Laser Micro-manufacturing: Technologies and Benefits
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I. About EcoLaserFact

EcoLaserFact stands for **ECO - efficient LASER technology for FACTories of the future**. It is a project funded by the INTERREG IVB Program. INTERREG North-West Europe (NWE) is a program of the European Union to promote the economic, environmental, social and territorial future of the North-West Europe area. INTERREG IVB NWE is a financial instrument of the European Union's Cohesion Policy. It funds projects which support transnational cooperation. The aim is to find innovative ways to make the most of territorial assets and tackle shared problems of Member States, regions and other authorities.

EcoLaserFact has for mission to facilitate the know-how transfer for cost effective laser based processes from research organizations to Small and Medium Enterprises (SMEs). EcoLaserFact supports SMEs in North-West Europe to validate solutions based on the latest advances in laser micro-manufacturing to produce highly functional and innovative products with an easy and cost effective access to on-demand processing and equipment. EcoLaserFact gives the opportunity to SMEs to gain experience in micro-fabrication in the context of their specific application requirements. This will result in raising the technical know-how for the production of high-tech products and improve competitiveness.

Ten partners from all over Europe have joined their forces and have initiated the project:

**Trainings to laser industrial materials** processing is essential for a good understanding of laser technology and a perfect control of laser materials micro processes. EcoLaserFact aims at widely disseminating the possibilities given by these new technologies to companies, and particularly SMEs. These training courses are free of charge and open to all interested parties. The EcoLaserFact consortium will present an introduction to laser security, and a detailed overview of laser micro-manufacturing technologies. The subjects addressed are laser subtractive and additive technologies. More precisely, the trainings deal with ultra-short pulse laser micro-machining, laser milling, surface texturing/structuring, master-making process chains, and laser micro-welding. We will show you some concrete examples of what lasers can do for you through demonstrations.
We offer online tools to show laser capabilities to tackle most of the technical problems in terms of laser micro-machining. Over 88 applications on different materials have been identified to better understand laser micro-manufacturing technologies. These services are free of charge. To learn more about our services, please visit our website www.EcoLaserFact.eu.

EcoLaserFact has also for mission to promote laser micro-manufacturing through its participation at events, such as workshops, infodays, and international exhibitions. You are welcome to visit us to discuss about your needs and to find innovative solutions. On the other hand, free feasibility studies are offered for the benefit of SMEs from the North-West Europe region for testing laser processing of materials. We help defining the most efficient technical solutions and realize the first demonstration samples. Any SME can make multiple requests for the same call. To submit your project, please apply online on www.EcoLaserFact.eu.

EcoLaserFact contributes to a more cohesive EU society as it derives from a cooperation of people from different countries working on common issues that touch the lives of EU-citizens.
II. Laser technologies

From the first gas laser to the flash pumped solid state laser, a first step has been done towards higher efficiency and compactness. Then with the advent of high power pumping laser diodes (highest efficiency, small footprint, higher reliability and stability) solid state lasers technology moved one more step forward with higher efficiency and more compact systems. The next major step has been taken by the introduction of the fiber laser technology with a clear improvement on laser characteristics (higher efficiency, excellent beam quality, compactness, high CW power, reliability). The latest developments concern ultrafast lasers, with pulse duration in the femtosecond regime, enabling a multitude of new applications. The specific properties of the fibre laser, such as high beam quality, high power or energy, combined with the ultrashort pulse technology make lasers a privileged tool for a lot of applications, and specifically for high precision material processing. Laser technology developments allow machining and processing with flexibility, high quality and accuracy, speed with a minimum of secondary effects (like thermal effects for instance). If one looks at the complete process chain, laser machining is very often cheaper than other machining options and produces less waste to dispose. The choice of the right laser source is primordial in laser machining, but it is the total process chain which will influence the final results in terms of quality, speed and cost. For non expert end-users making these choices is often impossible and this is why a project like EcoLaserFact is important for guiding and advising potential laser end-users.

A. Gas lasers

Gas lasers are lasers using gas as amplifying medium inside the laser cavity. Gas lasers were largely developed and used in the sixties and seventies, and then replaced progressively by solid state lasers. Gas lasers have low wall-plug conversion efficiency. Various gas lasers exist with low power and low energy, mainly for metrology or spectroscopy applications. There are two main exceptions: CO2 and excimer lasers that are largely used in material processing.

CO2 lasers can produce very high average power in a large range from tens of watts to tens of kilowatts. Its specific wavelength in the infra-red at 10.6 µm is weakly absorbed by metals compared to visible and near infra-red. This gives some advantages for engraving metals, ceramics and glass. It is also used to engrave and cut non-metallic materials as plastics, wood, Delrin, Mylar, paper, textile and rubber.

Excimer lasers have the main advantage to emit wavelength in the UV range (308, 248 and 193 nm), UV photons have energy enough to break the molecular link during the interaction with matter. So the main material removal process with an excimer laser is an ablative one, its superficial effect allows removing very thin layers of matter. This ablative effect leads to a clear, accurate cutting without ridges or a drilling with edges showing no bumps. Excimer lasers are also used to remove GaN semiconductor from the sapphire substrate, this laser lift-off is important for the manufacturing of high brightness blue LED (Light Emitting Diodes) and OLED (Organic LED). Due to their particular behavior, Excimer lasers can emit only in pulse regime (some tens of ns) and power scales from Watts to hundreds of Watts. One drawback of the Excimer laser is maintenance (regular replacement of the laser gas).
B. Diode Pumped Solid State Laser

The amplifying medium is a crystal or a glass, which is doped with active ions. The laser effect is due to the presence of these doping ions. The host material must be fracture resistant with a good thermal conductivity and easy to machine. The most known is Nd:YAG, but there are also Nd:YLF, Er:YAG, Yb:YAG, Ruby, Ti:Saphir, Cr:YAG, Ho:YAG, Er:glass, ND: glass, Alexandrite, Nd:VO₄ ... DPSSL are optically pumped, by flash lamps and more and more by laser diodes due their decreasing cost. They are working in continuous or in pulsed regime. DPSS Lasers are able to emit pulses in any duration from some ps (10⁻¹² seconds) to ns (10⁻⁹ s) or µs (10⁻⁶ s). They emit over a large range of power (or energy) from mW to kW (µJ to tens of J). Diode pumping efficiency is around 10 to 15%. They have a small footprint and their maintenance is not complicated. DPSS lasers commonly operate in the near infrared region, but they can also be frequency-converted with the help of non-linear effects produced inside specific crystals. Thereby, wavelengths in the visible, near ultra-violet and UV regions are possible, these being the so-called second, third and fourth harmonic frequency conversion, respectively. They are used in all domains: scientific, defense, medical, environment, instrumentation and material processing. During the eighties and nineties, DPSS lasers represented the most successfully completed laser technology. Since then they are little by little replaced by fiber lasers and ultrafast lasers, particularly for micro-machining.

C. Fiber lasers

Most of fiber lasers are based on Master Oscillator Power Amplifier (MOPA) architecture, namely an oscillator followed by several amplification stages. Fiber lasers can operate both in continuous or pulsed operation. The laser oscillator medium is typically comprised of an optical fiber doped by active ions. The choice of the ions defines the wavelength of the laser. For instance Ytterbium (Yb³⁺) is chosen to emit around the 1µm region, Erbium (Er³⁺) emits around 1.55µm, and Thulium (Tm³⁺) emits round 2µm. The cavity mirrors are obtained by engraving Bragg gratings inside the core of the fiber. So there is no free space propagation and the laser cavity is always aligned. The repetition rate of the laser is related to the cavity length of the oscillator. By using specific double clad optical fiber coupled to a fibered combiner, a very high level of pumping absorption is reached (up to 50% in the amplifiers stages). There are several advantages to the use of fiber laser:

- Always aligned
- Free maintenance, long lifetime
- Very compact device
- Cooling system: air convection
- Very efficient, 20 to 30% wall plug efficiency
One of the most important advantages is the laser beam quality, which is nearly the diffraction limit. This is due to the use of the fiber itself, without any specific adjustment or optics. A diffraction limited beam means that it is possible to focus on a very small spot diameter roughly around the wavelength. Similar to the DPSSL, harmonic generation leads to green or UV wavelength. The main drawback is the power limitation due to the section of the fiber. This drawback can be mitigated by increasing the core of optical fibers for instance.

Fiber lasers are now used in a large range of applications in telecom and medical but the most common use is in material processing and micro-material processing. The beam quality combined with the high pulse repetition frequency make the fiber laser a very good tool for marking.

**D. Ultrafast lasers**

Ultrafast lasers are lasers which emit laser pulses with extremely short pulse duration, typically in the range 10’s (10^{-15}s) to 10ps. The physical effect to produce these very short pulses (mode locking, self-mode locking) leads also to a very good beam quality around the diffraction limit. Therefore a strong focussing is possible to reach spot diameter of about the wavelength. In that case, a very high peak power density is obtained up to some TW/cm^{2}. The main specifications of ultrafast pulsed lasers are the following:

- Ultra fast: < 10fs to some ps
- Energy per pulse: from some nJ to some mJ
- Pulse repetition frequency: from some kHz to 100 MHz
- Average power: from 1W to 100W

These lasers are a little bit more complex than the previous ones. They are based on DPSSL or fiber laser or a mix of both. Today, they are nevertheless compact and reliable. Their high peak power density is very useful in micro-machining. Pulses are much shorter in duration than the time it takes for the heat to diffuse, enabling the ability to remove material with little or no damage to the surroundings. The affected thermal zone is reduced to the order of the spot size. Thus, cuts are clean and the ablation is very precise.

Ultrafast lasers can process almost any material gently with a high accuracy and high productivity. Applications are various, from cutting medical stents from polymer tubes or ultrathin plastic foil, drilling ultra-small holes in metal to structuring the surfaces of thin film solar cells. The lack of heat transfer from the femtosecond pulses makes it possible to ablate combustible materials and even explosives.
III. Manufacturing with laser

A. Laser choice

There exists a selection of lasers from the UV to the IR, which can be used for most micro-manufacturing tasks. Some of these possibilities are highlighted in the section on laser micro-manufacturing technologies. Making the right choice of laser is essential to ensure that the desired results will be achieved. Even though the use of lasers is becoming simpler, with a high ergonomics of the human-machine interface, there is still the requirement to use the different properties of lasers effectively to obtain the best results. The main laser characteristics and the properties to consider for micro-machining include:

- Wavelength (absorption, reflection by the material)
- In Continuous mode: Power
- In Pulsed mode:
  - Pulse duration (size of affected thermal zone)
  - Energy (ablation threshold)
  - Pulse repetition frequency (speed of the process)
  - Beam quality (focusing)

B. Main processes

1. Subtractive

Subtractive manufacturing is the process of removing material from a solid using a laser beam. This includes laser cutting, drilling, and marking engraving technologies to name some examples. Typically, the laser materials would be metals, polymers or ceramics. The use of a laser beam shows some advantages relative to mechanical scribing. For instance, laser ablation is a non-contact process, without any use of special chemicals.

Laser diode dicing, the wafer substrate material is GaAs with a thickness of about 100µm and the dicing stripe area between devices is close to 40µm. Laser bars have been cut using a femtosecond laser, with a very good quality cutting, reducing the impact on the semiconductor efficiency compared to classical mechanical cutting. (Multitel)

Silicon wafer (Trumpf)
2. **Additive or 3D printing**

Additive manufacturing makes parts by adding material instead of removing it. Additive manufacturing could be laser cladding or 3D printing. The laser micro-cladding, namely the projection of metal powder melted in-flight on a surface or metal wire directly melted on a surface, using a high power laser beam and finally deposited on the work piece. 3D printing is based on the use of a powder to be melted or resin to be polymerized, when illuminated by a high power laser beam. 3D printing can be very useful for rapid prototyping. Additive manufacturing today represents a high initial investment, fairly slow manufacturing speed, but as the technology improves and volumes of equipment increase, costs will decrease and quality will improve.

3. **Material modification**

Lasers can modify the surface or the refractive index of a material. For instance, surface functionalization at the micron scale leads to some colour effects on opaque materials such as metalloids. The technique of intra-material modification can be found in the perfume industry or wine industry, to insert a readable data matrix to ensure traceability and avoid counterfeiting. Material modification and surface functionalization are the domains which have the greatest research and development today, the possibility to modify or add properties of a material seems to be infinite.

4. **Joining**

Laser beam joining is a technique used to join multiple pieces of metal or polymer through the use of a laser. By applying highly localized heat via a contactless laser beam an airtight sealing of different materials is possible. Laser transmission welding enables the joining of transparent polymers with minimized thermal impact. With mid-infrared high Power lasers (1.9µm), edge to edge welding of polymer is now possible. With a precise control of the process, very good mechanical resistances and almost invisible seams are achieved.
IV. **Benefits to use laser for manufacturing**

In the micro-manufacturing processes defined above, the benefits to use lasers are based on their specific properties:

- High power, high energy, high fluence and peak power densities
- Well defined and accurate spot size
- Small affected thermal zone
- Non contact manufacturing
- Flexibility (single machine, multiple machining)
- No waste
- High movement speed of the laser beam
- Compactness and small footprint

All these allow laser micro-machining to satisfy the customer’s requirement which can be summarized as follow:

- A very high quality (clean, accurate, ...) to simplify or avoid pre- or post-operating
- A high machining speed
- To machine areas that are difficult to access
- To produce internal tooling
- To produce tooling with specific and various geometries
- To obtain parts very difficult to realize with classical machining and tools
- To clean without waste
- Real time control and measurements during processing
- Cost reduction
- User friendly interface

Even though more than one type of laser may be capable of producing the results, there is always an optimum choice when all factors such as laser properties, material characteristics, beam handling, process scalability, running costs and the general economics of the process are taken into account. Besides the high quality of laser manufacturing, the numerous benefits can be summarized in three points: ecology and sustainability, cost reduction and no alternative to manufacture.

**A. Ecology and sustainability**

1. **No wear**

Using the laser there is no contact between the tool and the part to machine. Contrary to mechanical tooling, there is no wear of the tool, so no need to replace the tool after a certain number of tooled parts. The photonic tool is always ready to use. There are no more well-worn tools to sharpen. There is no need to use lubricant oil and so no used oil with metal particles to treat for disposal.

2. **No waste**

Due to the increasing stringent regulations, waste management has become crucial for material processing. Waste streams from drilling, cutting, cleaning are collected, processed, handled, and transported, increasing their costs. So it is very important to note that laser machining reduce drastically the volume of waste. Laser cleaning of surfaces avoids the use of chemical products to remove dust, oxides, grease. During drilling or cutting no cooling fluids or lubricant oils are needed, so laser drilling or cutting does not generate waste to treat and evacuate.
BENEFITS TO USE LASER FOR MANUFACTURING

There are no more worn tools to throw out. Laser marking or engraving does not use ink nor solvents to permanently mark the parts and they avoid using adhesive labels which generally end as waste. 3D printing allows getting some prototype pieces or parts without having recourse to machined pieces or parts. Often we need some prototypes before reaching the right pieces which work well and assemble correctly with other parts. More often parts which are included in the housing and design or ergonomics aspects need a lot of prototypes to test in real handling before the choice of the definitive shape. So 3D printing highly reduces the classical mechanical tooling with its resulting metal shaving and machining waste. Laser surface texturing of molds replaces the chemical etching of the surfaces. The chemicals are toxic, corrosive and harmful to the exposed people. However, it may be necessary to couple the laser machine tool to a suction system to remove the particles of micrometric or nanometric size, harmful to the health of the operator.

3. **Energy saving**

Very often, the use of lasers can avoid pre-operations before tooling or post-operations after tooling, less operations means less energy required to obtain finished parts. Less mechanical manufactured prototypes leads to energy saving. Lasers are less and less energy intensive, DPSSL have higher efficiency than gas lasers or flash pumped SSL, and fiber lasers are very efficient machines with up to 30% wall plug efficiency for marking lasers.

4. **Sustainability**

Reduced energy consumption, greater reliability, faster processing, and reduced footprint are important ingredients to achieve sustainability. Laser tools can often perform multiple processes, leading to sustainability. The laser marking or engraving is permanent and does not fade away over time. The below examples illustrate how lasers are contributing to better sustainability.

- The laser micro-machining contribution can be seen in the realization of reduced consumption. For example, micro and complex holes drilled in the direct-injection valve for a fuel engine (from Robert Bosch, Gerlingen, Germany), allow saving up to 20% fuel due to more efficient combustion.

- Surface functionalization makes some medical implant hydrophobic and/or anti-bacterial leading to reduced post-operative complications.

- Laser scribing, dicing and cutting is now extensively used in Silicon and thin-film photovoltaic manufacturing.

**B. No alternative to manufacture**

1. **3D printing**

3D printing can produce almost any shape or feature, including those difficult or even impossible to produce by conventional manufacturing processes. 3D printing can support innovative design structures. The use of 3D printing technologies is increasing over the world. The main application is rapid prototyping, but the market indicates that large public would like to access this technology. Laser 3D printing is reserved to specialized people because of its expensive price. Only 3D printers based on plastic fusion are accessible for the moment, but due to the fast development of this new technology we can estimate that laser 3D printers will be also largely diffused.
2. **“Fragile” parts**
The lack of tool contact during laser processing avoids any pressure on the piece to manufacture. It makes the tooling of very fragile pieces possible, for example very thin metal or polymer foil. As it just needs to keep the pieces in place without strong and firm hold, very fragile parts can be manufactured without induced constraints and deformations during drilling and cutting.

*Laser cutting of a 38µm stainless steel foil (VITO NV)*

C. **Cost reduction**

1. **No pre- or post-operative actions**
In general terms, possibilities of laser micro-machining and the quality resulting from laser tooling do not require pre- or post-operative steps (except for additive technology which often need a polishing step). Less operations result in cost reduction. For example, laser welding does not deform the pieces avoiding their straightening-up. Laser welding time is roughly reduced by a factor of 10. Laser cutting provides very smooth surfaces with no burrs, so there is no need for a refinishing step.

2. **Flexibility**
The speed of displacement of the laser beam adds some possibility to adjust the speed of the tooling. Laser parameters (energy, repetition rate, spot size...) are very often adjustable in the machine itself leading to a high level of flexibility. Some machines have the possibility to change the emitted wavelength by using harmonic generation and to obtain new wavelengths: half, third, fourth and fifth of the wavelength. This gives more flexibility by allowing adaptation of the wavelength with the characteristics of the material to tool. Moreover, temporal pulse shaping allows adjusting the way the energy is deposited, which can be adapted to allow different tooling of different materials. All these possibilities give to laser micro-machining a high level of flexibility by adapting to different tooling and different materials with the same machine.

*Pulse shape library (ROFIN-SINAR)*

3. **Speed**
In general terms, laser processing is faster than classical tooling. Polymer welding can be done at several meters per minute. Laser cladding may lead up to 50% less lead time, and there is no mold or tools required.

4. **Waste**
As laser processing produces less or no waste, the associated cost to collect, dispose, treat the waste and environmental taxes, are significantly reduced.
V. Laser micro-manufacturing technologies

A. Cutting

Laser cutting is now a well-established process and it applies to a wide range of materials both metal and non-metal. Virtually any material can be laser cut. Key features of laser cutting are the following:

- Non-contact process
- No tool wear
- Very small thermally affected zone
- Good edge quality (square, clean, no burrs)
- High reliability
- High repeatability
- High speed and complete automatic process

With laser cutting, there is no need to apply force so there is no need to hold the parts firmly. As the affected thermal zone is very small, there is no constraint put inside the material and no deformations, particularly with very thin metal sheets. One of the most known laser cutting application is the realization of medical stents used to treat arteriosclerosis. It is easily understood that stent required a tooling with a very high degree of quality.

B. Drilling

Lasers can drill micro-holes in metal, ceramic, diamond, silicon and other semiconductor materials, polymers, glass and sapphire. It is used to manufacture micro-holes in fuel injection components, vertical probe cards, metered dose inhaler products, pinholes and slits for scientific instrumentation, inkjet printer nozzles, filters, sensors, high resolution circuitry, fuel cells, fibre optic interconnects and medical devices. There are four different ways to manufacture holes with a laser: single shot or percussion, trepanning or helical drilling. They allow holes with perfect and constant diameter or tapered holes. The holes have a sharp and clean edge. They can have an ultra small diameter up to around 1µm. Depending on the materials to drill and the quality required the laser single shot drilling can be very fast, up to thousands of perforations per minute.
C. Marking and etching

Jewelry, fruit, cheese and other food, electric cables, keyboards, mobile phone and tablets, switch, speedometer and gear-shift, drug packaging and pills, silicon chips and electronic components, metal sheet and mechanic pieces, pace makers, glass, pens, rules and calipers, mechanical tools... Today marking is present everywhere and it is impossible to imagine production without marking. The attachment of numbers, texts or identification codes, have become a part of the added value. Moreover, traceability is required in increasing number of domains. Marking is required in all branches of industry. Marking is one of the most versatile laser processes and it fulfills requirements to a high degree. Lasers allow permanent marking in a non-contact process. Laser marking can be obtained through different processes: ablation, engraving, annealing, foaming and coloring. The laser (DPSSL, fiber, ultrafast, CO₂, and excimer) and process shall be chosen according to the materials and desired results.

Engraving and ablation can be performed on all material, notably: metal, glass, wood, plastic, paint, ceramic, and laser marking film. Ferrous metals and titanium for instance supports annealing. Color change and foaming are more dedicated to plastics. Short and powerful laser pulses are used for engraving and ablation. Under the laser beam action the basic materials or coating melt and evaporate. In engraving, the material is removed and a hollow is created. Ablation is roughly the same, but the part removed is a coated layer that has a different color. Coated layers can be lacquer or special films.
Annealing: Some heated metals exhibit annealing colors which depend on the achieved temperature. The laser beam is used to heat the piece to the desired temperature where the marking should appear. This creates an oxide layer on the surface which fixes the color.

![Different colored annealing markings on steel (FOBA)](image)

Coloring: When the laser beam is applied on the work piece, it locally heats the surface resulting in some plastics to become darker by carbonization. The discoloration ranges between grey to blue-grey and black. Carbonization is used for light plastics and organic materials (paper, packaging materials, wood, and leather), in which the color changes from light to dark.

Foaming: When a laser beam is applied onto a base material, the heat produces a partial degradation creating gas-bubbles within the material. The bubbles are trapped under the surface layer of the base material and create whitish bumps. With dark-colored base materials, the marking appears much brighter as a lighter color of the base material, offering high visibility.

![Data matrix (3x3mm) on an electronic board (LASER SIC MARKING)](image)

The main advantages of laser marking are:

- No pre- and post-processing
- Durable, high-contrast marking
- No overall surface discoloration
- Fast compared to mechanical marking techniques
- Very small line widths possibility
- Flexible, individualized marking content
- Small footprint laser source
- Suitable for areas difficult to access

**D. Welding**

Micro-laser welding is a process using a high power laser density to weld two parts together. One advantage is that laser welding beam can be transmitted through ambient air rather than requiring a vacuum or inert gas shielding environment resulting in a very clean and high quality weld. Other main advantages of laser welding are:

- Non-contact and force free process
- Minimal affected thermal zone
- Free of pore and leak
- Without added metal
- Corrosion resistant
- Biocompatible as the base material
It is in medical technology that the most impressive uses can be found. The most known is the welding of pace makers. It is quite impossible to realize pace makers without lasers. It welds titanium parts with a very high quality with no refinishing requirements. Micro-laser welding is also used in other industries as electronic, semiconductors, automotive, jewelry, watch making, and many others.

Assembling two polymers with a laser is also feasible. This process simultaneously fuses two surfaces in contact. The quick cooling of the fused polymer provides homogeneity at the interface. Sometimes absorption is too low (transparent material) and it is necessary to increase it by additives like color pigments. In this case, the laser beam penetrates the transparent polymer to reach the absorbing one. The surface of the later is melted and due to heat transferred the transparent polymer is also melted at the contact surface. The advantage in this way is that the seam welding is done inside the component without any particles released.

Via laser transmission welding polymers can be joined. This is also possible for transparent polymers. Channel, reservoirs or other structures can be created using different laser processes.
**E. Additive**

The process of “Construction Laser Additive Directe” (CLAD) or laser metal deposition (LMD) is based on melting metallic powder by laser to the substrate to generate a sediment with perfectly controlled dimensions. This yields a strong metallurgical bond between the substrate and the applied powder track. It allows the production of near-net shape components or materials. Layers of matter are stacked successively to create technical and functional parts. Due to the low energy input in the component, the deformation of the part is controlled within very narrow tolerances. The fine microstructure which is typically obtained during laser cladding processes can even enhance the wear and strength properties of the material compared to the conventional manufactured material. This process is also used for repairing high added value pieces such as molds and can also add functionality. It is important to note that this process is economical and environmental because it:

- does not require a tool or mold
- does not require a cutting fluid
- does not produce dust and so matter efficiency is around 90%
- reduces manufacturing time.

![Example of CLAD technology (VITO NV)](image1)

![Manufacturing of 3D pieces for aeronautic applications (IREPA LASER)](image2)

**F. Laser cleaning**

A pulsed laser beam is focused and absorbed by the dust or coating at the surface of the substrate: the high temperature yields to micro plasma. This plasma generates a shock wave which detaches and ejects the dust from the substrate without metallurgical change or damage. Only the coating, dust, oxydes is affected and removed. It is necessary to adapt the laser wavelength to be absorbed by the target to remove and not to react with the substrate. This process is once again very environmental as it does not need chemicals as solvent, water or abrasive components (sand, glass bills). Laser cleaning process is mainly used for:

- Paint removal or de-coating
- Pre-treatment for adhesive bonding and coating
- Mold cleaning and de oiling
Cleaning of bonding groove and cleaning of clips before welding (CLEAN-LASERSYSTEME)

G. Prototyping and 3D Printing

3D laser printing is a general term for additive layer manufacturing, which groups together different processes: Selective laser sintering (SLS), stereolithography (SLA), selective laser melting (SLM) or direct metal laser sintering (DMLS), fused deposition modeling (FDM).

In all these processes, the laser beam scans a layer cross section and lays down successive layers, so it constructs layer by layer an object as the 3D desired shape. The scanning cross-sections are generated from a 3D digital description of the part (CAD file or scan data). The process uses sintering, melting or curing. The material can be small metallic particles, glass powder, or liquid materials as used for stereolithography. The primary advantage of this technique is its ability to create almost any shape or geometric feature especially previously impossible shapes to make. Parts are quickly realized, and are very useful for prototyping tasks.

This process can be faster, more flexible and less expensive when producing relatively small quantities of parts, than molded parts. 3D laser printing provides designers and concept development teams the ability to quickly test concepts, shapes, functions and ergonomics.

Skull prosthesis and maxillofacial (SIRRI)

Airduct for aeronautics and hearing-aid (MATERIALISE)
H. Surface texturing

Laser surface functionalization or texturing refers to the process of using laser techniques to provide a surface with a particular property. The texturing can be obtained by different laser processes as marking, engraving, ablation, micro-machining, and additive manufacturing. This process has several applications in plastic molded goods. Laser micro structuring and texturing using two different laser sources with pulse widths from nanosecond to femtosecond can be applied to generate functional surfaces of high performance components or production of micro replication masters. A wide range of advanced engineering materials can be processed efficiently, for example ceramics, hardened steel, bulk metallic glasses, titanium and nickel alloys. These processes involve machining of freeform surfaces of complex parts directly from 3D models by employing CAD/CAM tools. Some applications of laser texturing/structuring:

- High performance components with friction and drag reduction surfaces
- Tool making, electronic waveguides
- Biomedical devices/implants/stents, dentistry
- Jewelry, watches and high-value accessories

Intersecting trenches generated on stainless steel SS304 3D surface (THE UNIVERSITY OF BIRMINGHAM)

Metal surface texturization (MULTITEL)

Laser structuring (DMG MORI SEIKI AG)

Laser microtexturing of metals (LASEA)
A new laser-based manufacturing process was developed in the last decade and has recently become commercially available. The process is called laser milling. This is a process for direct material removal in a layer-by-layer method. The laser beam is scanned across the surface to produce the desired feature. The number of pulses at each position determines the depth of the feature. In practice the quality of the result is strongly dependent on the choice of laser and the scanning strategy adopted. 3D CAD data is used to generate CNC machining programs. The process is flexible and can be employed in a wide range of applications from one-off part production to the manufacture of small batches. The laser milling process removes material as a result of interaction between the laser beam and the substrate or work piece.

*Siemens star type structure produced by μs laser on copper, diameter 18mm (CARDIFF UNIVERSITY)*

**J. Packaging**

Laser scribing and perforation can be also used in packaging films to produce a selective weakening of the films. It is largely used in the food industry. Perforation of packaging films gives controlled atmosphere packaging to significantly increase the shelf life of fresh products, to release pressure during microwave cooking and also provides an air release during filling process.

*Easy and controlled direction opening (ROFIN-BAASEL Lasertech GmbH & Co.KG)*
K. Summary

The main advantages of laser manufacturing include non-contact tooling, flexibility, more environmental friendliness and very high quality. Laser manufacturing is implemented in several industries in a very large range of applications.

The different laser technologies yield to a large range of laser beam characteristics such as wavelength, pulse duration, energy and power, beam quality, pulse shaping which allow adapting the laser tool to a large range of micro-machining. The possibilities offered with laser equipment for micro-machining are increasing, as shown with the recent processes of surface structuration which have a huge potential. The figure below summarizes different applications and uses of laser machining taking into account the pulse duration and the processing depth.

![Laser applications vs laser pulse duration](ROFIN-BAASEL)
VI. Markets and trends

Good indicators of the laser micro-machining market are the laser markets. Material processing and telecom are the main markets for lasers. Micro-material processing accounts for 24% of the total of the material processing market. Marking accounts for around 14%. Laser micro-machining takes a very large part, almost 40%, of the material processing laser market.

<table>
<thead>
<tr>
<th>INDUSTRIAL REVENUE (US$M)</th>
<th>2012</th>
<th>2013</th>
<th>2014 (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARKING</td>
<td>$320.8</td>
<td>$342.3</td>
<td>$367.6</td>
</tr>
<tr>
<td>y-to-y</td>
<td>7%</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>MICRO MATERIALS PROC.</td>
<td>$564.2</td>
<td>$576.7</td>
<td>$594.5</td>
</tr>
<tr>
<td>y-to-y</td>
<td>2%</td>
<td>3%</td>
<td></td>
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<tr>
<td>MACRO MATERIALS PROC.</td>
<td>$1,425.8</td>
<td>$1,474.4</td>
<td>$1,541.0</td>
</tr>
<tr>
<td>y-to-y</td>
<td>3%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$2,310.8</td>
<td>$2,393.4</td>
<td>$2,503.1</td>
</tr>
<tr>
<td>y-to-y</td>
<td>3.6%</td>
<td>4.6%</td>
<td></td>
</tr>
</tbody>
</table>

*All industrial laser material processing revenues (INDUSTRIAL LASER SOLUTIONS 2014)*

Based on figures from Strategies Unlimited, the prediction of growth is pervasive, with a stronger growth for marking & engraving (45.3% growth from 2014 to 2015) and for laser 3D printing (20% growth from 2014 to 2015). Additive manufacturing is a pretty hot area, and should continue to increase due to decreasing cost resulting from increasing volume and innovations. Processing using fiber lasers and ultra-fast lasers should also increase.

<table>
<thead>
<tr>
<th>REVENUE (US$M)</th>
<th>2012</th>
<th>2013</th>
<th>2014 (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMI/PC BOARD</td>
<td>$184.2</td>
<td>$167.2</td>
<td>$166.7</td>
</tr>
<tr>
<td>y-to-y</td>
<td>-9%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>FINE METAL PROCESSING</td>
<td>$311.5</td>
<td>$323.6</td>
<td>$327.2</td>
</tr>
<tr>
<td>y-to-y</td>
<td>4%</td>
<td>1%</td>
<td></td>
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<tr>
<td>ADDITIVE MANUFACTURING</td>
<td>$11.5</td>
<td>$20.3</td>
<td>$22.8</td>
</tr>
<tr>
<td>y-to-y</td>
<td>76%</td>
<td>13%</td>
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<tr>
<td>OTHER</td>
<td>$57.3</td>
<td>$65.7</td>
<td>$77.8</td>
</tr>
<tr>
<td>y-to-y</td>
<td>15%</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$564.2</td>
<td>$576.7</td>
<td>$594.5</td>
</tr>
<tr>
<td>y-to-y</td>
<td>2.2%</td>
<td>3.0%</td>
<td></td>
</tr>
</tbody>
</table>

*All lasers < 1kW used for micro materials processing (INDUSTRIAL LASER SOLUTIONS 2014)*
VII. Why you should consider using laser for micro-manufacturing?

Following some basic laser choices (type and wavelength of laser, pulsed outputs, etc...) the main challenge is to establish the most efficient way to achieve the desired results. The needs of most clients can be divided into two:

- Can the part be made as designed? This is a technical problem of how to machine something.
- How can the technical solution be implemented in an efficient engineering fashion? This relates to the system for producing multiple parts, repeatably and cost-efficiently.

Solving these two problems generally achieves the objectives of micro-fabrication. In the medical world, products and the associated manufacturing processes must also be considered from a regulatory point of view, but laser processes have proven themselves to be inherently compatible with these demands.

Lasers are widely used across a wide range of markets, and the use is increasing constantly as companies understand the benefits of using laser micro-manufacturing. We encourage you to contact the EcoLaserFact members for a discussion on how your manufacturing may benefit as well.

VIII. Contacts

The report package is led by EPIC – The European Photonics Industry Consortium – which you can contact at any time for comments and questions at carlos.lee@epic-assoc.com.

To learn more about our services, please feel free to visit our website www.EcoLaserFact.eu.

To contact the EcoLaserFact consortium: info@ecolaserfact.eu.
IX. Acknowledgements

The authors would like to thank all companies, R&D center, universities, and clusters who contributed to this report:

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<thead>
<tr>
<th>COMPANY/CLUSTER/R&amp;D CENTRE/UNIVERSITY</th>
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<tr>
<td>EPIC - EUROPEAN PHOTONICS INDUSTRY CONSORTIUM</td>
<td><a href="http://www.epic-assoc.com">www.epic-assoc.com</a></td>
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<tr>
<td>MULTITEL (EcoLaserFact coordinator)</td>
<td><a href="http://www.multitel.be">www.multitel.be</a></td>
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<tr>
<td>KARLSHREU INSTITUTE OF TECHNOLOGIES</td>
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<td>BAYERISCHES LAZERZENTRUM</td>
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EcoLaserFact contributes to a more cohesive EU society as it derives from a cooperation of people from different countries working on common issues that touch the lives of EU-citizens.