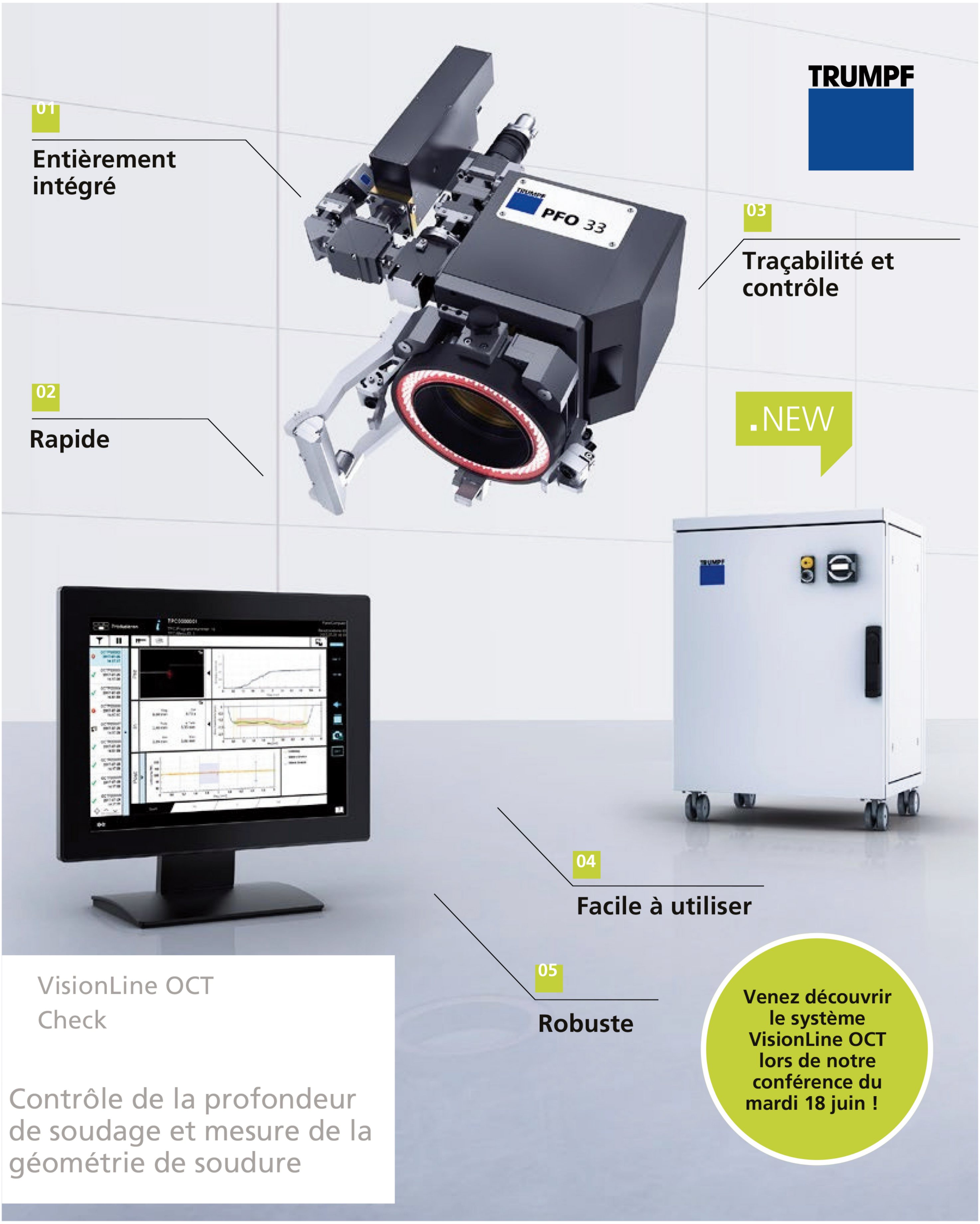

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Diagnostic mirrors for monitoring the laser material process

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1-Product Manager Optic & Fiber Optic, Laser Components Germany
2-Business Developer, Laser Components France

Process monitoring is a must have for reliable and traceable production jobs. High-precision diagnostic optics have become a key technology in many online monitoring processes, where the interaction of the laser beam with the material will be observed and analysed. For applications which require the highest reflectivity and damage threshold, with the lowest thermal drift, LASER COMPONENTS offers different coating techniques. As dielectric-layer optical systems become more and more complex, optical interference coatings (OICs) have been gaining increasing importance for these optics. OICs are formed by a layer stack of alternating transparent single layers of high- and low-refractive-index material [1,2]. A common method for manufacturing high-end coatings is plasma-ion-assisted deposition (PIAD), which is a combination of conventional electron-beam evaporation and a plasma assist source targeted directly at the surface of the substrates. Another coating technique is ion beam sputtering (IBS) coating. In IAD and IBS coatings the ion assisted coating process additionally allows the control of Energy input (compared to E-beam/PVD coatings). This allows to produce ultra-dense coatings which are moisture free and are not sensitive to temperature changes [3].

Therefore, the different techniques offer the possibility for spectral separation of processing/diagnostic wavelengths. No matter whether for OCT, pyrometer, thermo- camera or an observation in the visible wavelength range, the coating can be optimized for requirements of the application. Figure 1a shows the use of such mirror, where Figure 1b demonstrates in detail the specific coating. From the pilot laser 80% of the power is transmitted to align the optical beam path. 20% of the power is in direction to the material processing plane and can be used to position the whole processing head. More than 80% of visible wavelength range is transmitted to observe the process with a camera. To get a picture in correct colours and/or right amount of light can be additional defined by the coating design. The laser beam for the material process will be reflected better than 99% to reduce the losses to a minimum. The thermal radiation in the IR range is transmitted as well better than 80% for accurate measurement of the temperature. Finally, the optical coherence tomography wavelength, which is often very close to the laser beam wavelength, has a high transmittance to allow the depth measurement.

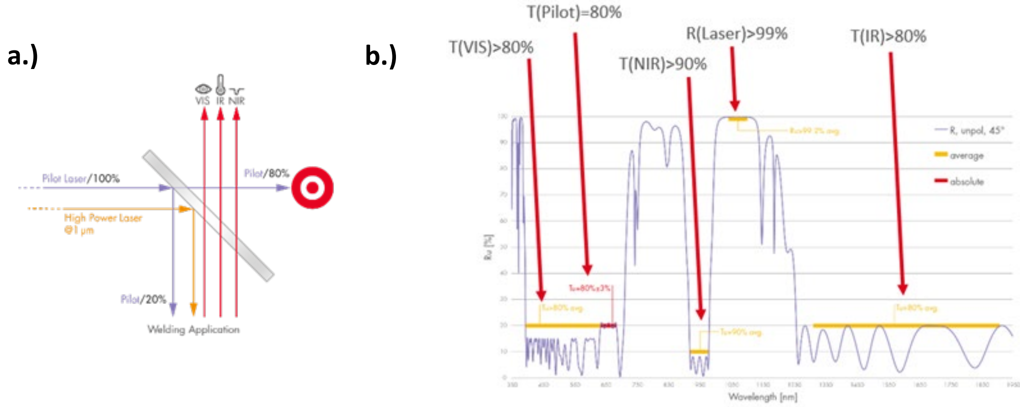

Figure 1 (a) The figure shows the principal use of diagnostic mirror. (b) This graph demonstrates the optimized and customized coating for different diagnostic processes.

For some application it is also important to monitor the laser beam itself. The diagnostic mirror coating can be designed for such purpose to record the beam quality for 6σ documentation. With IAD and IBS techniques complex coatings can be achieved. Furthermore, deformation due to high surface tension of ion assisted coatings can be compensated by compensation coatings, annealing and pre-curved optics. For some demands the use of E-beam/PVD coatings is recommended to produce a lower level of stress. The key for producing complex optical coatings for diagnostic purposes is in any case a good process control during the coating process which is done by **b**road**b**and **m**onitoring (BBM) in VIS and/or NIR wavelength range.

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CO_2 laser processing for laser induced-damage mitigation of fused silica optics. Process development based on numerical simulations

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Control of laser-induced surface damage of fused silica components is critical for reliable and cost-effective operation of high energy laser systems such as the Laser MégaJoule in France (LMJ), the National Ignition Facility (NIF) in the USA or the Shen Guang (SG) in China. This is specifically true for the final optical stages where high energy density UV radiation is required. Surface damage on fused silica components is linked to the interaction of high-energy photons with surface contamination or micro-fractures caused during polishing processes [1]. This holds true even for high quality polishing processes [2]. Initial surface damages materialise in relatively small areas of the order of micro-meters, however, they can rapidly grow under successive laser irradiation reducing the overall efficiency of the laser system and lifetime of the optical component. Ideally, a technique to repair such components should eliminate the damaged site or prevent growth of it, therefore, allowing an optical component to be used several times before its final replacement.

CO_2 laser processing has proven to be an effective technique for laser-damage mitigation of large fused silica optics. Still, it is a technique very sensitive to the material thermo-mechanical properties and laser intensity variations. This leads to negative effects such as surface deformation, residual stress, debris formation, or solidification of viscous flow in the form of raised rim structures around a threated zone [2,3]. Collaboration between CEA-CESTA and Institut Fresnel has yielded CO_2 laser mitigation processes based on the micro-ablation of cone-like shapes to remove damaged sites on large aperture fused silica optics. Sets of CO_2 laser processing parameters have been identified that can repair damaged sites and increase the laser-induced damage occurrence to > 10 J/cm^2 [3]. In this work, we present our latest results focusing on the strategy followed to reduce post-processing negative effects, like rim structures and surface debris formed around treated zones, which contribute to formation of new damaged sites. Numerical simulations based on commercial software COMSOL-Multi-physics are used to have a better insight of the thermo-mechanical dynamics occurring during the laser processing of fused silica. Results are used as guidance to improve the processing parameters of the mitigation process.

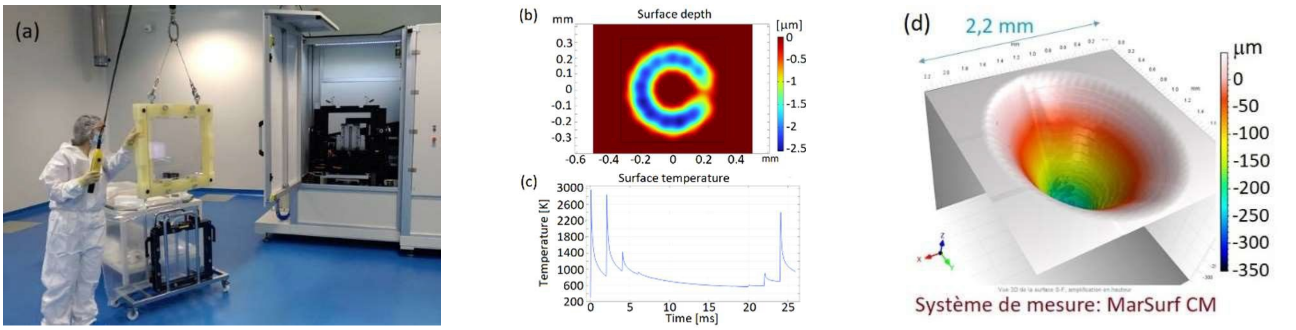

Figure 1 (a) Image showing an operator holding a damaged fused silica window (40 cm x 40 cm size) similar to the ones used in the LMJ, before it is mounted on the laser processing machine (MULO - Machine d'Usinage Laser des Optiques) to get repaired. (b) Numerical simulation results of the ablated depth of a circle of 210 □m radius by a pulsed CO_2 laser signal modeled as a Gaussian beam with a beam diameter of □$_{spot}$: 390 □m, pulse duration t_p: 80 □s, and peak power Pp: 116 W. (c) Evolution of the residual surface temperature of the axial zone where the initial pulse starts interacting with the material surface. Such results offer insight on the heat accumulation effect that happens closer to the central area of a cone-like shape reparation zone, and provide information that can explain features observed on the ablated cone morphology (e.g. bumps, rim shape, etc). (d) Image obtained with confocal microscopy of the surface profile for a typical conical crater of 2,2 mm diameter ablated with a CO_2 laser with a beam spot of 390 □m.

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Soudage laser manuel : une révolution dangereuse ?

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Les chaudronniers et métalliers sont totalement renversés ! En cause, ces petits lasers sur roulette qui envahissent et révolutionnent le métier de soudeur. Une torche, 2 pièces et hop c'est soudé ! Aussi simple que ça et ce sont les professionnels qui le disent ! Oui mais !!!! Et la sécurité ? Les informations qui circulent disent tout et surtout n'importe quoi ! Au final, chacun a sa propre idée du risque et sa solution pour s'en protéger ! En peu de temps, plusieurs accidents graves en France rappellent que les lasers (et particulièrement ceux-ci) sont dangereux pour les yeux et la peau ! Compte tenu de l'engouement suscité par ces nouveaux appareils qui se vendent comme des petits pains (ou chocolatines), nous proposons de rétablir des vérités sur les risques liés à l'utilisation de ces lasers.

How to improve laser safety behavior in industry?

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Nowadays, lasers are used in a very broad spectrum of applications, with a wide range of specifications and performances. Inevitably, this multiplicity of uses is accompanied by ever-increasing laser risks, particularly in industry! Even though regulations have improved considerably in recent years, notably with the implementation of Decree 2010-750, which lays down minimum safety requirements for people exposed to artificial optical radiation, it is not uncommon to encounter dangerous situations in the workplace. These situations, sometimes dramatic, are very often linked to inappropriate behavior when handling a laser. The question is, how can we assess and improve employee behavior? Why do we still see disobedience of safety rules and negligence? And, of course, how can these problems be resolved?

The aim of this presentation is to describe laser safety behavior in industry. People new to laser work (with less than two years' experience) frequently injure themselves. This can be attributed to inexperience or poor supervision (totally absent, inadequate or faulty tutoring). The improvement is noticeable among employees with between two- and five-years' experience in the field. On the other hand, the accident rate rises again for employees with more than five years' experience. British studies[1,2] have examined the effectiveness of training and behavioral changes. In particular, laser safety training has been shown to be effective in raising awareness of optical risks, but changes in behavior remain slow. These studies also show that, overall, the mistakes made today are very similar to those made in the past. They are still due to problems of handling (compliance with instructions) and/or poor protection.

Based on these various observations, the aim of the presentation will be to provide an analysis and keys to understanding these behaviors. The various tools[3,4] that can be used to improve laser safety in the workplace will be presented, along with an analysis of their effectiveness and limitations. In particular, we will look at how human behavior can be taken into account, how risk perception[5] can be assessed, and finally we will analyze the types of tools and technologies that can help maintain good laser safety habits. Particular emphasis will be placed on the use of virtual reality to teach laser safety techniques. Indeed, virtual reality for educational purposes is gaining ground these days, thanks to its immersive capabilities[6]. But what about virtual reality for laser safety training? Is it the right tool for the job? Baptiste Fabre and Aude Caussarieu show in particular that virtual reality must be deployed with caution[7], reserving its application for scenarios in which the advantages of this technology outweigh the problems of cognitive overload, often inherent in these new technologies. Tools of this type have recently been developed, and we'll be looking at their effectiveness in learning and skills transfer applied to laser safety, thanks to preliminary tests. Finally, we'll look at their advantages and limitations for such learning.

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Laser micromachining, decoration, what are the challenges ?

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For many years lasers are used for marking, engraving, machining, … it is not a competition with other way of working but a complement. It is also a very good opportunity to respond to today's challenges.

- Work on smaller and smaller parts
- Use less and less raw materials
- Consume less and less energy
- Produce less and less waste
- And always increase performance and quality

Laser Cheval works in laser application since 1974, it means that 50 years of innovation ! We developed efficient solutions for luxury decoration and are going even further with our latest innovations.

[1] Micromachined part by laser

[2] Colored part by laser

While this talk, we will detail our latest machines innovation and show you some examples of application…

[1] Micromachined part by Laser Cheval, (2023)
[2] Colored part by Laser Cheval, (2023)

Dynamic beam shaping: delivering superior efficiency and capabilities to boost adoption of laser microprocessing across industries.

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Laser is the production tool of the future. High resolution, permanent, contact-less, consumable-less, laser light delivers a superior level of value-added with minimal ecological footprint. This is particularly true in the field of surface treatment, where incumbent technologies for preparation (wet processing, sand blasting) or personalization (ink-jet printing, screen-printing, pad printing) are increasingly under pressure due to their ecological impact. Laser microprocessing is a leading candidate to meet both industrial and ecological targets, enabling new applications with strongly positive social impact to reach the mass market.

Laser microprocessing has the right cards in hands but its industrial adoption remains limited today, because it requires an investment deemed too large by most industrials from an economical and skills standpoint. Dynamic beam shaping with spatial light modulators (SLM) is one particularly promising technology to unlock these bottlenecks.

First, dynamic beam shaping enables multibeam processing. Multibeam processing readily offers multifold increase in process throughput and efficiency, therefore strongly reducing cost per part and ROI.

Going beyond, dynamic beam shaping is the cornerstone of the development of smart industrial laser tools, enabling remote maintenance in operational conditions and AI-assisted operation to ease the daily use of micromachining machine on the production floor.

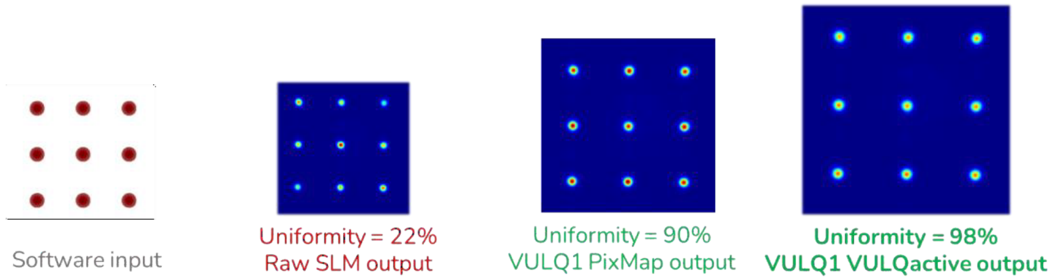

Figure 1: VULQactive active feedback control loop delivers cutting edge beam shaping quality in an automated manner.

A first section of this talk will present state-of-art of industrial multibeam laser solutions and their market, supported by current industrial cases to illustrate differences to standard laser microprocessing.

A second part of the talk will highlight recent progress in making this superior level of performance accessible to non-expert solution integrators and end-users. Additional technological bricks (fig.1) will be presented, as well as their contribution in the frame of next generation production lines.

The conclusion will give a broader view as well as some perspective on this exciting and rapidly evolving field.

Redefining Automotive Light Signatures through Precision Laser Engraving

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The light signature in the automotive market has evolved from a functional aspect to a distinctive design element. Car manufacturers now use unique LED patterns to create recognizable brand identities. It plays a pivotal role in defining a vehicle's identity in which Laser technologies clearly have a great role to play.
Our exploration will illuminate the application of Laser solutions in engraving complex designs and intricate details onto lighting moulds. We will delve into the challenges associated with tool path generation, where the management of millions of points becomes imperative for precise engraving over geometries exceeding 1 meter in length and how GF has implemented Femto lasers on large machines to address the needs of these lighting applications.

While Femto technology has been available for years on small machines, GF introduced a Femto solution on the LASER S 1000 & 1200 in 2023, utilizing new hollow core fiber delivery to accommodate large-sized machines. This innovation unlocks applications where accuracy and shininess properties are crucial and allows to use it on large molds.

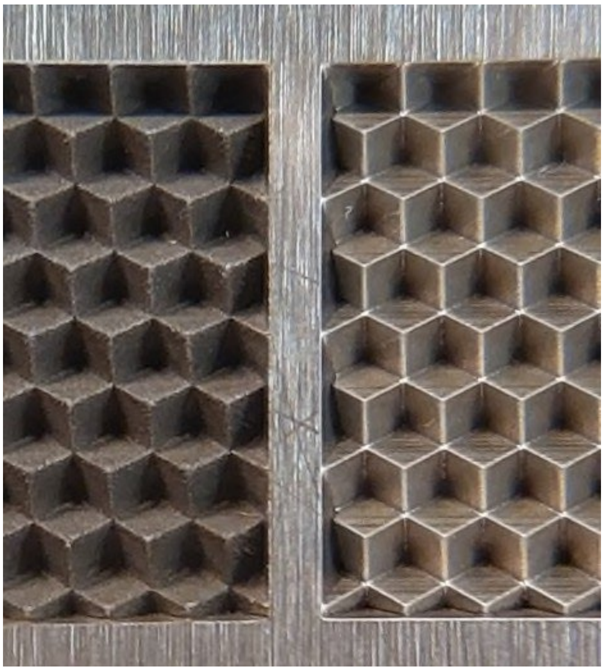

Figure 1: Illustration showcasing a lighting geometry achieved with a nano laser alongside the enhanced benefits achieved with femto technology.

The machine to tackle these applications is however only part of the solution. The process of generating machine tool paths in Laser Texturing typically involves wrapping a grayscale image onto a 3D model, where different shades of gray determine material removal depth. While effective and file size-friendly, this method faces limitations in automotive lighting due to wrapping inaccuracies. GF Machining Solutions is therefore developing an alternative approach using geometric CAD elements for tool path generation which however do pose issues linked to the large, generated files. To address the issues posed by the file size and the large number of points of these geometrical elements in the CAD program, through LaserCAM (part of LaserSUITE360) and the “substitution” mode GF aims to allow working directly with the point cloud generated by the light simulation software and substituting each point with a corresponding tool path to be engraved.

These innovations facilitate wider adoption of Laser micro machining and engraving in automotive lighting by enhancing process efficiency and accuracy, narrowing the gap to position Laser as a viable alternative to traditional subtractive technologies such as milling.

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Photonics in the Field of Electric-powered Vehicles

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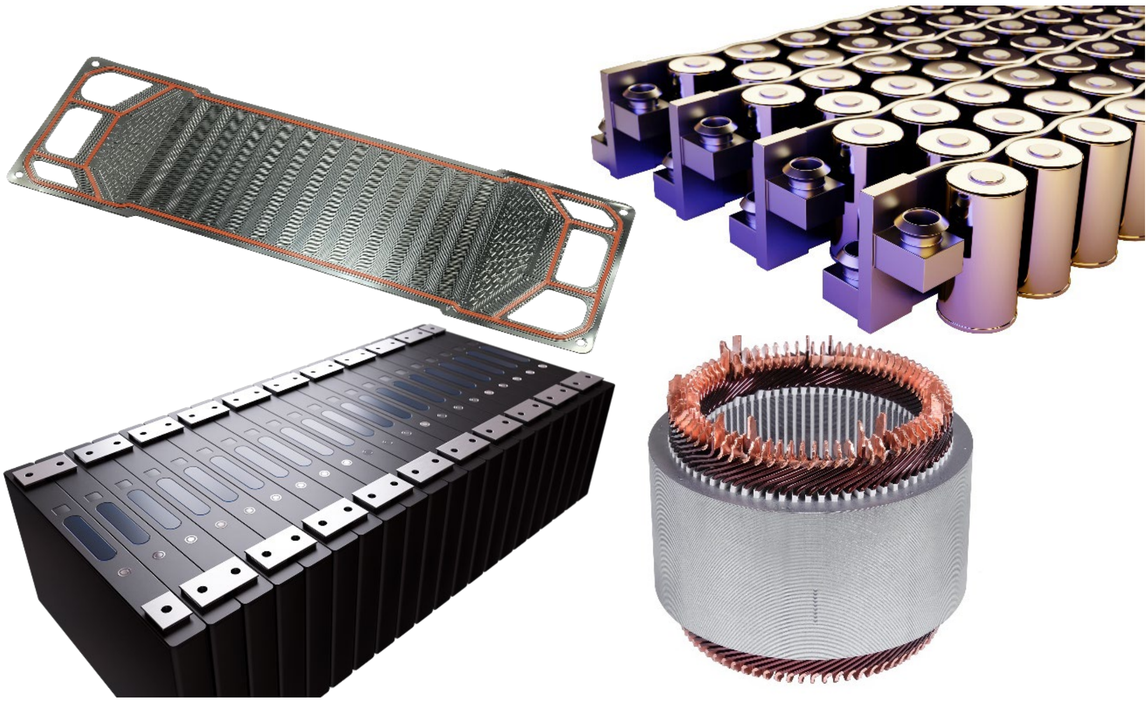
It is becoming increasingly clear that there is more than just a gradual change in the automotive industry, especially when it comes to future drive systems. There are different designs and degrees of electrification - from hybrid to pure battery vehicles - with different electrical outputs, ranges and driving shares. New components significantly change the share of value added in the vehicle. The focus of value creation is shifting further from mechanics to electrics/electronics. Whether e-mobility or hydrogen propulsion, the laser and photonics industry has seized the opportunity to change manufacturing processes and convince decision-makers of the undisputed benefits of photonic tools in the relevant production chains. And since most applications, e.g. in battery manufacturing and their use for e-mobility, started from scratch, the most profitable manufacturing tools could and can be used directly. It turns out that it makes sense not to transform an existing process from the "pre-laser age" into the modern age. The laser has undoubted advantages over other tools in these production chains. When you talk about processing speed, low energy input, automation, which is very easy to implement with lasers, energy efficiency and freedom from contact, then there is no getting around the laser as a tool

This contribution to PLI CONFÉRENCES 2024 provides an overview of some applications in battery production, in battery use and also in fuel cell production from the perspective of a supplier of sensors and processing tools, without claiming to be exhaustive.

When we talk about automated production, the ***sensor*** has been an essential component of a production chain not just since Industry 4.0. Sensors monitor production and the tools themselves. E.g. when welding thousands of seams per shift in series production for lithium-ion batteries in electric vehicles, users often want to stop their fully automated machines if the laser process suddenly exceeds the previously defined limits. Such interaction with the machine is only possible with dedicated sensor technology.

In the context of laser-based manufacturing, Precitec has been a guarantor of reliable tools and process-adapted sensor technology for many decades. The presentations for this conference will show how crucial the right sensor technology is in order to ultimately process the data with the help of AI algorithms to such an extent that concrete added value for customers can be derived from it.



Potentials of beam shaping strategies in laser welding

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The intensity distribution of the laser beam determines the amount of energy, which is locally absorbed by the material and thus influences all other process characteristics during laser material processing. As a result, it has a significant impact on both the process's stability and the quality of the welds produced. Recent laser beam sources and beam shaping technologies enable the variation of intensity distribution to optimize laser material processing. Stabilization of welding and cutting processes has recently been demonstrated using multi-core fibres, diffractive optical elements (DOE), superposition of multiple laser beams, or fast spatial oscillation of the laser beam via scanner optics [1]. The most recent beam shaping technology for coherent beam combining allows for the flexible generation of a wide range of intensity distributions, as well as their dynamic modulation at frequencies of several MHz [2,3,4]. High-speed X-ray imaging captures the effect of static and dynamic beam shaping on the shape of the keyhole and how it changes during laser welding [4]. The results show that specific beam shaping strategies stabilize the keyhole while reducing spatter and pore formation [5]. Furthermore, the geometry of the keyhole influences the characteristics of the fluid flow in the melt pool during welding [6], as shown in Figure 1. This enables the development of beam shaping strategies, which optimize the melt flow in order to significantly improve process efficiency and weld seam quality [6].

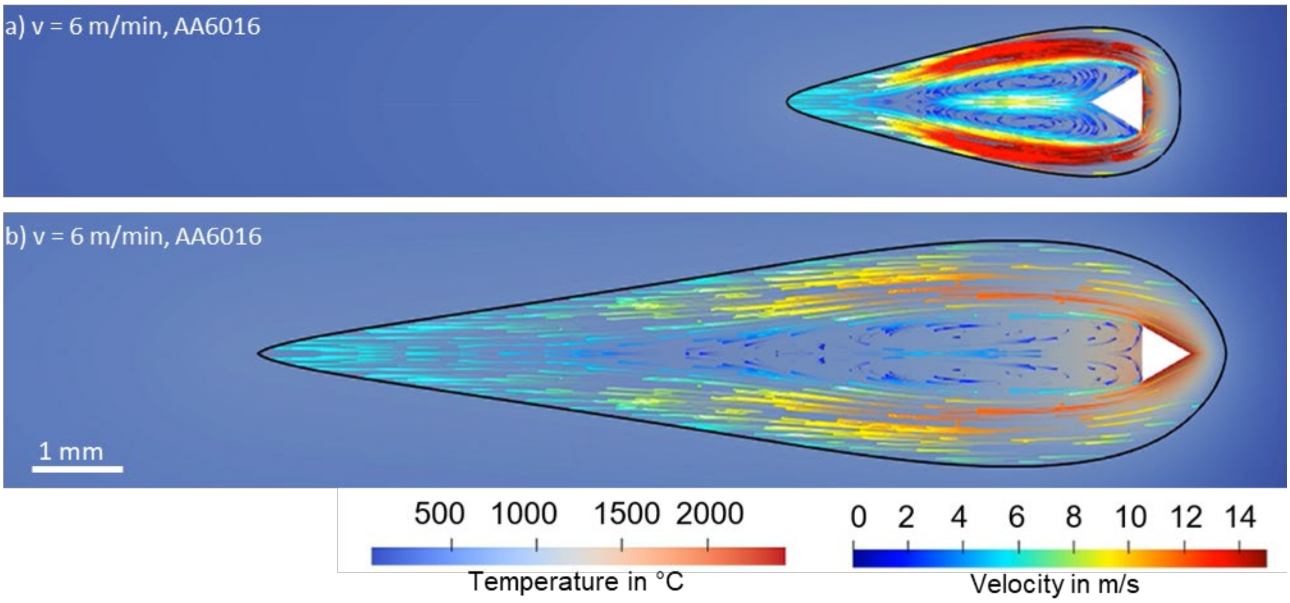

Figure 1 calculation of melt flow during welding with different capillary geometries (a) reverse triangle. (b) triangle points in welding direction.

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[2] J. Wagner et al. Coherent beam combining–unlimited flexibility in laser material processing: An analysis of the effects of CBC on the laser welding process. PhotonicsViews 19.3 (2022)
[3] R. Weber et al. How to tune ultra-fast dynamic beam lasers for materials processing. under review at Procedia CIRP (2024)
[4] J. Wagner et al. Influence of dynamic beam shaping on the geometry of the keyhole during laser beam welding. Procedia CIRP, 111 (2022)
[5] M. Sawannia, Response of the melt pool and welding capillary on laser beam shape changes in the kHz regime, under review at Procedia CIRP (2024)
[6] J. Wagner et al., Influence of beam shaping on the thermal efficiency during laser beam welding, under review at Procedia CIRP (2024)

High-speed heat accumulation temperature monitoring in high-throughput laser surface micro-processing

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High-average power laser material micro-processing with high pulse repetition frequencies initiates heat accumulation effects that can decrease processing quality even for ultrashort laser pulses. In order to gain deeper insights into these effects, a high-speed temperature measurement system was developed using infrared (IR) detectors and dedicated optics (Figure 1) [1]. Appropriate calibration methods were developed for temperature evaluation from measured signal for different application fields. Evaluation algorithms were invented for analysing thermal characteristics from the signal. Hardware implementation of the algorithms using field programmable gate array (FPGA) was realized for real-time monitoring of heat accumulation in nanosecond time resolution during laser micro-processing. The system was used for analysis of thermal processes in laser micro-machining by ultrashort pulsed [2], short pulsed and continuous lasers combined with polygon scan head for fast laser beam movement (Figure 1b). A variety of applications was analysed, e.g. high-throughput laser surface texturing (LST) for increasing adhesion of thermal spray coatings (Figure 2), LIPSS formation by multi-beam laser system, lithium battery electrodes processing and GHz burst laser ablation. The developed diagnostics system can be applied for analysis, monitoring and real-time control of processes in a wide range of pulsed laser applications, e.g. LST, micromachining, polishing, drilling or 3D printing.

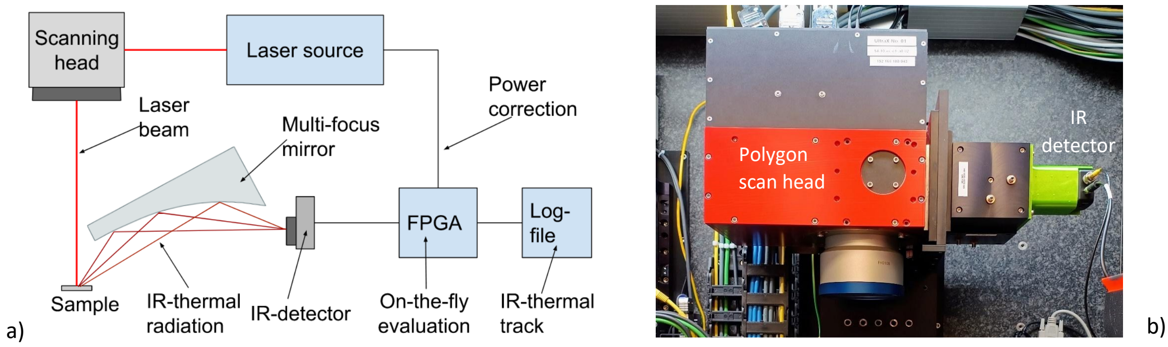

Figure 1: a) Schematic representation of the monitoring system; b) Photo of polygon scan head with mounted in-line IR detector

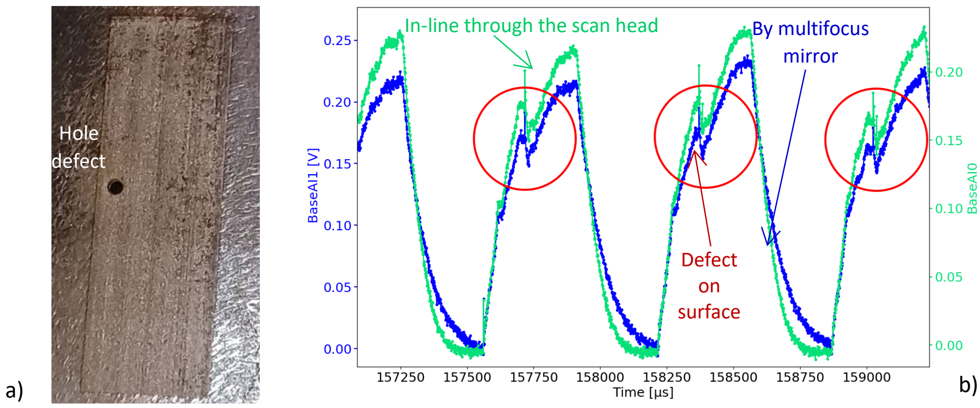

Figure 2: High-speed heat accumulation monitoring of LST process with a defect, 200 W nanosecond laser, 60 m/s scanning speed: a) Photo of the laser scanned surface with 1 mm defect; b) Abnormal decrease of the recorded IR-thermal signal in the defect area.

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[2] D. Moskal, J. Martan, M. Honner, C. Beltrami, M.-J. Kleefoot and V. Lang, Inverse dependence of heat accumulation on pulse duration in laser surface processing with ultrashort pulses, International Journal of Heat Mass Transfer, 213, 124328, (2023).

High throughput laser micro-drilling for hybrid laminar flow control

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Microdrilling can be defined as the creation of holes with diameters of up to a few hundred microns. For larger holes, in general, drilling can be carried out using mechanical tools. However, for micro-holes, the laser is undoubtedly the most suitable tool. It offers excellent drilling quality and high productivity rates. At Tekniker, we began several years ago to translate the high-productivity microdrilling results obtained in the laboratory to the scales needed by the industry, both in terms of surface area to be processed and quality and productivity rates. The application that has driven all this research has been the hybrid laminar flow control technology (HLFC) for the aerospace industry [1]. This technology uses millions of drilled holes in the leading edge of different parts of an aircraft to minimize turbulence, thus reducing friction and hence, fuel consumption.

The first approach to making millions of holes on metal sheets was the use of the single-pulse laser drilling (SPD) technique. In SPD, modulated emission lasers (QCW) are used to melt the metal of the metal sheets. At the same time, the melted material is carried away by a high-pressure inert gas. In this way, micro-holes can be obtained at productivity rates as high as 700 holes per second on a thickness of around 1 mm [1]. The second approach was the use of trains of shorter laser pulses in the range of few tens of nanoseconds (technique called percussion drilling or PD). The aim was to decrease the weight of the melting processes versus ablation and thus, to increase quality. This technique can produce holes at rates of 300 holes per second, leaving one side of the sheet free of burrs [2]. The third approach has been to use laser pulses with even shorter durations (in the range of a few hundred femtoseconds) in order to further increase the weight of the ablation effects during the drilling process. The initial experiences obtained with a custom-designed prototype for this working regime show promising results in terms of quality at slightly lower productivity rates [3]. This presentation will provide an overview of the prototypes built to study these three techniques on large surfaces and will show the advantages and disadvantages of each of them for the HLFC application as well as for other potential similar microdrilling applications.

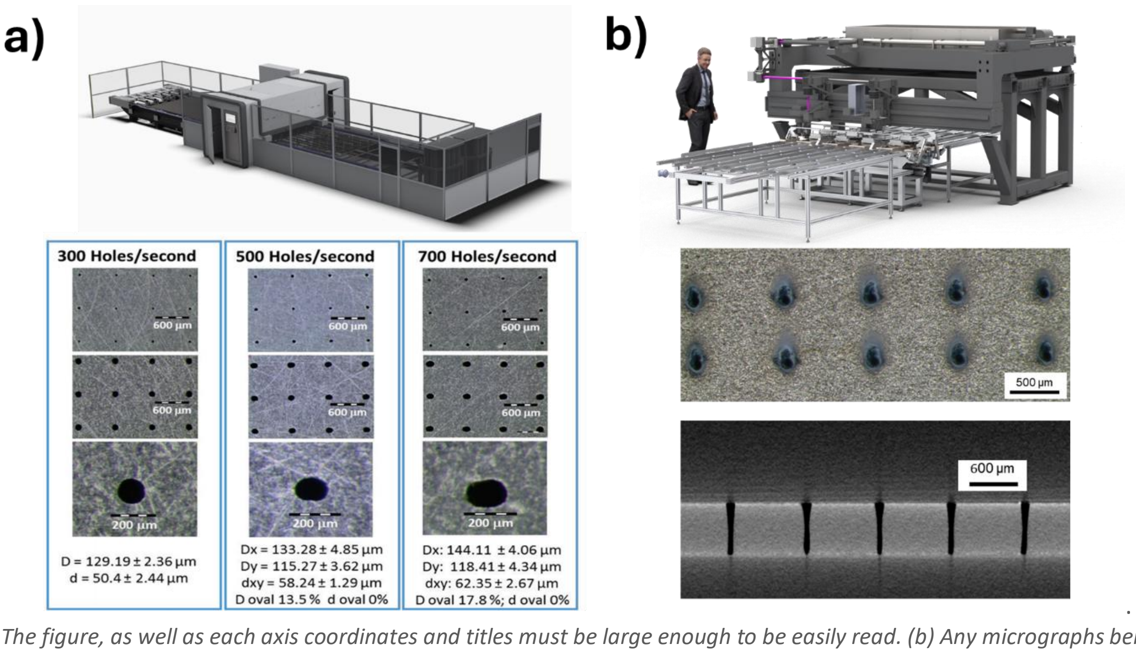

Figure 1 (a) The figure, as well as each axis coordinates and titles must be large enough to be easily read. (b) Any micrographs being used should have a scalebar and good contrast in order to ensure proper visibility. The font of text in the figures should be Calibri.

[1] R. Ocaña, C. Soriano, J. I. Esmoris and R. Sánchez. Fiber Laser Based Single Pulse Drilling for Production of Perforated Titanium Sheets for HLFC Structures, Journal of Laser Micro-Nanoengineering 14, 54 (2019)
[2] A. Stephen, R. Ocaña, J. Esmoris, C. Thomy, C. Soriano, F. Vollertsen and R. Sanchez. Laser micro drilling methods for perforation of aircraft suction surfaces, Procedia CIRP 74, 403 (2018)
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Ultra-short pulsed laser welding of crystals, glasses, metals, and more

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Optical components are now used in an enormous range of products and devices. A well-known problem in the assembly of these devices is how to join the optical components either to other optical materials, or to structural materials like metals. Considerable resource and effort have been spent in developing reliable bonding methods, often using adhesives. Despite attempts to standardise these process solutions are typically bespoke to the components involved and still exhibit serious issues in terms of outgassing, creep, accuracy and aging. An alternative solution, preferably avoiding the requirement for an interlayer material is therefore desirable. Ultra-short pulse laser welding is just such an alternative technology. First demonstrated in 2005 for glass-glass welding [1], and of glass-metal welding in 2008 [2] there is now considerable industrial interest in this emergent technology.

The combination of ultra-short pulses and high NA focussing optics allows for extreme peak energy densities, typically in the order to TW/cm^2. This energy density allows for strong multi-photon absorption in the otherwise transparent optical material in combination with linear absorption on the surface of opaque structural materials. This generates a highly confined plasma surrounded by a thin layer of melt, typically in the order of a few 10's of microns. By continuously translating the focus across the material interface the resulting highly confined melt-plasma zone allows for welding of materials with highly dissimilar thermal properties, like glass and metal.

The process does, however, have several challenges associated with it. Firstly, close contact is required between the parts at the interface, without this the high-pressure plasma is liable to escape and the result will be ablation rather than welding. Secondly, although the confined thermal zone allows for welding highly dissimilar materials thermal stress during the component's lifetime (e.g. thermal cycling or ambient temperature changes) can produce significant stress at the interface leading to poor performance or failure. Thirdly, the welding process induces some stress within the optical component and for high precision polarisation-sensitive applications the resulting stress induced birefringence may be detrimental to performance.

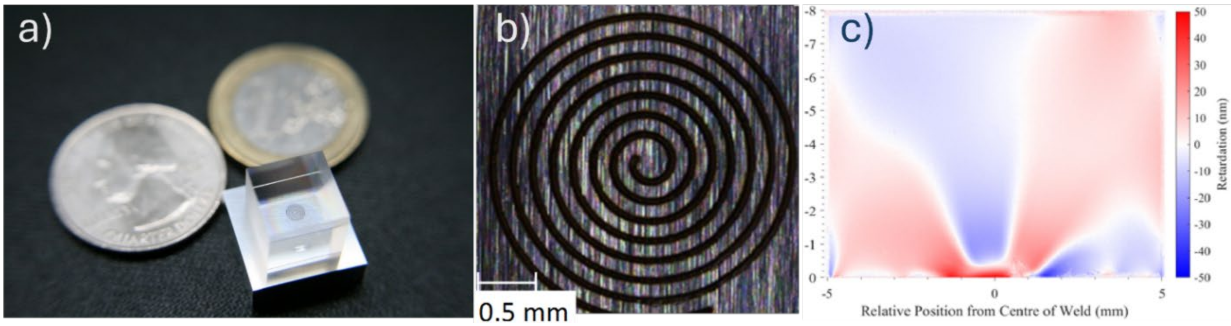

Figure 1 (a) Exemplar test sample of ultra-fast laser welding. (b) Exemplar micrograph of a spiral "spot weld", CF Figure 1(a). (c) Exemplar stress induced phase retardance of a glass-metal weld measured with a polariscope in side-view, adapted from [3].

At Heriot-Watt University we have carried out research aimed at investigating and addressing these issues; investigating surface preparation and mounting conditions required to allow for close contact and developed a unique optical polariscope quantify and to analyse the stress induced birefringence from welding and subsequent thermal cycling. This presentation will focus on recent developments including new material combinations and the measurement and analysis of weld-induced stress within the optical components, as well as thermal-induced stress under extreme environmental temperatures.

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Quantum Photonics : Every Photons Count

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Optics and photonics are a core enabling element of quantum technologies, as many of the systems require very precise control of light. To enable many of the applications highlighted above this contribution (mainly focused on Quantum sensing & communication) additional innovation and supply chain development is required. In this contribution we will then review the current opportunities available to optics and photonics suppliers involved in the race of the revolution of Quantum 2.0

Quantum mechanics haves been studied in the research community for nearly a century, resulting in the invention and commercialization of technologies such as laser systems, MRI imagers, transistors, nuclear power generation, and more. These devices and technologies are viewed as the products of the first quantum revolution, or Quantum 1.0.

As our ability to manipulate and control individual quantum objects (e.g., photons, atoms, electrons) increases, we are approaching a second quantum revolution, or Quantum 2.0, which could further enhance performance features such as capacity, sensitivity, speed, and security for numerous end uses.

Nouvelle Aquitaine Initiative NAQUIDIS CENTER[1] , launched in 2021, has the ambition to capitalize on 20 years of a strong territorial effort in the domain of photonics to amplify the quantum wave initiated worldwide at the beginning of the decade.

In this contribution we will mainly focus on the « real-world » photonics based applications (mainly on sensing & communications where photonics & lasers will have a major impact.

Indeed, While Quantum computing receives most of the attention by the mainstream media, most experts believe that quantum sensors and clocks (first pillar investigated by the NAQUIDIS CENTER [1]) will bring earlier commercial success if they can outperform conventional techniques cost effectively and in a smaller and often portable form factor. In fact, some types of quantum sensors – such as atomic clocks and cold atom interferometers – are already commercially available. Work is ongoing to bring new products to market, while making existing systems smaller and more robust. Quantum sensors take advantage of the extraordinary sensitivity of quantum states to their environment to create more sensitive and precise measurement devices to improve navigation (with or without GPS), network synchronization, geological surveying, medical imaging, LiDAR, etc.

On the other hand, Quantum communications leverages the properties of quantum state preparation and measurement as well as intrinsic quantum phenomena such as entanglement and squeezing to create secure communications networks and to enable a range of longer-term applications including distributed sensing and remote or distributed quantum computing. A primary motivation for developing quantum communications networks is to create secure communication networks to protect against the potential data security threat posed by quantum computing. A quantum computer capable of implementing Shor's algorithm could factor large integers exponentially faster than a classical computer, rendering common asymmetric public key encryption protocols such as RSA ineffective.

After a brief overview of the current photonics technologies implied in these emerging quantum fields, we will conclude our talk by a specific class of laser dedicated to the cooling & manipulation of cold atoms whose wavelength has to be resonant with their respective atom or ion transition.
In some cases, these transitions are in the near-UV and blue-violet spectral frequency ranges. Commercial lasers at these wavelengths (if available at all) are often relatively less optimized than lasers developed for telecom applications at infrared wavelengths. Higher-performance and more stable lasers in the near-UV and blue-violet spectrum are desired to ensure precise qubit preparation and manipulation. To stay at the forefront of this technology, France has decided in 2023 an ambitious plan of innovation & sovereignty leaded by Institut d'Optique, namely AtomQtrl [2] whose ambition and current status will conclude our talk.

[1] https://www.naquidis.com
[2] https://www.atomqtrl.fr

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