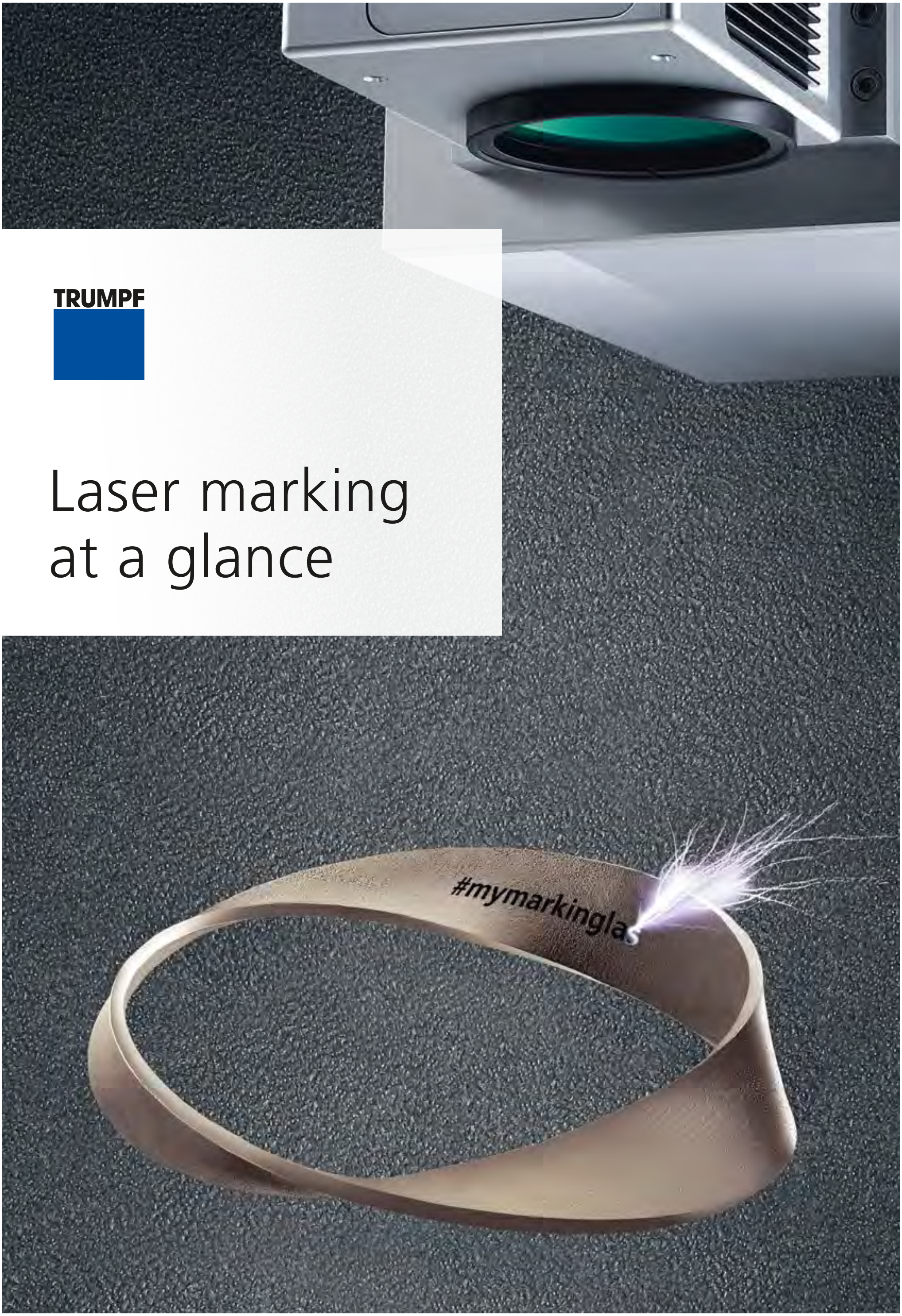
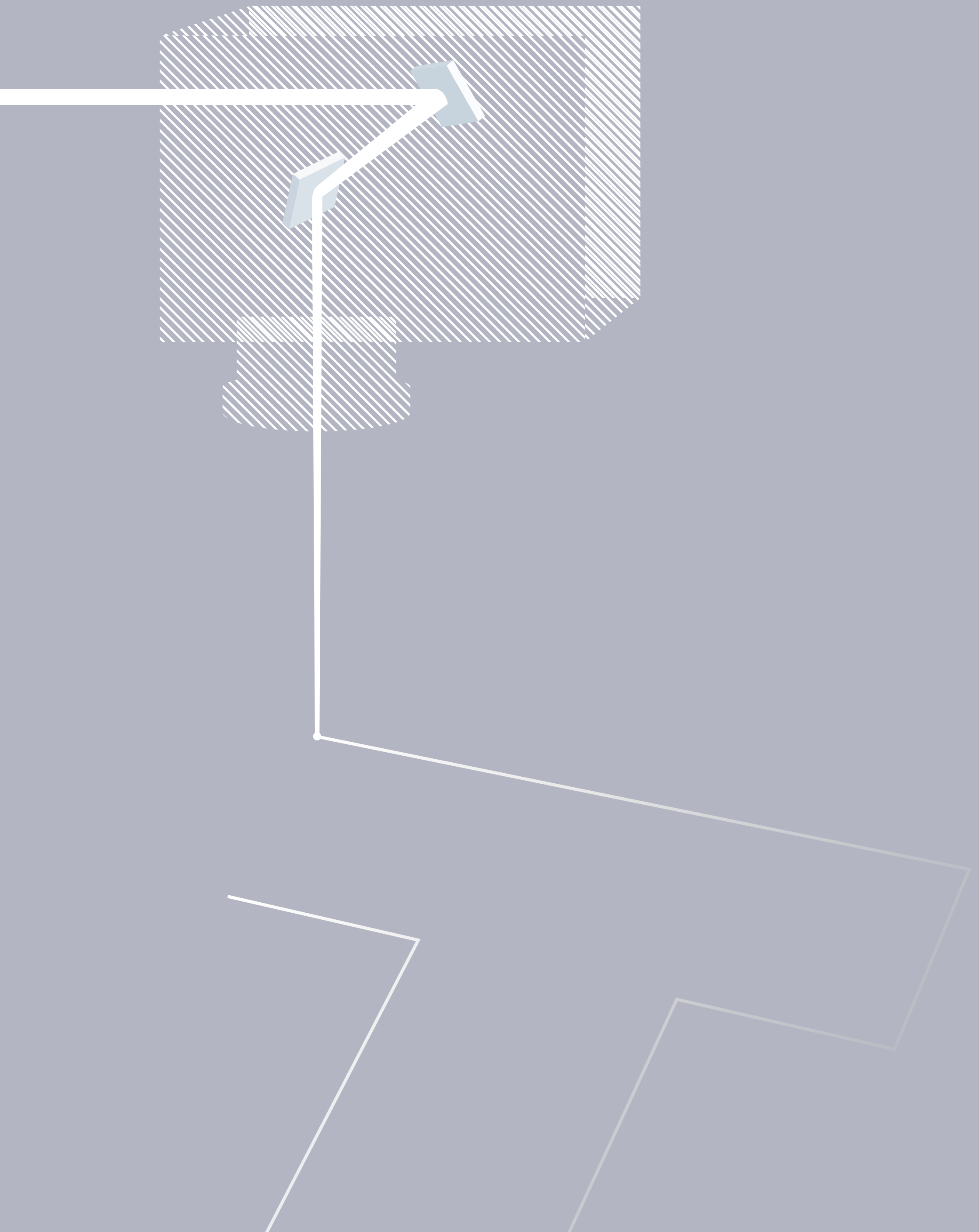
TRUMPF

Laser marking at a glance



Laser marking at a glance

Marking lasers perform more
and more tasks in the industry.
In this manual, you can
find out what role marking lasers
play in the different sectors.
You will learn about the technical
background of processes as
well as laser systems and receive
a guide to practical marking.



1. APPLICATION AREAS AND SECTORS

Nowadays, it is becoming more and more common for industrial markings to be applied with a marking laser. Lasers have established themselves as the marking tool of choice in industry, as they are contactless, highly flexible, easy to integrate, and produce perfect quality. From higher traceability requirements through to the raw materials, counterfeit protection, customized products and the desire to acquire a component that functions as its own data carrier in a smart factory — these are all trends that argue in favor of marking lasers.

It doesn't end there. The application spectrum of pulsed or marking lasers already extends far beyond just marking components; these tools are now conquering new terrain in process preparation and surface treatment.

Laser marking stands out when compared with **conventional marking methods** due to quite a number of **advantages,** which is why it has become a firmly established method within the industry.

The advantages at a glance:

- High level of **flexibility** in the marking geometry
- High marking **quality** (very clear-cut edges)
- High **reproducibility**
- **No tool wear** due to non contact processing (enables high quality at low costs)
- **Low heat input** affects material only minimally
- Easy **integration** into fully automatic production sequences
- **No preparatory work or reworking** necessary
- Can be used on a **wide range of materials** (ceramics, metals, plastics, etc.)
- Very **fine structures and small markings** possible (into micrometer range)
- Option to mark **large surfaces**
- Can reach areas that are **difficult to access**
- High **marking speed**
- **No** expensive and potentially environmentally damaging **disposable materials** necessary, e.g. ink
- **Environmentally friendly** and waste-free

THE AREAS OF APPLICATION AND APPLICATION BENEFITS OF MARKING LASERS IN INDUSTRY ARE MANIFOLD:

Easy and permanent marking of a component, whether on the component itself or via a nameplate.

Marking lines and points.

Apply processing data as machine-readable codes for automatic further processing in a smart factory.

Function-specific markings, e.g. legends on switches, key-boards, tachometers— day-and-night design also available with illumination function.

Product labeling by applying logos and names …

… or design elements.

Identification through unique device identification (UDI) code for continuous traceability, in view of regulations around product liability.
↓

←
Precise component identification, e.g. via a Data Matrix Code.

→
Counterfeit protection through markings, e.g. using customized symbols or logos.

→
Customization, e.g. by applying the customer's name on everyday items, such as cosmetic products, seat covers …

Creation of functional surfaces through structuring.
↓

←
… or even on identification documents.

→
Preparation for subsequent process steps, e.g. welding or bonding: cleaning, ablation, structuring of surfaces.


Mobile Marker
max. 500 kg
TRUMPF
TruMark 5000

1.1 TRACEABILITY

One of the reasons why it is important for industrial companies to mark their products is that **product liability laws and certifications** have become stricter. In the case of rejects and fault costs due to faulty supplier components, the costs can be legally passed on to the party that caused them. This compels the industry to document which elements were processed and to assign them to each order and component accordingly. Manufacturers of **security-related components** in particular — such as suppliers for the automotive and aerospace industries, for medical technology, and also increasingly for sensor technology as well as electronics/electrical engineering — are obliged to be able to report at any given time which of their individual components were used within complete systems. Only a permanent, easily readable marking can meet these requirements.

The requirements with which an industrial marking must comply are:

- **Permanent** marking
- **High contrast** of the marking compared with the base material for easy machine readability
- High **flexibility** in content and form
- **Material-conserving** marking
- Integrating the marking into **documentation systems,** e.g. by documenting measurement data directly on the component
- Entirely **cost-efficient** system

Reasons why products should be marked to ensure traceability:

- Clear **identification** of components from incoming goods through to outgoing goods
- Identification of **faulty components** from particular batches
- **Documentation** of statistical process and quality control
- Storage of working results and measuring data in one **database**
- Reading out and retrieval of **processing programs** (production control)
- **Protection** of original products **against counterfeits**

WHAT TYPES OF MARKING ARE THERE?

Conventional markings on industrial components can be divided into design and text markings as well as one-dimensional (only coded in one direction) and two-dimensional (coded in x/y direction) types of coding. There are **four principle types:**

Free text

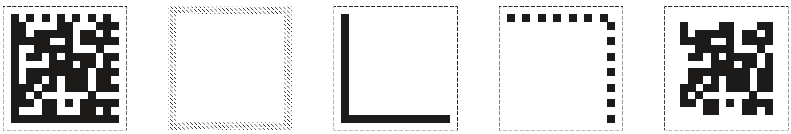
There is a huge spectrum of application possibilities for free text in industry — from serial numbers and nameplates through to the phrase "Made in Germany". It is in terms of variables and serial numbers in particular that the laser comes into its own, as these can be marked in one continuous automated process. In principle, it is possible to use any font, but there are also laser-optimized fonts that don't intersect, which means that any risk of scorching can be avoided. These standard fonts have been designed specifically for technical applications such as laser marking, although importing TrueType fonts (such as the Windows standard fonts) also produces good results, as does the use of any symbols or special characters.

Bar code

A bar code consists of a row of lines and gaps of varying thicknesses. The order is determined using a binary coding logic. This is how data (often rows of numbers for logistics processes) can be prepared for being read by a machine. The data is collected using a bar code scanner or a camera, and any further processing is carried out electronically. Creating the marking with a laser ensures maximum readability.

Data Matrix Code

The Data Matrix Code is probably the most well-known machine-readable 2D code. It was developed by the US company International DATA Matrix in 1989, in order to include more information into a code than had been possible with bar codes so far. A Data Matrix Code consists of five elements: two continuous lines (solid border), two broken lines (broken border), the actual data cells (data storage) and four light fields that function as a quiet zone around the code. Most Data Matrix Codes are square, although you also find rectangular ones.



Data Matrix Code	Quiet zone	Solid border	Broken border	Data storage

Design elements and graphics

Graphics are often used for decorative purposes or for applying a company logo onto a component, for example. The complexity of these types of graphics often varies quite significantly. As a general rule, it is possible to import them in any conventional vector-oriented graphic format (DXF/DWG, HPGL, IGES, etc.) and pixel format (BMP, JPG, etc.). The software used to create marking content is equivalent to a fully fledged CAD graphics program — for translating graphics content into laser programs.

Right:
Customized lipsticks using varnish stripping, and design possibilities on blue anodized aluminum.

Below:
Color annealing on titanium.

Graphic applied to a car headrest using a marking laser.

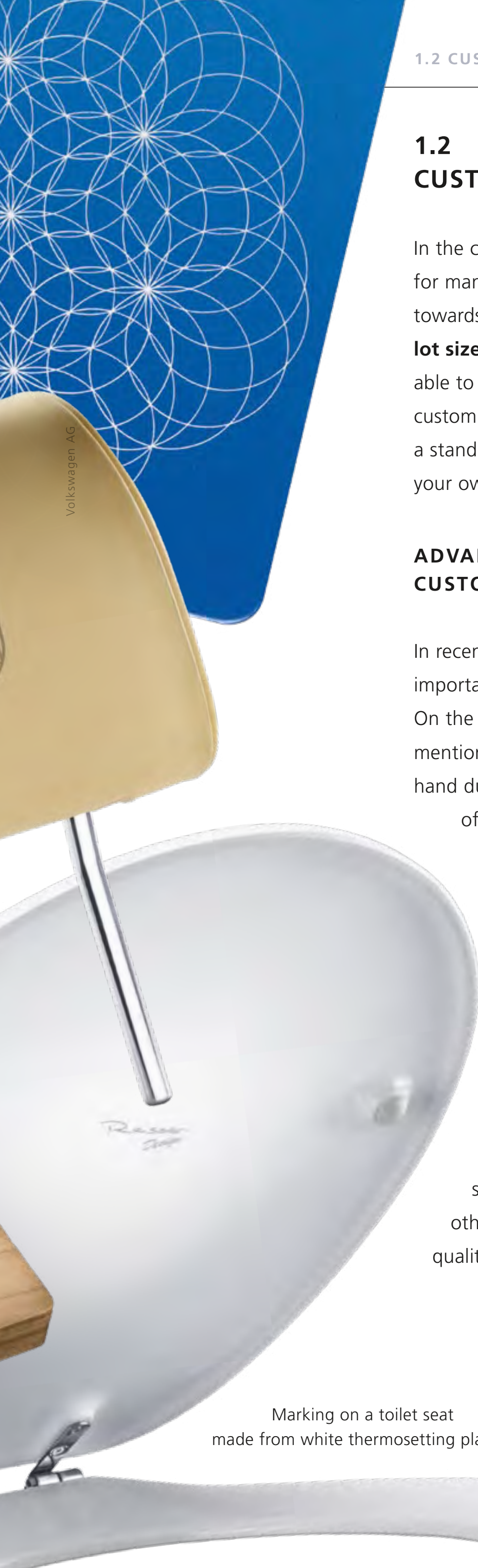
Designs on fabric and wood.

1.2
CUSTOMIZATION AND DESIGN

In the current era of Industry 4.0, flexibility is a top priority for many industrial applications. Everything is trending towards **as much customization as possible** and towards **lot size 1**—which means marking processes have to be able to keep up. Laser marking is ideally suited for etching customized features on products manufactured in a standardized manner—be these design elements or your own name.

ADVANTAGES OF LASER MARKING FOR CUSTOMIZATION AND DESIGN

In recent years, lasers have become established as a highly important tool for marking industrial production goods. On the one hand, this is a result of the advantages already mentioned with regard to **flexibility,** and on the other hand due to the further developed **user-friendliness** of marking systems. There are practically no limits to the design possibilities, without having to compromise on quality. Thanks to easy integration into the manufacturing chain, it is also possible to incorporate customization options into the series production process. Users can apply their designs to a **wide range of materials.** The spectrum of possibilities becomes even greater if you incorporate additives into plastics or use ultra-violet lasers. As a result, using a laser marking system means you can potentially replace several other processes in one go—and achieve better quality at the same time.



Marking on a toilet seat
made from white thermosetting plastic.

1.3 PROCESS PREPARATION AND SURFACE TREATMENT

Using short-pulse lasers for tasks other than classic marking applications has been the norm for quite a long time. Thanks to their robustness and flexibility, they can also be used for entirely different applications within the industry. The two most frequent areas of application in terms of marking are the treatment of surfaces for preparing subsequent joining processes and the functionalization of all types of surfaces.

WHY USE MARKING LASERS FOR PREPARING JOINING PROCESSES?

Functional layers—such as insulations or coatings for protecting surfaces—can be challenging for joining processes like laser welding, soldering, and bonding. Although these can sometimes be counteracted with corresponding parameterization, this has a negative effect on the quality of the joining process. During the welding process, the raw material of the functional layer combines with the molten metal and, thus, disturbs the process. This can lead to **spatters** and **inclusions.** The consequences are sometimes similar in the case of dirt layers. In the absence of an integrated laser process, it becomes necessary to carry out **complex pre- and postprocessing** such as chemical cleaning or sandblasting in order to guarantee quality.

In this situation, a marking laser serves as the ideal preparation tool. With short, powerful pulses, it can remove protection, oxidization and functional layers, oil, grease, and other contaminants from components just from the areas that need joining. This method of localized cleaning makes the whole process very fast and ensures that functional protection layers beyond the seam points remain intact. The welding process runs more **homogenously, faster, and with absolute repeatability.** If a marking laser is used in joining preparation, it can also apply a Data Matrix Code or serial number to the component simultaneously. This takes care of both cleaning and traceability in a single step.

At a glance—the advantages of using a marking laser as a complementary tool in joining processes:

- **Easy integration** into fully automatic production sequences, as all sequences are carried out using computer control and because data can be transferred very easily via interfaces.
- **No** further **preparatory work or reworking** necessary
- Option to mark **large surfaces**
- Reach areas that are **difficult to access**
- High **processing speed**
- **Environmentally friendly** process

WHAT TYPES OF PROCESS PREPARATIONS AND SURFACE TREATMENTS ARE THERE?

Cleaning for welding preparation

With short and ultrashort pulses, marking lasers remove unwanted coatings from seam points with utmost precision and without affecting the surface underneath. This leads to both efficient processes and high-quality results in the subsequent welding stage.

The advantages of welding laser-cleaned components include:

- Higher welding **quality**
- Significantly **fewer spatters** during the welding process
- **Fewer pore inclusions** during welding
- Significantly **smoother welding process**
- Local cleaning in a matter of seconds **precisely** at the seam points
- High **reproducibility** and uniform cleaning result on the surface
- Replaces time-consuming cleaning measures such as baths or sandblasting, and can operate entirely **without chemicals** or other additional aids, residue-free

Removing grease and oil

In some instances, production-related grease and oil can collect on components. It is advisable to remove these layers from the seam points to ensure a smooth and spatter-free welding process and to guarantee high-quality results. The laser light from the marking laser vaporizes the dirt, affecting the surface just very slightly.

Example

A typical area of application is the removal of oil residue from **tubes.** In just a single pass, the marking laser can reliably vaporize the oil from all around the two ends of the tube. The steam is transported away via a suction device and there is no need for using compressed air.

Removing corrosion and oxides

Corrosion and other forms of oxidation on the surface distort the visual appearance, hamper any further processing (e.g. joining through bonding or welding), and restrict the functionality. To combat these effects, the material can be vaporized with a laser and sucked away. You simply adjust the laser power to the degree of corrosion and, if necessary, pass over the area several times. A single pass removes corrosion of up to 100 µm thick. Using a scanner system, the removal rate is typically up to 30 cm^2/s.

Cleaning molds

Using a marking laser to clean molds enables the extensive vaporizing of just the process residue, and without wearing away the mold. Due to laser cleaning, the industry no longer requires the use of cleaning methods that are either energy-intensive, problematic, or cause wear, such as chemicals, dry ice, brushes, and sandblasting.

Example (1)

Laser cleaning can be used in the manufacturing of **tires,** for example. In tire manufacturing, rubber is vulcanized in a tire mold using high pressure at 170 °C. When removing the tire, rubber residue and other separating agents stick to the negative profile of the mold. With the application of a pulsed laser, you can vaporize this residue of varying thickness in these geometrically complex forms on a regular basis.

Video: "TruMicro 7050 — laser cleaning" www.trumpf.info/4lvxjy


(1)


(2)

Decoating

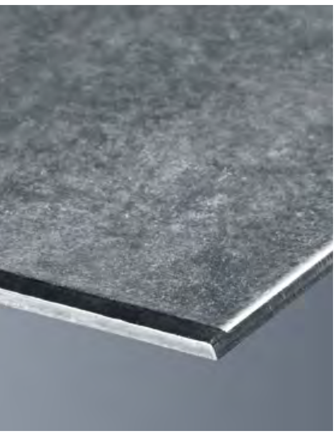
In **welding,** galvanizing and applying nickel plating and anticorrosion layers can lead to spatters and pore inclusions. To ensure that the process is smooth and to guarantee high-quality results, it is advisable to remove these layers from the seam points. Following the same principle, these types of layers can also be removed locally before **soldering.**

Example (2)

Deep-drawn, custom-cut steel sheet blanks, made up of different grades of material and sheet thicknesses **tailored blanks**, are protected against corrosion with a 10 to 20 μm thick layer of **aluminum-silicon alloy (AlSi)**. During welding, the protection layer causes spatters and porosity, which means that the connection is not necessarily secure. For this reason, it nevitable to target and ablate the AlSi layer from just the seam points, without affecting the base layer material underneath. Using short laser pulses makes it is possible to ablate the layer with a processing speed of more than 5 cm^2/s.

Example (3)

In the automotive industry, a bevel gear is welded with the gearbox housing **(powertrain)** for the axle differential. Over its lifespan, this component is required to transmit immense forces — and the demands placed upon the laser welding process are just as high. Spatters and pore inclusions from the protective phosphate coating on the bevel gear can make the component unsuitable. For that reason, shortly before welding, a marking laser vaporizes the phosphate coating and any oil layer right at the seam point, using scanner optics. As the bevel gear is rotationally symmetrical, the component is turned during the decoating stage. Although the laser remains rigid during the process, the scanner allows the beam to oscillate, so that the desired area can be covered.



(3)

Stripping

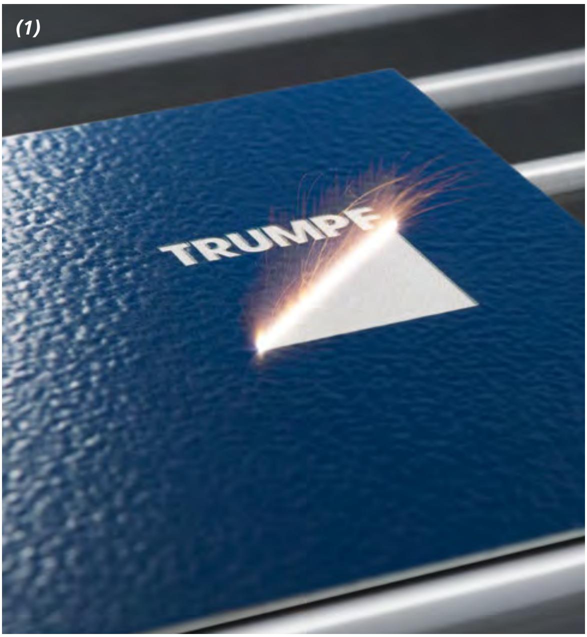
Stripping involves the local or complete removal of color or paint, without affecting the surface underneath. Stripping serves to increase electrical conductivity, to prepare a component for a subsequent welding or bonding process, to create a window in the case of transparent components, or to prepare a component for a recoating.

Example (1)

Sometimes it is only by removing the paint that a mark is created, for example on **powder coatings**. The laser removes the powder coating up to the base material.

Roughening

Roughening involves optimizing surfaces for adhesives, injections of plastics, or thermoplastic. Laser pulses create a relief structure on the surface of the material, allowing these materials to unite, thereby creating a secure bond. As a result, the roughened surfaces support joining techniques that are of particular importance for lightweight design and composite materials, such as CFRP: **bonding** and hybrid **form-locking bonds** made of metal and plastic.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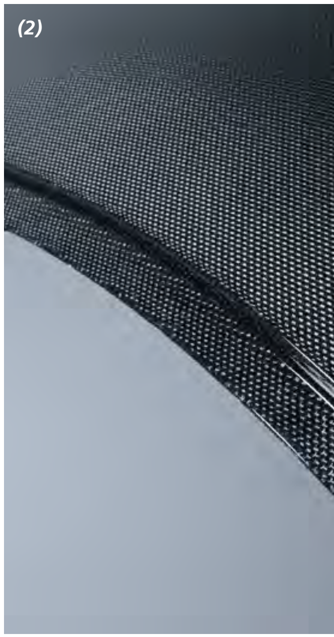
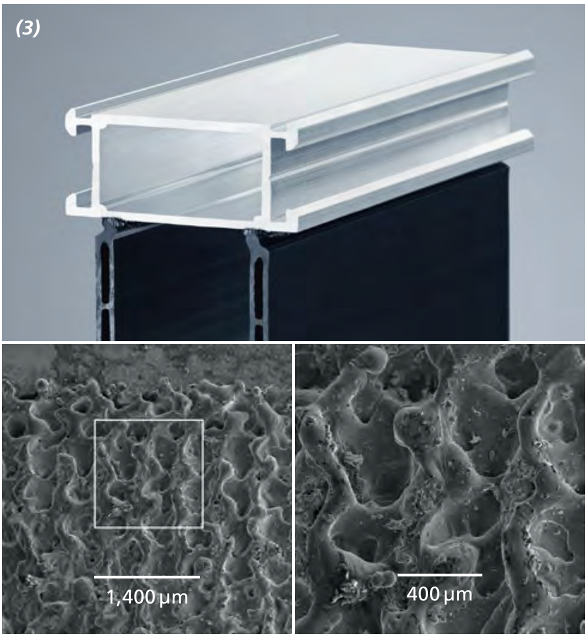

(2)

Example (2)

The bonding of **fiber composites** such as CFRP involves improving the adhesive properties of the materials, without damaging the sensitive carbon fibers. In this case, the laser's key advantage is its precision: with a meticulously precise pulse configuration, the laser light activates the surface in just the required area and cleans it with one pass—and only to the required depth.

Example (3)

Form-locking **bonds between metal and thermoplastics** are an important element when it comes to lightweight design. They are created through a high-power nano-second laser preparing the surface of the metal joining partner for adhesion. The laser pulses create indents through engraving and material bulging—even on large adhesive surfaces. Subsequently, the metal joining partner, or even just the joining area, is heated up (also possible with a laser for example). The thermoplastic material flows through the indentations. If it is cooled, the result is a secure bond, which can also be optimized in terms of the later flow of force. It is also possible to use this method for joining fiber-reinforced plastics with metal.



CHANGING TRIBOLOGICAL PROPERTIES

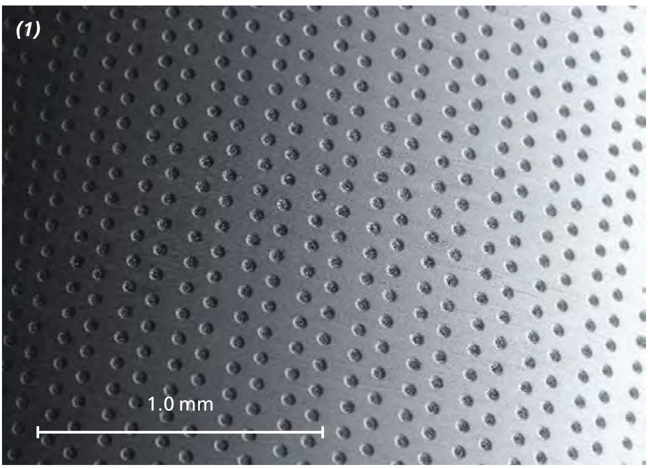
With laser pulses, it is easy to engrave tiny structures into the material, either to reduce friction (for reducing wear or lubricant consumption) or to actively increase friction (for antirotation locking or for a higher surface pressure). In this case, the laser-induced structures are either cells, pockets, lines, or spirals.

Example (1)

Typical application areas of laser structuring for reducing friction include the running surfaces of cylinders and the bearing seats of **shafts**. In this case, grease lubricant cells are applied. It is also possible to structure the inside of tubes, whereby the laser light shines diagonally into the tube, structuring the surface. This is facilitated by the step-by-step adjustment of the focus level via internal defocusing.

Example (2)

A typical application area of using laser structuring for increasing friction is the **bearing seat of a connecting rod** in a drive. The ridge structure increases the surface pressure of the bearing shells at the large end of the connecting rod and decreases the risk of slipping at high torques.



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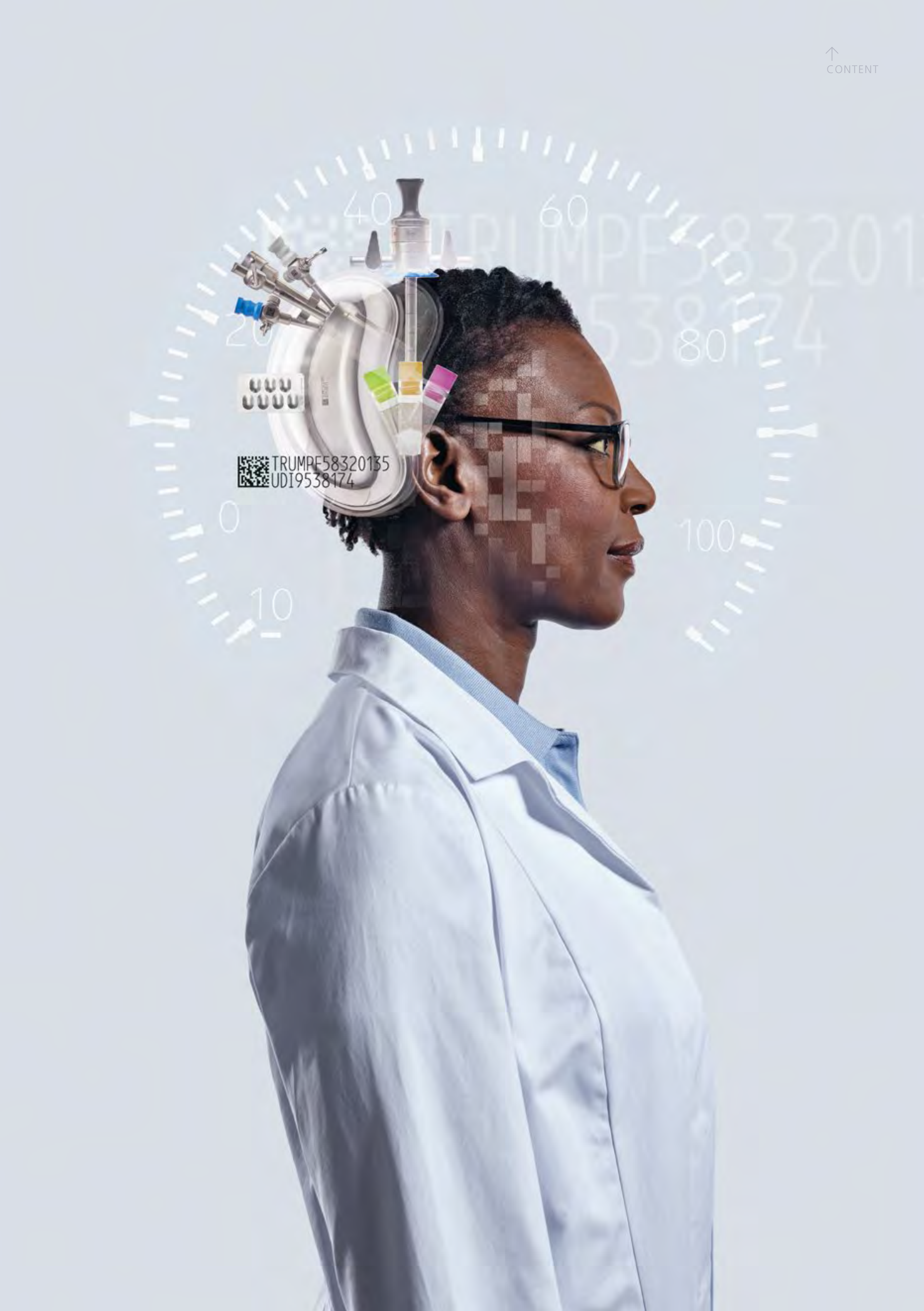
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1.4 MEDICAL TECHNOLOGY

PARTICULAR CHALLENGES OF THIS SECTOR

Qualification

Quality management in the medical technology industry is strict. Amongst other things, it also comprises validating any process that occurs within the production process. One part of this validation stage involves qualifying any equipment used — known as equipment qualification (EQ). Every piece of machinery, even if it was only used on the periphery of the production process, is checked according to the strictest technical standards. And of course, this is also the case for marking lasers. An equipment qualification is usually divided into the following qualification stages:

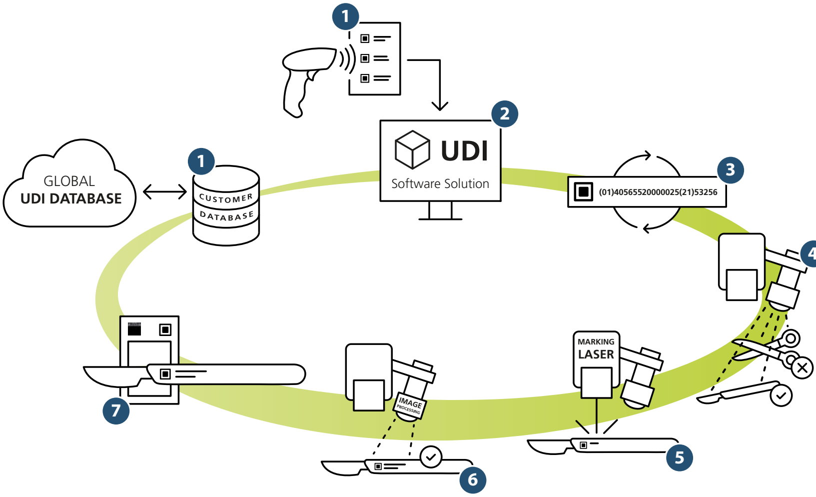
- **Design qualification (DQ)** outlines the requirements the machinery needs to comply with and how this is to be achieved. This is often illustrated within specifications.
- **Installation qualification (IQ)** verifies whether a machine complies with the documented requirements, such as scope of functions, and whether it has been installed correctly and all necessary accompanying documents are present.
- **Operation qualification (OQ)** verifies whether the machine functions correctly within the selected work environment. This stage includes checking that the system, including all its individual settings, function according to the operational specifications.
- **Performance or process qualification (PQ)** checks whether the machine carries out the process within the process boundaries in a statistically safeguarded manner, according to the specifications.

Manufacturers like TRUMPF can support customers with these qualifications, by offering standardized packages for the IQ and OQ, for example. This gives the user the advantage of receiving the necessary documentation straightaway.

Implementing the UDI requirements

Important markets like the US, China, and the EU place high demands on the traceability of medical technology. The key word here is **unique device identification (UDI)**. Although the details of regulations vary, one thing is always clear: it is mandatory for medical products to be marked with a code that contains any relevant information (e.g. manufacturer, batch number, production date).

CONTENT



Steps to obtaining a UDI-compliant marking

Step 1: The software is connected to databases. It is also possible to input information into the system via external manual scanners, for example.
Step 2: An interface processes the input data and, for example, connects databases or control systems with the marking laser.
Step 3: The UDI module creates the regulations-compliant code using the UDI-relevant data and individual extensions.

Step 4: An image-processing device recognizes the component and its position automatically. The software transmits the information to the control, which places the marking in the correct position.
Step 5: The laser marks the workpiece.
Step 6: Subsequently, automatic quality control is carried out via a camera, which reads and evaluates the quality of the marking.

Step 7: The marked data is matched with the database and saved for documentation purposes —with additional information if desired.

Video: “UDI-conform laser marking”
www.trumpf.info/tv7f8w

Video: “Success story of our customer Miethke”
www.trumpf.info/0hyjw5

UDI marking on surgical stainless steel and laser marked tube.

Traceability must be guaranteed across the entire supply chain and the entire lifespan of the product. The code should be readable for both machines and humans. It is essential that the user has marking software that can provide all of the necessary features. Therefore, it must be able to master common standards such as GS1, HIBC, or ISBT 128 and include the necessary interfaces for importing all of the required data and, if necessary, also be able to reexport these for any relevant database.

APPLICATIONS

Black marking with ultrashort pulse lasers (USP)

To meet the quality requirements that legislators around the world place upon medical technology — providing **permanent readability** and **corrosion resistance** — black marking has become the process of choice. Black marking involves using a laser to apply a particularly dark, contrastive marking to the surface, without removing any of the material. The ultrashort laser pulses create structures that are just nanometers wide. The rough surface — known as nanoripples — ensures that the distribution (directed reflection) of the light is reduced and effectuates a deep blackening of the marking, which is clearly visible from any angle.

Technical background of black marking in chapter 2.1

The **advantages of black marking** at a glance:

- High **contrast** of the marking
- Consistent **quality** with large batch sizes
- High **durability** (even if sterilized hundreds of times) and clinical preparation
- **Corrosion resistance**
- **Visible from any angle** (even in bright operating room) through matt marking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123448733
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300

1.5 AUTOMOTIVE

PARTICULAR CHALLENGES OF THIS SECTOR

One of the automotive industry's key issues is using appropriate markings to guarantee seamless traceability and ensure the clear identification of components for protection against counterfeit. These are application areas in which marking lasers are often used, as they comply with the demands of the manufacturing requirements in this industry. These include:

- The **pace** is extremely high, as batch sizes can be very large, depending on the component. As a result, marking processes have to be **highly productive** but still run with precision.
- To deliver **consistently high quality,** the marking processes have to be stable and reproducible. The required tolerances are minimal and have to be complied with unconditionally.
- The **availability** and **service life** of the laser should be high, even if a machine has been shifted a number of times, so as to recoup the often comparatively higher start-up investment costs.
- Many automotive components are manufactured under difficult conditions, e.g. within the immediate proximity of foundries. As a result, the means of production must be able to deal with **environmental factors** such as high temperatures.
- In addition to a high degree of flexibility, **the user interface has to be easy to use and intuitive.** It must also be possible to carry out the set-up of different processes quickly and, ideally, without external assistance. Furthermore, less well-trained operators should be able to handle marking lasers reliably.
- Automotive companies are international companies with manufacturing processes that are spread out across the globe. This means that the **service** of their machines should be ready to react quickly and purposefully in any country.
- Long-term **development partnerships** between manufacturers and system providers give rise to positive synergy effects.

Traceability, protection against counterfeit process preparation, and design are the areas of application of marking lasers.

CONTENT

APPLICATIONS

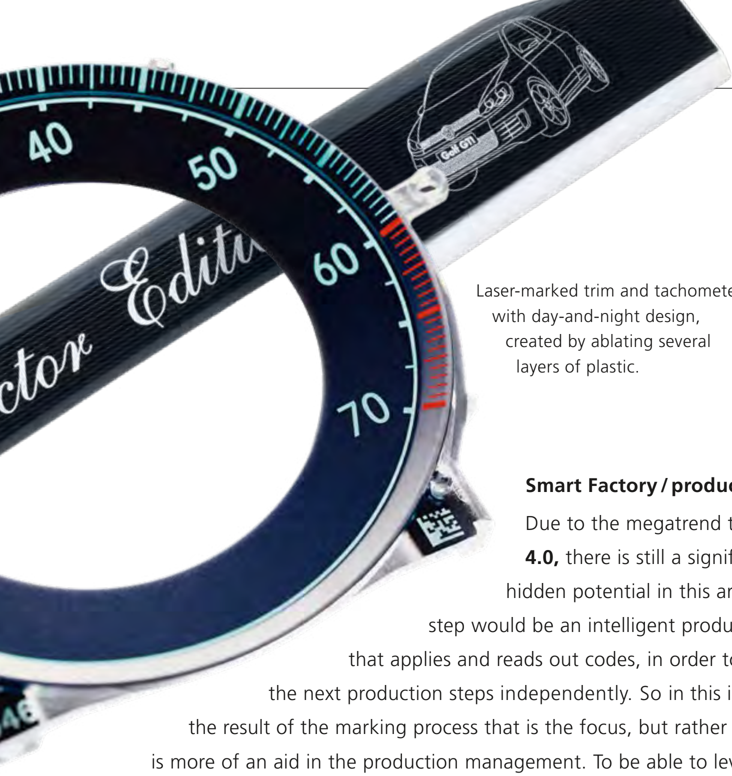
Clear labeling for traceability and protection against counterfeit

The complex topic of traceability brings with it several application examples from the automotive sector. The one encountered most frequently is surely the application of **Data Matrix Codes (DMC),** although **1D bar codes** are also still used. The application of **serial numbers, texts, logos,** and **certificate seals**—intended for component identification—also belong to the core applications in terms of traceability.

The processes that are generally used for this are engraving and—depending on the material—annealing or foaming, and color changing. A typical example is light/white DMCs applied onto dark plastic surfaces.

This is the method used for marking almost every component in a vehicle. A well-known example of this is the **vehicle identification number (VIN)**, which has a clear identification purpose. In order to protect against manipulation, the VIN is applied to several areas of a vehicle and is always engraved to at least 300 µm conforming to standards, which ensures that it is readable at all times. A challenge for the marking process is that engraved areas are usually painted over afterwards, which is not allowed to impact negatively on the marking quality. A great advantage of the laser here is its non-contact use, and therefore freedom from wear, in comparison to mechanical processes such as needle engraving. Using lasers, peripheral devices such as robots are not subject to strain and their life is greatly extended. A further example for a similar type of marking is shift stamping. Shift stamping involves engraving data about the component and the shift onto any part that comes out of the press plants, and is how an even larger quantity of data can find its way into a vehicle. What all of these points have in common is that handling the production data can be made more efficient by implementing a holistic approach. In this regard, modern production software and databases contribute a vast number of useful functions, which makes handling the data much easier.

Laser marking on headlamp housing.



Laser-marked trim and tachometer with day-and-night design, created by ablating several layers of plastic.

Smart Factory / production management

Due to the megatrend towards **Industry 4.0,** there is still a significant amount of hidden potential in this area. The next logical step would be an intelligent production process that applies and reads out codes, in order to be able to control the next production steps independently. So in this instance, it is not the result of the marking process that is the focus, but rather the marking is more of an aid in the production management. To be able to leverage all of the opportunities afforded by intelligent production, numerous marking lasers need to be integrated into the production chain, ideally with as little hassle as possible.

DESIGN AND CUSTOMIZATION

Above and beyond producing components that have a functional role, lasers also play a huge part in automotive manufacturing when it comes to customization. Some manufacturers give their customers the option of adding individual embellishments to their car, for example by adding **design elements** to headrests, interior doors, glove compartments, and other areas. This is usually achieved via color change. In the premium sector in particular, a significant number of decorative markings are applied to **leather, wood, or fabrics.** The huge challenge in this regard is having to work with natural materials — grained wood, for example, is not the most even material for applying markings. The solution is to use intricate parameterization, so that the desired result can be achieved without damaging the material.

However, there are other design elements — also applied with a marking laser — that serve a particular purpose. This includes the day-and-night designs of operating elements, such as tachometers or switches.

In any case, regardless of whether the designs are a decorative addition or have an optimization function, it is obligatory for the marking process to have stable process parameters and tight tolerances.

PROCESS PREPARATION AND SURFACE PROCESSING

Marking lasers can be used for many purposes other than the actual marking process:

- Cleaning and ablation for joining preparation
- Structuring for bonding and coating preparation
- Creating tribological surfaces
- Roughening for metal-plastic bonds in lightweight design

Electromobility

Due to the increasing demand for electromobility, manufacturers of electric motors are looking for more productive processes that are easy to automate. This is why short-pulsed lasers are being used more and more in this area.

Coating preparation

When battery cells are filled, there is the risk that battery acid and anode or cathode materials will leak and cause contamination. A laser can clean and structure these areas in just one process step. This allows any subsequent coating processes — for electrical insulation for example — to run smoothly.

Stripping hairpins

An important area is the construction of **stators:** instead of winding copper wire around the individual stator grooves — as was often the case before — manufacturers have started embedding rectangular copper rods (called "hairpins" due to their shape) into the entire groove, using compressed air, and then contacting them via laser welding.

The copper rods are covered with an insulation coating, which requires ablation at both ends locally **(hairpin stripping)**. Using marking lasers to do this is a far superior method than mechanical processes like planing and milling and can be up to 80% more productive. In the case of insulation coatings that are transparent for the laser, it penetrates the insulation and sublimates a small part of the copper surface. The gas pressure that builds up removes the insulation material in one clean swoop **(blast-off)**.

CONTENT

Hairpins stripped for electric motor using short-pulse laser.

Activated surface.

In the case of a nontransparent coating, the marking laser simply ablates this layer by layer. Either way, the result is an area that is perfectly prepared for welding.

New applications in battery manufacturing

In battery manufacturing, marking lasers step away from their usual remit and can in fact be used as cutting and welding lasers. This involves cutting the most delicate of metal films, such as anode or cathode films (coated aluminum or copper films), as well as other materials, with a minimal heat-affected zone and as sparingly as possible. Welding also requires working with utmost precision, in order to avoid penetration welds on the sensitive contacts and to prevent the workpiece from deforming.


600 V AC
250 V DC
125 V DC
10 AMP
0,25 AMPS
0,5 AMPS

1.6 ELECTRONICS

PARTICULAR CHALLENGES OF THIS SECTOR

The particular demands in electronic applications make the case for the increased use of marking lasers:

- Electronic components are very sensitive. **Process reliability, calculated energy input,** and **adhering to tolerances** are therefore imperative.
- Electronic components are exposed to extreme conditions, which means that markings need to be highly **durable.**
- Electronic components consist of different materials, which requires the use of **different wavelengths, pulse durations,** and **power classes** to ensure that the most appropriate beam source can always be used for the right process.
- Electronic components are often produced in large quantities. As a result, **productivity** is extremely important and reliant on lasers that are both **robust** and have a **high uptime.** They should also be as **compact** as possible and be equipped with several **interfaces** for **flexible** fields of application.

APPLICATIONS

Marking

In the electronics sector, components are always **marked with a Data Matrix Code,** which is the most frequent way in which marking lasers are used in this area. This involves marking different types of materials that have different requirements, using a number of different processes.

Marking lasers are also used in electronics to apply functional markings, such as nameplates, **CE marks, and batch numbers.**

DESIGN AND CUSTOMIZATION

To date, apart from the manufacturer's logo, design and customization have only played a small part in the manufacturing of industrial electronic components. Functional markings are more important when it comes to mass-manufactured products, such as plugs, cables, and switches. Nonetheless, when there is a call for decorative elements, marking lasers are also the tool of choice in the electronics industry. The recommended product for this type of application is a UV laser, as it creates the marking using a photochemical effect instead of just heat input. This method also enables markings to be applied to flame-retardant materials.

CONTENT

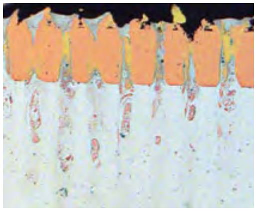
PROCESS PREPARATION AND SURFACE TREATMENT

You can also use marking lasers in production steps in a manner that you might never have guessed was possible, such as preparing all manner of materials for joining. The laser’s task in this case is the **roughening, structuring, or cleaning** of surfaces, as joining partners prepared in this way adhere together much better.

Marking lasers for joining

A similarly new application in the electronics sector with a vast amount of potential is using nanosecond-pulsed marking lasers for welding. The short pulses allow you to join sensitive and thin components such as **metal films** more or less without any heat input, and consequently without any distortion or deformation. At the same time, using a marking laser for joining processes permits a high degree of conductivity. In battery manufacturing, this is exemplified by nano-pulsed marking lasers applying several pulses one after the other to a weld point. At a microlevel, it is possible to tell that this is no common weld (no intermetallic phases), but rather the pulses generate a type of mini hook-and-pile fastener (= form fit), enabling the joining partners to join together mechanically, and any contact resistance is kept to a minimum. In this way, contacting different types of metals (e.g. aluminum with copper) does not pose a problem, and metal films and membranes can be joined without becoming distorted.
Furthermore, it is also possible to cut films with a laser.

Right: Laser markings on different levels on a protection switch.



When joining metal films, nano-pulsed marking lasers create a type of mini hook-and-pile fastener rather than the conventional metallurgic melt bond. This prevents the occurrence of brittle inter-metallic phases when different types of metals are joined.

Reliable product identification using a marking laser on different electronic components — even when space is scarce.


200
150
250
275
100
50
Jeans
BabyProtect
Shirts 15 min.
Sport
10 min.
20 min.
40 min.
herz
apfel
hof
.de

1.7 WHITE GOODS AND CONSUMER GOODS

PARTICULAR CHALLENGES OF THIS SECTOR

You'll be hard-pressed to find a material that can't be marked with the right kind of laser. As a result, you see lasers being used for marking in all manner of application areas. Quite often, the challenge is simply in identifying them.

- The marking fields can sometimes be **very small** — for example in the case of watches — but also **very large** as in the case of washing machines.
- **Lot sizes also vary** when marking products that are mass-produced, i.e. white goods or household objects such as pots, ensuring high productivity and the ability to integrate the marking process into production lines is essential.
- **Customization** is a megatrend that has taken hold of the consumer goods industry in particular. Customized products, such as jewelry, mobile phones, and bags, are often produced in **lot size 1,** which is an ideal field of application for the highly flexible laser tool. This enables the creation of entirely new business models, such as the immediate marking of the customized data that consumers want to have on their products. For this, the laser can extract the data directly from the database, e.g. from the online shop, and then apply it to the product.
- Consumer goods are in constant use, and this is why it is essential to ensure that markings are of excellent **quality.** Price is also a factor in this sector: The laser's high degree of flexibility, energy efficiency, and wear-free operation without the need for disposable materials convince in this respect, too, and in principle, the up-front investment costs are quickly recouped.

Markings on food, kitchenware, and showerhead.

APPLICATIONS

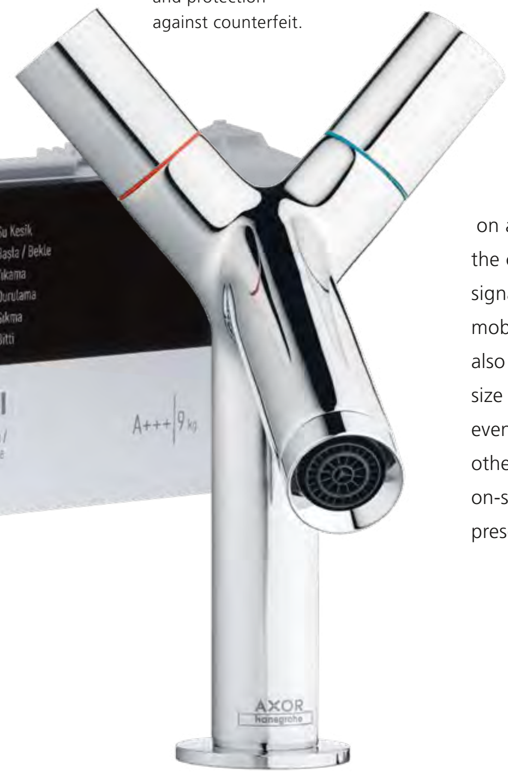
Usability, identification, and counterfeit

Probably the most common application in the consumer goods area is **functional markings** that make a product easier to use, or markings for **identification.** At the moment, consistent traceability of household devices and consumer goods are seldom a requirement. However, **QR codes** and **Data Matrix Codes (DMC)** are gaining in importance for another reason: quite a number of everyday items are becoming smart and these DMCs can store a significant amount of information. From quick access to the online operator's manual through to

Markings on a washing machine and vacuum cleaner button, which assist the user in operating the products.

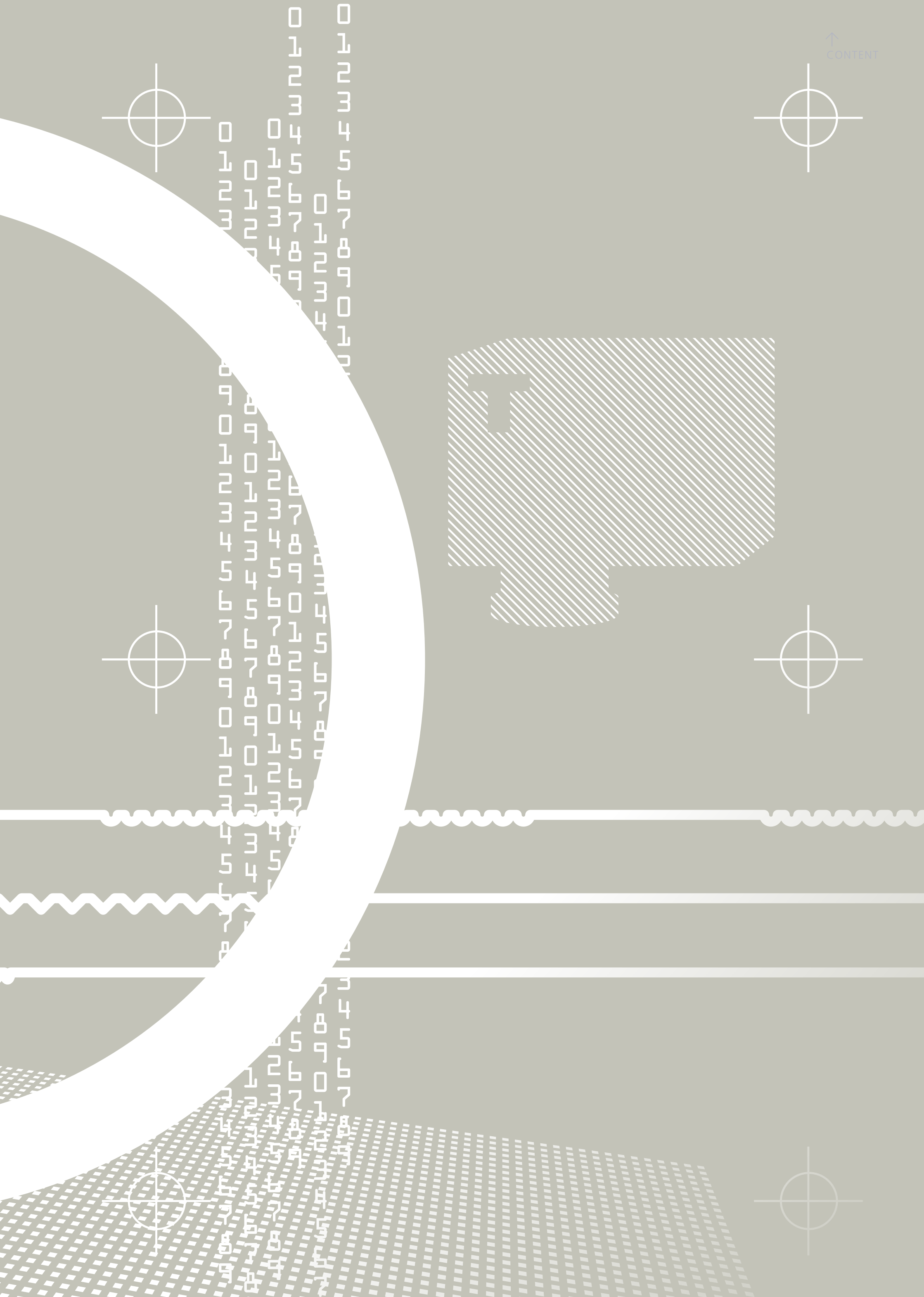
service-related notifications. Machine and smartphone-readable markings that are linked to a database may be the solution. Markings in the material or in particular locations that serve as a form of protection against counterfeit are also a category in their own right. Furthermore, there is currently a trend in the food industry for using lasers to apply a marking straight onto the skin of fruits and vegetables — for example an organic seal or other information. This is a way of avoiding problematic packaging, and there is an additional aesthetic benefit for the customer.

Razor housing, tap and pan: laser markings for product designation, conditions of use, and protection against counterfeit.



DESIGN AND CUSTOMIZATION

It is within the consumer goods industry that design plays a particularly major role, as it is a way for brands to stand out from the competition and to offer their customers **aesthetic added value.** Marking lasers are becoming more and more important in this regard, as they can be used on almost any kind of material. Another trend is the customization of goods — using your own signature, for example — no matter whether on a mobile phone, tablet, bag, or water bottle. This is also an area of application for marking lasers, as lot size 1 poses no challenge for these items. Finally, event organizers at trade fairs, launches, parties, and other special events can use marking lasers directly on-site to impress their visitors and customers by presenting them with a customized gift.



2.
BASICS OF LASER MARKING

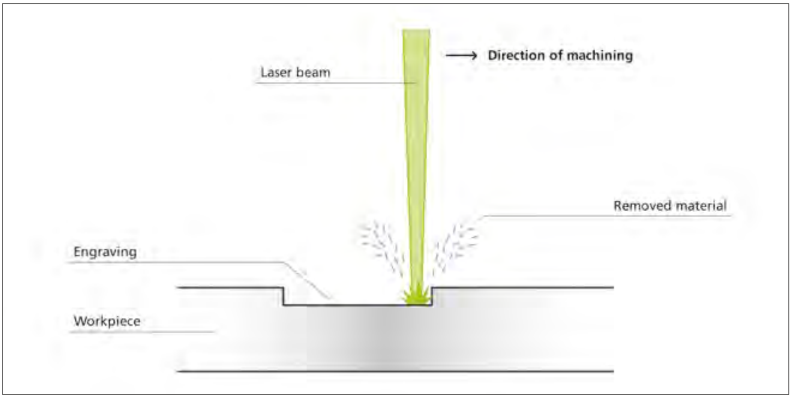
Marking lasers are the ideal tool for a large number of processes and types of material. However, it is obvious that not every process is compatible with every material. To obtain the best results, you should always consider what it is you want to achieve by using a marking laser. Once you have established that, you can work out the best way of applying it for your task.

2.1 METAL

Metals are characterized by their fixed lattice structure and free electrons, which is what gives them an opaque appearance and enables them to conduct electrical currents. When a laser beam hits the surface of a metal, a certain percentage of the light is absorbed and there is an interaction with the electrons. Depending on the intensity and exposure time of the laser light, the absorbed light increases the surface temperature or causes the material to melt and evaporate.

DEEP ENGRAVING

In tool manufacturing and mold making or when marked components still require reworking or additional painting, laser engravings need to be applied deeper into the material — into the millimeter range. Typical applications include injection molding tools as well as punching and embossing tools, for example. Deep engraving has also proved useful for engraving vehicle identification numbers.



Engraved markings are applied to a material by combining melting and evaporation removal processes.

Video "Engraving of nonferrous metals"
www.trumpf.info/lg9fq1

Video "Engraving of cast aluminum"
www.trumpf.info/9rizps

ENGRAVING AND BLACK ENGRAVING

Engraved markings are applied to a material by combining melting and evaporation removal processes. The power density of the laser beam is extremely high with this particular method, which causes the material to melt and partly evaporate during the process. The resulting steam pressure pushes out the melt and leads to the formation of a melt burr on the edge (material bulging). This typically occurs when using short-pulse lasers. With ultrashort-pulse lasers on the other hand, it is possible to create an engraving that is free of burrs. In this process, the material evaporates straightaway and creates a depression — the engraving, which is an extremely wear-resistant type of marking. In the case of metals, the interaction of the molten base material with the atmospheric oxygen leads to the formation of oxides which are different in color. The surface, which is generally very rough, absorbs a lot of light, and this is why the markings are usually black in appearance, or — depending on the material — dark gray (aluminum) or dark brown (steel, brass, copper). Due to their dark color, these markings are often referred to as "black engravings".

Embossing punch with deep engraving.

Black and white engraving for a Data Matrix Code.

Video "Engraving of galvanized steel": www.trumpf.info/efsro4

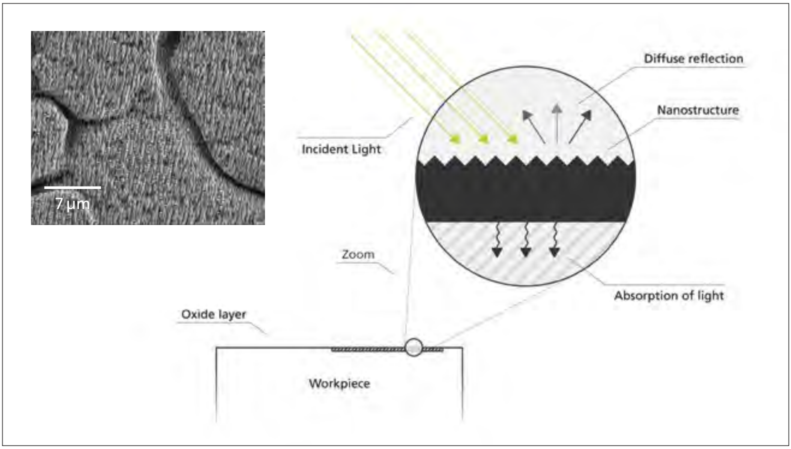
WHITE ENGRAVING

Applying a white engraving involves structuring the surface in a way that causes the material to melt only slightly. The result is a smooth, highly reflective surface, which in the case of certain materials such as galvanized steel has the appearance of a white marking. Due to the low penetration depth, the coating remains intact and so does its corrosion-resistance properties. This type of white engraving has a particular advantage when applied to dark metals such as hardened steel as the high contrast improves the readability of the marking. Furthermore, as the penetration depth only extends into the micrometer range, it is also suitable for engraving component surfaces that would be too greatly affected by a conventional engraving process.

ANNEALING AND BLACK MARKING WITH ULTRASHORT-PULSE LASERS

Annealing heats the material locally to just below its melting point. This generates oxide layers on the surface of the workpiece which are associated with metallic annealing colors. The contrast and the color depend on the thickness of the oxide layer, and the quality of the surface remains completely unaffected. It is also the preferred method whenever a precision fit is required or there is a need to avoid material bulging. You can only anneal metals that change color when under the influence of heat and oxygen, i.e. steels and titanium, but not aluminum or nonferrous metals. It is also not possible to anneal carbide metals and achieve a dark contrast. In this instance, it's only possible to create a light discoloration using a nanosecond laser but a black marking with an ultrashort-pulse laser.

Black marking is a marking process that produces very high-contrast, dark markings. It involves using ultrashort laser pulses to structure the surface with nanoripples or LIPSS (laser induced periodic surface structures). This structured surface reduces the amount of light that is reflected, and the result is a deep, matt blackening of the marking, which appears the same when viewed from any angle. Black markings are ideal for rust-free stainless steels, aluminum, titanium, copper, brass, and chromed plastics.



The principle behind black marking using ultrashort-pulse lasers.

Using ultrashort-pulse lasers

In most cases when applying a black marking, markings on stainless steel have to be resistant to corrosion—particularly in the medical technology industry. This can be achieved by using ultrashort-pulse lasers with a pulse duration in the picosecond or femtosecond range. As the duration of the energy input is so short, there is no opportunity for the heat to reach the adjoining atoms. Furthermore, the heat input is very low during the surface structuring in the nanometer range. This process is often referred to as “cold processing”. In addition to the surface structuring, a chromium-oxide compound is the second fundamental ingredient needed to achieve a corrosion-resistant black marking on stainless steel. The heat exposure is lower compared to annealing with short-pulse lasers, which enables sufficient free chromium to remain in the surface, thus promoting the self-healing process of the passive layer. This results in more corrosion-resistant oxide compounds on the surface.

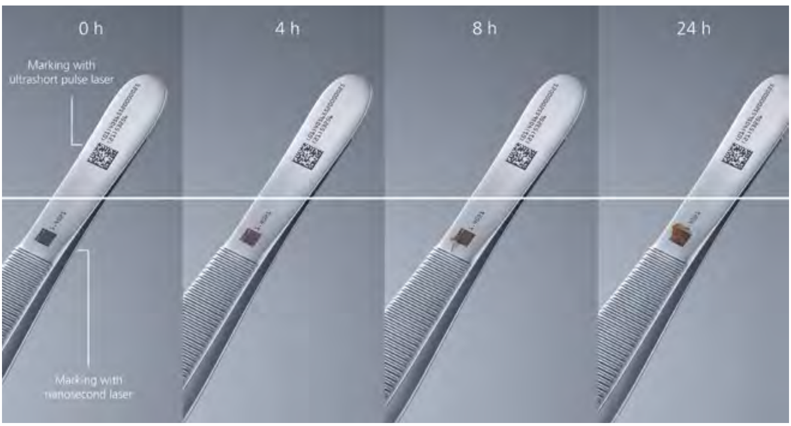
Process qualification

To ensure that the readability and durability of black markings are long-lasting, even when they come into contact with harsh cleaning agents and high temperatures as in the case of medical technology devices, it is advisable to use targeted passivation. In this case, an acid bath consisting of nitric acid or citric acid removes highly reactive components from the surface (e.g., free iron ions) and encourages the quick formation of a new and clean chromium oxide layer, for even better corrosion resistance. The surface is cleaned simultaneously during this process, and sulfurs are dissolved. The aim must always be to create a laser marking that can withstand the passivation process and any continual cleaning processes. With the precise selection of parameters, passivation may even no longer be needed. Using an ultrashort-pulse laser is the best solution in this regard. However, a number of factors need to be taken into consideration, which can be roughly summarized as follows:

- The chemical composition of the material
- The surface quality of the material
- The purity of the surface
- The potential passivation process

The following approach is recommended as the best way of evaluating these considerations and factoring them in when designing your process:

1. Study of the parameters (potentially with different types of lasers)
2. Analysis of the corrosion resistance and passivation stability (no fading of the marking)
3. Definition of a process window
4. Correlation between the laser parameters, the structure of the oxide layer, and corrosion resistance



Black marking enables you to produce all kinds of markings which are still clearly legible even after numerous cleaning and passivation cycles and have higher corrosion resistivity.

Using a nanosecond laser

The reality of any production process is that it may not be possible to acquire an ultrashort-pulse laser, for any number of reasons, but at the same time there is the need for applying black markings — in this case by annealing. Although this method also produces good results, it can be more susceptible to corrosion or the ideally suited process window is smaller. However, by clever design of the process, it is also possible to obtain the same level of corrosion resistance with a nanosecond laser. To ensure the surface of the marking does not melt, weak laser parameters should be used. Passing over with the laser between two to four times enables layers to build up uniformly, which results in good readability and durability. However, annealing using a short-pulse laser produces a marking that is less matt black, and reflects slightly more light. To a certain extent, the marking also has to be viewed from a particular angle.

Annealing on a rounded surface.

MARKING CHROMED COMPONENTS

Chromed materials (e.g., bathroom fittings) are often marked by applying a white engraving. This involves melting the surface just very sightly using short pulses in the nanosecond range, so that the chromium layer remains intact. This process helps to avoid delamination. Through the use of ultrashort pulse lasers and the associated surface structuring, black marking can also be achieved without causing delamination.

ANODIZED COATINGS

Markings on anodized or galvanized materials are often applied by removing the surface layer until you reach the base material. As anodized coatings are usually dark in color, the final marking is light in contrast and easy to identify. In the case of transparent or naturally anodized aluminum, it is also possible to penetrate the transparent anodized layer and to apply the marking on the boundary layer without damaging the material. This involves marking beneath the actual surface, so the result is fully corrosion-resistant and also very high in contrast (black).

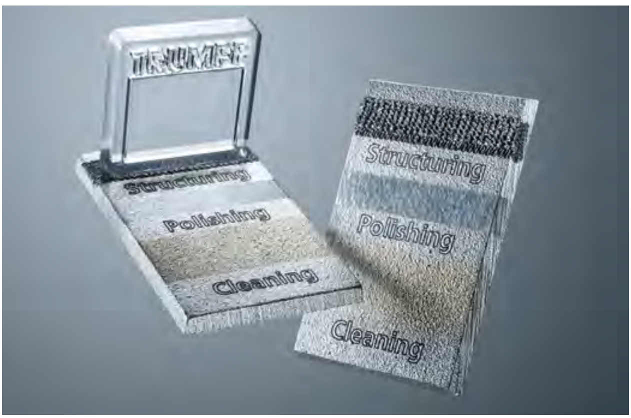
Video “Ablating of anodized aluminium”
www.trumpf.info/4bmfx3

SURFACE PROCESSING

Alongside applying all types of markings, marking lasers are also very useful tools for a broad range of surface processing tasks, especially when it comes to metallic materials. These tasks can fundamentally be divided into three main groups:

- Cleaning: Lasers are able to remove unwanted layers from a component, either locally or across a large surface area. This includes the evaporation of oils, grease, oxides, and the removal of residue from molds.
- Layer removal: As a general rule, lasers can remove any desired layer from the component in exactly the right area. This includes decoating and stripping, for example.
- Structuring: Lasers have the ability to alter the properties of a surface quite significantly. This includes roughening and changing tribological properties, for example.

For more information about the advantages of marking lasers see chapter 1.3 “Process preparation and surface treatment”.



2.2 PLASTICS

Plastics are synthetically created, organic materials. They are made up of hydrocarbon compounds, which are formed into macromolecules. The only exception are organic silicon compounds. Plastics are subdivided into three groups according to their inner structure.

THERMOPLASTICS

Thermoplastics consist of filamentary macromolecules that intertwine and do not have any crosslinks. At room temperature, thermoplastics are hard. However, when exposed to increasing temperatures, they first become soft, then take on a liquid form, and then disintegrate. In a soft or liquid state, they can be molded into almost any desired shape.

THERMOSETTING PLASTICS

Thermosetting plastics comprise of macromolecules that are closely interlinked at a number of different crosslinking points. When they are heated, their mechanical properties change only very slightly, as the crosslinks do not allow the macromolecules to shift. If thermosetting plastics are heated to a very high temperature, they disintegrate without initially becoming soft or fluid.

ELASTOMERS

Elastomers are plastics with rubber-elastic properties. They are built up of macromolecules that are interlinked in a wide mesh structure. When subjected to heat, the rubber-elastic properties change only slightly. If heated too much, elastomers also disintegrate without first taking on a liquid state.

ADDITIVES

The base structures of plastics contain all kinds of different additives:

- Fillers such as carbon black, quartz, and glass fibers
- Processing aids such as lubricants
- Additives such as chemical stabilizers or flame retardants
- Soluble organic dyes
- Chromophoric pigments

The combination of the additives influences how well a laser is able to mark a plastic. Quite often, a slight change to an additive — for example a dye — can bring about a considerable improvement in the marking properties. The crucial factor is that it must always be possible for the material to absorb the wavelength of the laser.

MARKING LASER PROCESS

There are four different ways in which lasers can be used for marking plastics:

- Color change of the surface (discoloration, bleaching, or carbonizing)
- Engraving (removing material from the matrix material on the surface)
- Surface change (foaming or melting)
- Ablation of layers (e.g., paint)

ABSORPTION CHARACTERISTICS

The manner in which the laser beam interacts with the material can vary greatly. The important thing when using a marking laser is that the material has sufficient capacity to absorb the light. In the case of metals, most of the light is reflected. With plastics, on the other hand, light absorption and the transmission or diffuse reflection of the light are of greater significance. As plastics do not have much heat conductivity, the energy loss during the marking process is very low. This enables you to apply markings to plastics with significantly greater speed than in the case of metals.

The macromolecular basic structure of plastics — the matrix — generally absorbs light within the ultraviolet and far infrared ranges of the spectrum. The different additives absorb light at different ranges along the wavelength spectrum. Additives such as carbon black absorb light in the near infrared range, which means they can also absorb the wavelength of a solid-state laser. Dyes, on the other hand, absorb light in the visible light range. As you can acquire lasers with different wavelengths, you can select the ideal wavelength for the relevant material.

ADDITIVES

It is advisable to mix certain industrial plastics with laser-sensitive additives to meet the requirements of good readability and high-quality marking. These additives change the chemical composition of the plastics, thus adapting the material to the particular application or product. The specific optical, thermal, physical, and electrical characteristics of the plastics remain largely intact. Laser additives are usually color-neutral. They can consist, for example, of passive pigments — in the form of tiny mica platelets — which are mixed into the material in a very low concentration. This improves the absorption of the laser radiation of a certain wavelength (usually designed for 1,064 nm) in the material. In addition to the color contrast, it is also possible to increase the processing speed through laser additives.

WAVELENGTHS

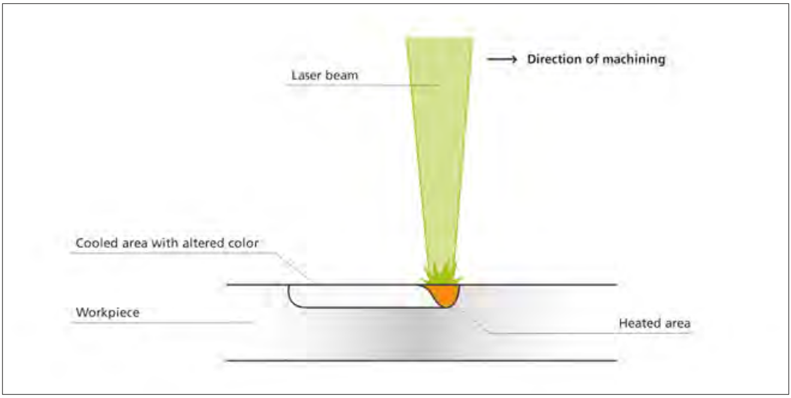
The role of the laser wavelength is always a crucial factor in the marking of synthetic materials, especially if you want to select the most suitable laser for a specific application. Absorption is heavily influenced by the types of additives that are incorporated. You have a greater choice of plastics that lend themselves well to being marked if you use a solid-state laser with a double frequency (532 nm, green) or triple frequency (355 nm, UV), which also often produces better results than the standard systems with a wavelength of 1,064 or 1,030 nm.

WHAT TYPE OF PLASTICS CAN BE MARKED USING CONVENTIONAL SHORT-PULSE LASERS WITH A WAVELENGTH OF 1,064 NM?

Good marking results without additives	**Average marking results without additives, but good marking results with laser additives (color-dependent characteristics)**		**Not possible to mark, or only with special additives**
ABS PC PPSU PBT PBTP Styrene (SAN) PEEK UREA	PS PI PETP POM PPS ASA	PES PEI PES PE PA PVC TPE	Polyester PU Polyolefine (PEHD, PP) PMMA PTFE

COLOR CHANGE AND CARBONIZATION

You can be selective when choosing the color molecules that you want to bleach or change in color. By using the energy of the laser beam, it is possible to target individual molecules (e.g., color pigments) and either destroy them or change their structure. This process is particularly gentle on the material and the surface: The surface remains



Color change: The laser energy changes individual molecules in a targeted manner, thereby causing a color change.

Video "Coloring of plastics (ABS)"
www.trumpf.info/2xc87p

CONTENT

largely intact and smooth. If material and wavelength are well matched (e.g., by using laser-sensitive active pigments), it is possible to achieve the same effect even in the case of 1,064 nm. However, with this wavelength, the plastic usually already carbonizes in the matrix. During the carbonization process, the carbon-based plastic practically burns (i.e. carbonizes) on the surface. Carbonization is often used for marking light-colored plastics with a penetration depth of up to 200 µm. In the case of transparent materials (e.g., polycarbonate), there is partly a type of shadow effect in the depression, depending on the laser light transparency and the penetration depth of the laser radiation.

FLAME-RETARDANT PLASTICS

The marking of flame-retardant plastics (e.g., in the electronics industry) is a special case, as by definition they should be impervious to the effects of heat. Similar to when processing other types of plastics, it is important that the material and the wavelength are perfectly matched. The recommended laser to use in this instance is a UV laser.
It enables you to apply dark gray markings onto light-colored materials. The discoloration is caused by the breaking up of chemical bonds as the photons have a high level of energy when the wavelength is short. As the material does not burn and carbonize, this process is sometimes referred to as “cold marking” with a high-quality surface.

Laser marking ...

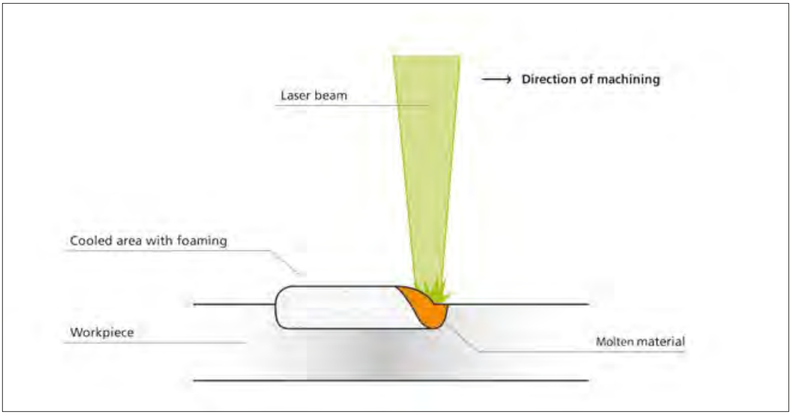
... via color change.

Marking of flame-retardant plastics.

Foaming.

FOAMING

Using the foaming process, it is possible to apply raised markings on plastics. This method involves the laser melting of the matrix material in a very targeted manner, which forms small gas bubbles that get trapped when the material cools down. The raised marking created in this way is around 20 to 40 µm high, quite wide and has a relatively lower spatial resolution, which makes it a more suitable process for applying markings that do not require much precision. The light is reflected in a diffuse manner, and, on dark plastics, the marking is light in appearance. However, the rigid foam consistency of this type of marking means that it is not particularly scratch-resistant by comparison. Nevertheless, as the marking penetrates the material by up to 80 µm, the overall readability is generally still quite long-lasting. However, if the surface has open pores, dirt might settle in the marking over time, causing the contrast with the material to decrease. It is not possible to use the foaming method with every type of plastic, and is usually only used with black or dark colors.



Foaming creates raised markings.

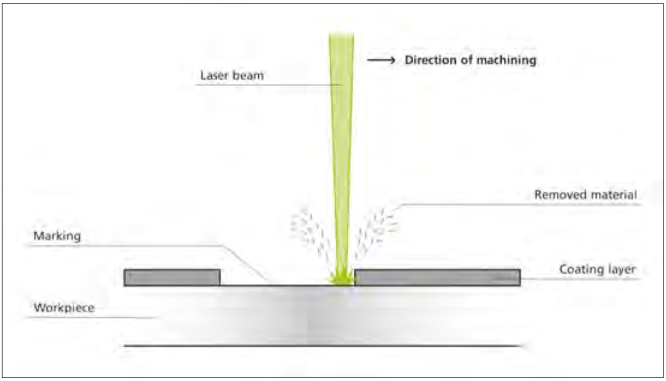
Video “Foaming of plastics (PA6)”
www.trumpf.info/zcf71h

Video “Foaming of plastics (POM)”
www.trumpf.info/r856xa

ABLATION OF A TOP COATING

Plastics that are either painted or have several layers can be marked by ablating a thin top coating from the material. It is the color of the base material or base coating underneath the top coating that creates the contrast. This process involves the removal of paint or special layers in the case of laser marking films. To achieve a high-quality marking, the top coating and the substrate material should be high in contrast, possess good absorption capacity for the wavelength of the laser, and have a very homogenous layer thickness.

CONTENT



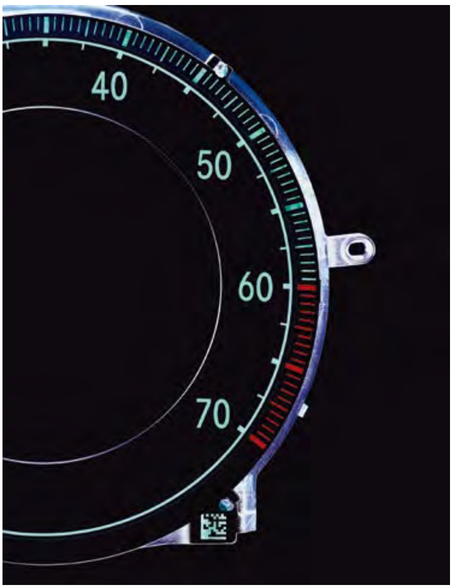
In ablation, the laser removes a coating layer.
The underlying base material is visible in the mark.

Marking achieved through laser ablation.

Day-and-night design

An example of components that can be marked through layer ablation is operating elements with a day-and-night design, such as buttons inside a vehicle. In daylight the symbols are white, and at night they are illuminated from behind. This type of marking is procedurally very complex, due to the different composition of the paint used and the partially very glossy surfaces.

The semitransparent base material must not be damaged during the ablation of the top coating. For this reason, a two-layer removal process is usually applied. In the first step, a small part of the paint is left, which is then removed during the second step with reduced laser power. For day-and-night designs, there are lasers with high pulse-to-pulse stability available.



Example for day-and-night-design.

Laser marking foil

In some cases, it is not possible to apply a marking onto the material directly — due to the characteristics of the material or for production-related reasons. An alternative solution is to apply labels. These consist of self-adhesive laser marking foil that can be cut to the required shape and marked with the laser. These labels are generally made from special acrylate foils with a two-layer structure, whereby the top layer is removed with a laser and the second layer creates the required information (ablation foils). The foils are available in different color combinations and are highly resistant to any impact from chemical, temperature, and environmental influences.

In addition to these types of foils, whereby the top coating is removed, emissions-free color-change labels are also available. In this case, the marking is created through an irreversible color change of laser-sensitive pigments within the material of the label. Process speeds are much faster compared with ablation foils, and as the material is not actually removed, there are no emissions. As a result, this process meets a number of hygiene and food law requirements.

Video “Ablating of plastic foil”
www.trumpf.info/9i0axd

Printed circuit boards

The manufacturing of printed circuit boards is an area that often requires markings to be applied on the smallest of areas, due to the persistent miniaturization trend in this industry. This often involves the use of compact Data Matrix Codes. This is where lasers come into their own in terms of quality, as they are much more precise compared with inkjet or label marking processes. There is also no need for the use of consumables or additional materials of any kind. Depending on the desired result, it is possible to use different types of lasers. During the marking process of the printed circuit board, the wavelength of the CO_2 laser is absorbed directly by the solder resist, causing the coating to turn white. However, with a solid-state laser, it is possible to apply considerably finer markings, as the resolution is significantly higher. In general, you also achieve a better contrast than with CO_2 lasers, as the wavelength is absorbed by the copper layer underneath the solder resist layer rather than by the solder resist layer itself. This increases the temperature of the copper layer, causes the coating to blast off completely, and exposes the copper layer. In both cases, the marking parameters have to be matched to the thickness of the solder resist layer.

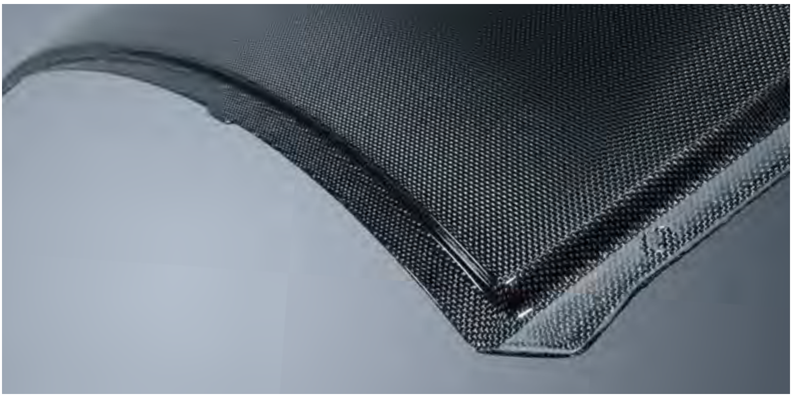
2.3 OTHER NONMETALS

In addition to metals and plastics, ceramics and sintered mixed materials can also be marked with the laser. The primary advantages of this process are revealed where mechanical processes reach their limits due to the high material hardness. Uniform marking on natural materials such as wood, leather, and fruits is often difficult because of the sometimes variable absorption behavior.

The processes vary as much as the materials. Ceramics and other brittle-hard materials such as semiconductors are engraved, ablated, and drilled. Glass can also receive subsurface marking. Fiber composite materials are ablated and drilled. Color changes predominate in natural materials, and in isolated cases (e.g. leather), even perforations are possible.

CFRP

Carbon fiber reinforced plastic (CFRP) is a composite material in which carbon fibers are embedded in a plastic matrix as a fabric or tissue. The challenge when laser processing this material is to avoid damaging the sensitive fiber composite as this would endanger the overall stability of the component.



Video “Laser processing of CFRP”
www.trumpf.info/igtem7

Surface structuring and ablation

To manufacture CFRP-CFRP or CFRP-metal composites, the marking laser roughens the CFRP surface to prepare it for the adhesive process. The possible applications also include exposing individual fibers as well as selective surface processing of the matrix material (like epoxy).

Infrared laser light makes it possible to realize attractive ablation rates with acceptable quality. However, there is a significant heat-affected zone, because the fiber material absorbs the infrared laser light almost completely. At the green wavelength, the quality is significantly better, but the ablation rates are somewhat lower. The best quality is produced by ultraviolet lasers.

Marking

Lettering, codes, or logos can be marked in CFRP using color change or engraving. The same conditions apply to engraving as to ablation. A color change is usually produced in the plastic matrix. The selection of parameters depends on the matrix material. Generally, the UV laser achieves good results, but the contrast usually stays somewhat low.

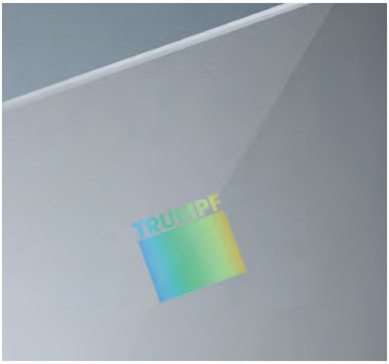
GLASS

Because of its transparency and its amorphous surface structure, glass is a difficult material for laser marking. Infrared laser light is as good as not absorbed. There is only an interaction when the laser beam is extremely focused on the workpiece or the peak pulse power is very high, as in the case of the ultrashort-pulse laser. Processing with ultrashort-pulse lasers is also possible with IR lasers at a wavelength of 1,030 nm. That is due to the interaction between the laser radiation and the material, which is very different from processing with long pulses. In the case of glass, free carriers are first created by multiphoton absorption which then continues to absorb laser radiation and creates many new free electrons caused by impacts like an avalanche (also called avalanche ionization). These processes are very fast in comparison to heat conduction processes. Frequency-tripled lasers with a wavelength of 355 nm are used in short-pulse lasers. The glass also absorbs the laser light from this UV laser very well because of the high-energy photons.

Glass subsurface marking

If the focal point is not on the surface of the glass, the marking laser can also mark the inside of the material. To do that, the focus of the laser is underneath the surface of the glass. The spatial and temporal energy density of the pulsed laser beam is greatest at the focus, and this creates the smallest microcracks in the glass, which give off a diffusely white reflection of the light, making visible a kind of frosted subsurface marking. Intentional nanoripples break up the light in a way that creates a kind of rainbow effect like in a hologram. In both cases, the surface of the glass is not damaged. This kind of marking is used for security features, for example, as well as in optics—whether it be tiny markings in glasses or lenses—so that the surface remains smooth.

CONTENT



Markings inside the glass — left, with hologram effect.

Thin layer ablation

If the glass is coated, for example with a metalized mirror, the laser can precisely ablate the layer, producing the marking. Ablation is often carried out from the rear through the glass. The interaction on the boundary surface efficiently ablates the layer without damaging the surface of the glass.

CONTENT

CERAMICS

Ceramic materials are inert, inorganic, nonmetallic, and polycrystalline. They are normally formed from a raw mixture of ceramic powder, organic binder, and fluid at room temperature and only obtain the features typical of the material during the sintering process at high temperatures. Technical ceramics and other brittle-hard materials such as sapphire are very difficult for conventional processes. Their advantages, including chemical stability, fixed lattice structure, high degree of hardness, good insulating behavior, and a high level of scratch resistance, still make them a very valuable material for electronics manufacturing (for LEDs, insulators, and capacitors).

Engraving aluminum-oxide-ceramic wafers is a typical application for marking lasers. Depending on the process parameters selected, short-pulse lasers can achieve pure white deep engravings or engravings with a very readable contrast level.

The particular challenge lies in avoiding microcracks in the material. These cracks are created when too much energy goes into the material, which negatively influences the existing lattice structure. Burrs and even stresses are created that promote the formation of cracks. The heat-affected zone should therefore be kept as small as possible. Depending on the type of ceramic, green marking lasers may also be suitable for high-quality, high-contrast markings if the material absorbs this wavelength well — in most cases, however IR lasers are already well-suited for this.

Ultrashort-pulse lasers are only used for deep engraving, when an especially small heat-affected zone or a very precise engraving is required. Productivity can also be increased with ultrashort-pulse lasers. Ceramics can also be cut or scored with ultrashort-pulse lasers, to be precisely broken afterwards (score and break).

Engraving on ceramic.

SILICON/SEMICONDUCTORS

Ultrapure, crystalline silicon is the best base material for microelectronics. This is due less to its electrical properties than to its chemical, physical, and technically useful properties. All conventional computer chips, memories, and transistors use ultrapure silicone as their starting material. These applications are based on the fact that silicon is a semiconductor.

The targeted storage of foreign atoms (doping), such as indium, antimony, arsenic, boron, or phosphorus, can introduce a wide spectrum of changes in the electrical properties of silicone.

Typical applications for marking lasers include engraving codes or simple text labels with short-pulse lasers on silicon wafers.

IR lasers penetrate deep into silicon, but better results are often achieved with the green wavelength, because it is absorbed on the surface.

To ensure the purity of the components required by the semiconductor industry, the components must be free of particles after laser processing. This is achieved by selecting the appropriate process parameters, in particular on the front of the wafer. The so-called soft mark process only slightly colors the surface white and melts it slightly without producing particles. However, a higher contrast, dark engraving (hard mark) is possible on the backside of the wafer, because a certain level of particle emissions is allowed on that side. The engraving may still only be a few micrometers deep, not to weaken the material at this location. The heat-affected zone must also remain small, so that sensitive electronics are not damaged by localized high temperatures. This requires lasers with high pulse-to-pulse stability.

Processing of silicon.

2.4 NATURAL MATERIALS

In organic materials, such as paper, cardboard, wood, and leather, localized heating causes burns when irradiated with IR wavelengths or chemical conversion reactions are triggered — especially when processed with UV wavelengths — which manifest themselves in color changes or engravings. Carbonization with an IR laser causes a kind of sunburn on the material, while UV lasers do something more akin to bleaching the material. The challenge always lies in the fact that materials have inconsistent properties, which means marking results are often not completely reproducible.

LEATHER

Chemically, leather consists of protein, fat, water, and tanning agents along with substances that are added during processing, such as dyes and chromium. The proportions differ greatly depending on the field of use and the quality. The surface is mostly inconsistent in structure, with a very mixed chemical composition, and without a clear chemical structure. Difficult conditions when using a marking laser.

An energy influx that is to great normally causes undesired burns, which means the process speed may only remain in the moderate range. With careful selection of the process parameters, both the UV laser and the IR laser are suitable. CO_2 lasers just burn the material in this case, which usually causes an unpleasant smell from the material.

Markings on leather.

Food-safe laser marking on a cucumber.

Color change and slight ablation

Design elements and markings can be applied to the leather with the color change process. The smallest possible application of energy means the surface of the material remains intact. Often, it is sufficient to ablate only a micrometer-thick layer on the leather with short pulses. If the pulse duration is too long, this creates very visible, dark heat-affected zones.

Perforation

Besides color change, drilling is a common leather processing technique — small holes or circular depressions, rectangles, and squares are made in the leather for decorative purposes or for breathability. Depending on the use, the shapes are applied from the front or from the back — in this case, the pattern can only be seen from the front side with backlighting. Since drilling requires a greater input of energy than color change, the challenge is to keep the heat-affected zone as small as possible and to avoid burns. The use of UV lasers or nitrogen as an assist gas help avoid burns, hardening, and unpleasant odors.

FRUITS AND VEGETABLES

Fruits and vegetables are often labeled with messages or logos for advertisement purposes. Another important field of use is labeling fruits and vegetables with production information — the technical term is "natural branding", like labeling organic items as such. Fruits and vegetables primarily consist of water and carbohydrates (cellulose, sugar) and are covered by a peel or leaves with a variable surface structure. The surface is very sensitive, and the energy input cannot be too great, otherwise it will be damaged. UV lasers are definitely the gentlest option. The interaction between the laser light and the fruit is similar to a focused effect of the sun on the material: bleaching the color pigments on the surface.

CONTENT

UV laser marking on wood.

WOOD

As with all other natural materials, wood is nonhomogenous as well and presents the same challenges to material processing with lasers. Similar to leather, laser marking on wood is primarily done for aesthetic reasons, to create decorative elements. Color change and engraving are common, sometimes in combination. As with leather, perforation and drilling are also used on thin veneer materials to create designs that can be seen with backlighting.

In principle, the same conditions that apply to laser marking of fruits and vegetables apply to laser marking on wood. The UV laser is the tool of choice in this case as well, because it essentially simulates and intensifies natural processes. The wood darkens as an effect of the UV light. The process parameters must be carefully selected for wood as well to ensure the energy input is not too intense, making the heat-affected zone not too large. Only moderate process speeds can be used to achieve a high-quality, uniform marking. A certain amount of carbonization to increase the contrast within an engraving may even be desirable from a design perspective. IR lasers can also be used for engraving and carbonization effects.

2.5 PROCESS PARAMETERS

Is a marking laser economical for a certain application? There are two important factors in answering this question: process speed and quality. Process speed can simply be measured in time, and the following criteria apply to quality:

- **Contrast:** The marking should stand out well from the color of the base material.
- **Homogenity:** The color of the marking should be uniform over the entire typeface area.
- **Contour accuracy and sharpness of detail:** The contours of the marking should match the required design as closely as possible. Details must be replicated sufficiently.
- **Positioning accuracy:** The position of the marking should match the required value.
- **Durability:** The marking must be resistant to scratches and abrasions. It cannot have microcracks and must be resistant to corrosion.
- **Absence of burrs:** High-quality engravings often must not have any burrs, otherwise reworking will be necessary.

How can the desired quality be achieved? By balancing the interaction of the essential process parameters. These are presented below.

PULSE REPETITION FREQUENCY / REPETITION RATE

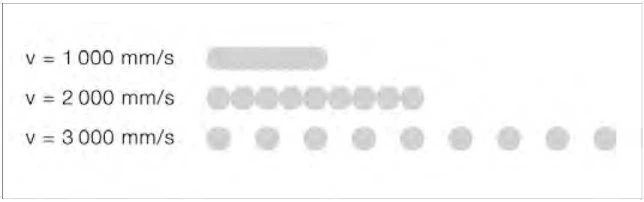
In short-pulse lasers, the pulse frequency determines the frequency of pulse repetition. They go from several kilo- up to the megahertz range. For Q-switched solid-state lasers, the following rule applies: For high repetition rates, the pulse duration is longer and the peak pulse power is low. The pulse duration is shorter and the peak pulse power is high when the repetition rate is low.

PULSE LENGTH

The pulse duration is the time between the beginning and the end of an impulse measured in seconds. Marking lasers usually have a pulse duration in the nano-, pico-, or femtosecond range. For fiber lasers that are designed as oscillator amplifier systems (MOFPA), pulse duration adjustment is more flexible with respect to the pulse repetition frequency, because the pulse duration is determined by the seed pulse.

DEFLECTION SPEED

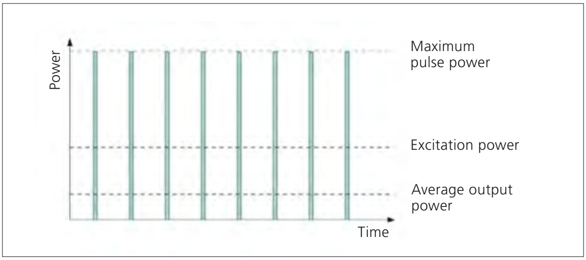
The deflection speed is the speed at which mirror deflection causes the laser points on the workpiece to advance. If the deflection speed is too low in relation to the pulse repetition frequency, the individual marking points overlap too much. If it is too high, the points are too far from each other and there is no longer a connected line.
The deflection speed must be adjusted to match the pulse repetition frequency in order to achieve the desired marking results.



At low deflection speeds, points become a line.

AVERAGE POWER

The average power of a laser beam can be calculated from the peak power, duration, and frequency of the laser pulses. It is always under the power of the laser pulses (peak pulse power). Rule of thumb: A higher average power normally makes faster processing speeds possiblee, if the workpiece can handle the corresponding energy input.



For pulsed solid-state lasers the maximum pulse power exceeds the excitation power.

$$P_m = P_p \cdot f_p \cdot t_p$$

P_p = Pulse power
E_p = Pulse energy
t_p = Pulse duration
f_p = Pulse frequency
P_m = Average power

PULSE POWER AND PULSE ENERGY

The pulse power value can be calculated from the average power of the laser, the pulse repetition frequency, and the pulse duration. The pulse energy (E_p) is the product of the pulse power and the pulse duration. Rule of thumb: The higher the pulse energy, the more material is ablated with each pulse. The higher the peak pulse power, the quicker the threshold for material removal is reached and the more intense the interaction with the material is. For example, in metals the amount of vaporization increases. With high peak pulse power, engraving can still be carried out with a large focal diameter and with a greater focal length (greater working distance, large labeling field, and greater depth of focus).

$$E_p = P_p \cdot t_p$$

WAVELENGTH

The wavelength of the laser light determines its place on the electromagnetic spectrum as well as its color, e.g. ultraviolet, green, infrared. The wavelength determines in large part how light is absorbed by the material and also influences precision, depth of focus, and photon energy. With shorter wavelengths, a smaller focal diameter is possible, but the depth of focus is then not as deep and the photon energy is higher.

ABSORPTION

The degree of absorption indicates how much laser light is coupled into the workpiece, how much is reflected, and how much is transmitted, i.e. how strong the effect of the laser light actually is. The degree of absorption changes depending on the material and wavelength. It is also affected by the incident angle of the laser beam, the temperature, the physical condition, and the surface quality of the workpiece.

BEAM QUALITY

Beam quality is understood as how well a laser beam can be focused and how high its focus is. The factor M^2 serves as a quantification of the focusability of a real beam and thus of the beam quality, which represents the ideal Gaussian beam with $M^2 = 1$. The larger M^2 becomes, the worse the beam quality. The higher the beam quality, the smaller the focal diameter that can be produced, or the greater the Rayleigh length as the measure of the depth of focus with the same focal diameter. For marking, that means, for example, that the depth of focus is greater, the higher the beam quality of the laser is.

FOCAL LENGTH

The focal length of the focusing optics indicates the distance between the center of the optics and the focal point of an ideal parallel beam and thus determines the working distance between the laser and workpiece. Rule of thumb: The shorter the focal length, the stronger the beam is focused and the smaller the focal diameter and Rayleigh length. However, the marking field size also changes. The shorter the focal length, the smaller the labeling field.

RAYLEIGH LENGTH AND DEPTH OF FOCUS

The beam expands according to the focus. The Rayleigh length indicates the distance to the focus at which the beam cross-section area doubles and the intensity is halved. The doubled Rayleigh length is often referred to as depth of focus. For example, a large depth of focus allows for a high positioning tolerance of the workpiece or the marking of curved surfaces.

$$z_{Rf} = \frac{\pi}{4 \cdot \lambda} \cdot d_f^{\,2} \cdot \frac{1}{M^2}$$

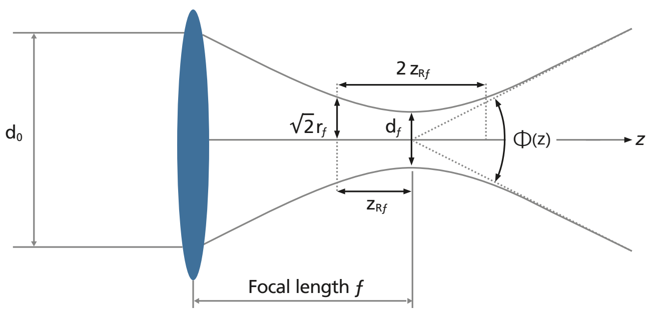
z_{Rf} = Rayleighlength
d_f = Focal diameter
λ = Wavelength
M^2 = Beam quality

FOCAL DIAMETER

The focal diameter is the place where the laser beam has its smallest cross section. Rule of thumb: The smaller the focal diameter, the higher the power density in the focal point. However, this must be adapted to the procedure. And the smaller the focus area, the finer and more precise the material can be processed.

$$d_f = \frac{4 \cdot \lambda}{\pi} \cdot \frac{f}{d_0} \cdot M^2$$

d_f = Focal diameter
λ = Wavelength
f = Focal length
d_0 = Raw beam diameter at focal lens
M^2 = Beam quality



FOCUS POSITION

Ideally, the focus should be exactly on the workpiece surface — this is influenced by the working distance and focal length. Whether the focus deviates from its ideal position during marking is critical or less critical, depending on the material and process, but can also be desired, for example to achieve larger line widths or to reduce the energy density of sensitive materials, for example to produce annealing marks and to only heat the material.

PROCESSING GEOMETRY (LINE SPACING, HATCHING)

Each instance of processing leaves a wider or narrower track with a specific geometry in the material. This does not have to correspond exactly to the focal diameter, but must be taken into account, for example, when marking bar codes or Data Matrix Codes with a certain correction distance in the module size. With filled contours, lines with a certain line spacing (or possibly also a line overlap) are juxtaposed. The area energy and thus also the process result can be adjusted by different distances of the hatches.

ENERGY DENSITY (FLUENCE)

Fluence is the energy over the area of a laser pulse. Together with absorption, it determines how strongly laser light and material interact. Depending on the material, a certain threshold fluence must be exceeded so that the material can be ablated by the laser (ablation threshold).

POWER DENSITY (INTENSITY)

The power density a laser beam — also called intensity — is the power per area; it is highest in the focal point. Higher power and smaller focal diameters produce a higher irradiance. This allows high processing speeds to be achieved.

2.6 LASER

There are numerous marking lasers and marking laser systems on the market, from large to small, from expensive to inexpensive, from pure lasers to all-round carefree marking stations. Their common basis is the laser, but there are differences in the beam sources here too. In addition to the beam source, a successful marking process also requires beam guidance with optics to shape the light, adjust the focus and image it on the workpiece, a computer and software to create marking contents, and a control to allow all components to work together correctly. This finished marking system consisting of a beam source, optical unit, computer, software and control for integration into complete systems is called an OEM marking laser. Optional sensor systems ensure repeatability and process reliability. Finally, a turnkey marking station creates a safe and ergonomic work environment and contains, for example, axes or fixtures for positioning the workpiece. All these components must work together to ensure a successful marking process. The following chapters provide a brief overview.

BASIC LASER DESIGN

Although there are different laser categories, they all work according to the same physical principle. One of the basic components is the **laser-active medium.** This is a substance that emits the laser light and in which it is amplified. Various substances can be used as active media — gases, solids or fluids. It is important that they emit electromagnetic radiation (that is light) as soon as they are excited and fall back from the excited state to energetically low states.

The second main component is the **resonator** which in the simplest case consists of two mirrors plus an active medium which always reflect the light back into the active medium. The resonator determines the direction of propagation of the light and ensures sufficient amplification of the beam through stimulated emission. One of the two resonator mirrors is partially transparent to the laser radiation. The power beam for material processing is then outcoupled here.

Other important components of each laser are the **pump source,** which supplies energy to the active medium, and the **cooling** system which prevents excessive heating of the system.

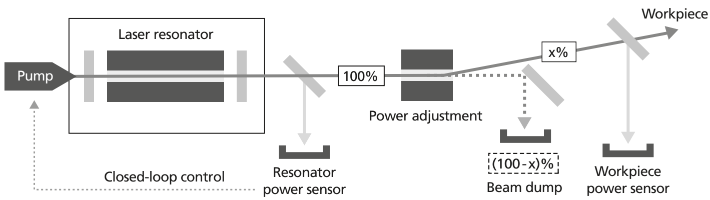
DIODE-PUMPED SOLID-STATE LASER

Diode-pumped solid-state lasers (DPSS) are frequently used for marking laser applications. Laser diodes serve here as pump sources that pump energy into the rod-shaped laser crystal. This can be done either from the side (transversal) or at the front surfaces (longitudinal). The latter variant allows for the construction of a laser with higher beam quality, since the temperature distribution in the laser rod is more homogeneous. This makes it possible to have a very compact design. Diode-pumped solid-state lasers are characterized by short pulse durations, resulting in very high pulse peak power powers of several 10 kW with an average output mostly in the range of in the range of 5 to 25 W. The monochromatic pumping of the laser with diodes causes a very high efficiency and thus a high degree of energy efficiency. High beam qualities and high pulse peak powers resulting in good focusability and power densities deliver best application results.

The laser light is generated in the laser crystal and is reflected back and forth between the resonator mirrors and amplified each time it passes through the laser rod. Due to the partially transparent decoupling mirror, a part of the laser light emerges from the resonator, which is then used for the marking laser application. Short pulses (typically 8 to 100 ns) at pulse frequencies between 1 and 200 kHz are generated with the help of an electro-optical switch in the resonator, the so-called **Q-switch.** Normally, this switch is optically transparent. Generating an acoustic wave in the crystal changes the refractive index locally. The beam is deflected, the oscillation of the laser beam between the mirrors is stopped and the laser “goes out”. During this interruption, however, the diode module continues to pump energy into the crystal. If the beam path is released again, the light energy is suddenly discharged. A high-power laser pulse is released.

In modern diode-pumped solid-state lasers, power regulations of the resonator are often used to ensure an exact power output over the entire life of the laser. In addition, external acousto-optical modulators are used to linearly scale the outgoing laser power and emit it with pulse accuracy, so that the application can be perfectly set.

In addition, a nonlinear crystal can be integrated into the beam path to double or triple the frequency of the laser light. The laser then emits green laser light or UV light. In addition to the Nd:YAG or Nd:YVO_4 fundamental wavelength (1,064 nm) or Yb:YAG fundamental wavelength (1,030 nm) in the near infrared range, frequency-doubled (green visible light, 532 or 515 nm) or tripled (UV, 355 or 343 nm) laser radiation is used. Frequency-doubled and -tripled solid-state lasers are mainly used for marking plastics, natural materials or glass.



Diode-pumped Q-switch solid-state laser with laser power control
and external acousto-optical modulator (power adjustment).

FIBER LASERS

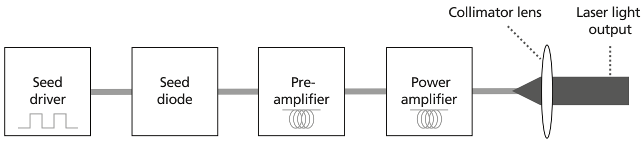
A fiber laser is a diode-pumped solid-state laser in which a fiber serves as the laser-active medium instead of a rod-shaped crystal. The fiber, often doped with ytterbium, does not have to be cooled like the rod. Since their surface area is very large in ratio to their volume, heat dissipation to the surrounding air is sufficient. The resonator ideally consists only of a long, thin quartz-glass fiber. Backmirror and outcoupling mirror are integrated in the end pieces of the fiber. The beam source can be attached directly to a transport fiber. All elements then form a continuous piece of fiber.

The laser power is determined by the fiber length and the core diameter. However, the pulse peak power cannot be increased at will, since a too high power density could damage the fiber. Fiber lasers are highly efficient for this purpose. The power input for a 20 W system is around 300 W, which is less than a standard hair dryer. In addition, integration is easy due to the robust design and the small dimensions of the laser head, deflection unit, and supply unit.

Fiber lasers can be designed as oscillator amplifier systems, also called master oscillator fiber power amplifiers (MOFPA): the seed pulse is amplified in a second fiber. This achieves relatively favorable high average outputs.

Another technical advantage of the fiber laser in the MOFPA design is that, in contrast to a Q-switch laser, the pulse duration can be adjusted independently of the pulse frequency. It is therefore possible to use short pulse durations at high frequencies in the megahertz range. In practice, this means an extremely high processing speed, even for fine or temperature-sensitive materials or when ablating very thin layers. When processing metals, the melting and evaporation percentages can also be controlled particularly precisely in order to control the quality and ablation rate. The higher the melt content (that is the longer the pulses), the higher the ablation rate. The higher the proportion of evaporation (that is the shorter the pulses), the better the quality.

In addition, it is possible to vary the pulse shape of MOFPA fiber lasers. This increases the flexibility for parameter setting. For example, a longer plateau at the end of the pulse can keep the material at a higher temperature for a longer time, or a steep, sloping flank can cool it down faster.

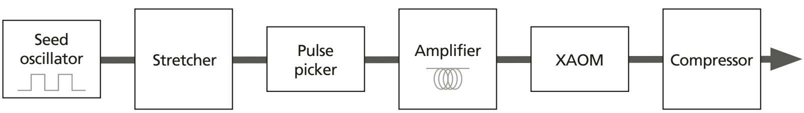


Principle structure of a master oscillator fiber power amplifier (MOFPA) setup.

ULTRASHORT-PULSE LASER

By using ultrashort-pulse lasers, marking lasers can be used for applications that go beyond traditional marking applications. Due to the extremely short duration of the pulses, the interaction period between the laser pulse and the material is so short that almost no thermal processes occur between the processing area and the surrounding material. This is often referred to as cold processing. Typical areas of application are burr-free engraving, sublimation cutting, black marking or, due to the low heat influence, plastic processing.

The ultrashort-pulse lasers used at TRUMPF for marking are fiber lasers that operate according to the power amplification principle. This process, which was awarded the Nobel Prize in Physics in 2018, initially generates ultrashort laser pulses of low power



Principle structure of a fiber based ultrashort-pulse laser.

and pulse energy. These pulses are amplified in a medium to the output power of the ultrashort-pulse laser. The amplified ultrashort pulses have tremendously high peak intensities. In order to prevent the pulses from destroying the fiber itself during amplification in the fiber, they must first be stretched in a "stretcher" for a very long pulse duration. In long pulses, the same energy is distributed over a much longer period, the intensity drops below the damage threshold of the amplification medium and therefore amplification is no longer a problem. In order for the amplified pulses to regain their original extremely short pulse duration, they must be compressed in a compressor after amplification. The result are amplified, ultrashort laser pulses that deliver the amplified energy in an extremely short time and thus lead to the tremendous peak powers. All ultrashort-pulse lasers from TRUMPF have a patented acousto-optical modulator that enables the continuous regulation of the laser power and ensures lasting process quality.

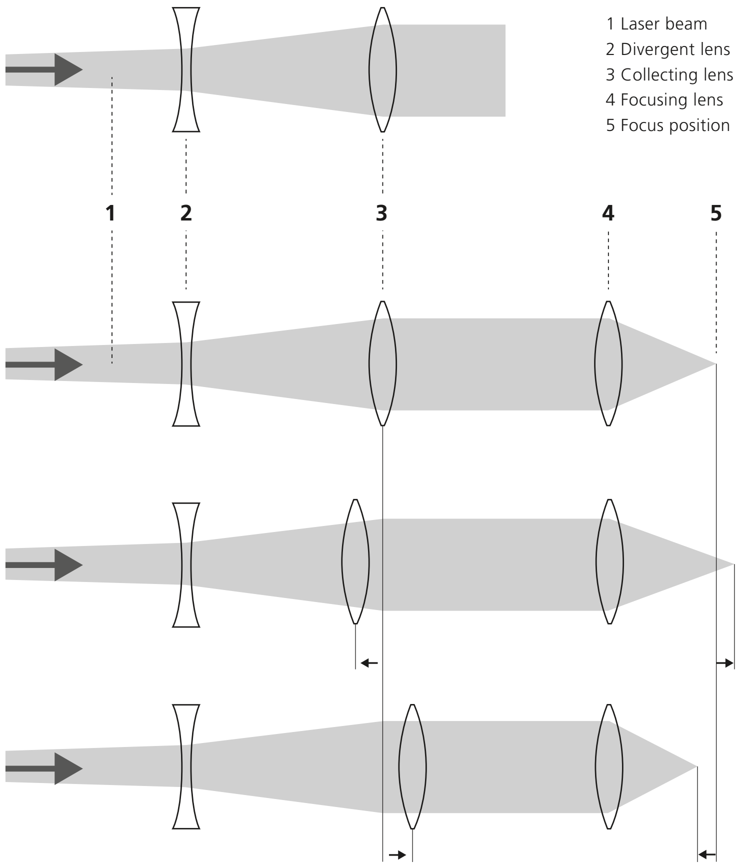
Ultrashort pulse laser for assembly lines.

2.7 BEAM GUIDANCE AND FOCUSING

The beam guidance is the path that the laser light travels after leaving the resonator and going to the focusing lens, for example, via mirrors and laser light cables. A rough distinction is made between two phases in beam guidance: beam expansion and beam deflection. Finally, in the focusing lens, the beam is focused on the workpiece.

BEAM EXPANDER

After the resonator, the laser beam is expanded and parallelized (collimated) in the beam telescope. This usually consists of two lenses that can be moved against each other: a diverging lens and a collecting lens that act as a telescope.



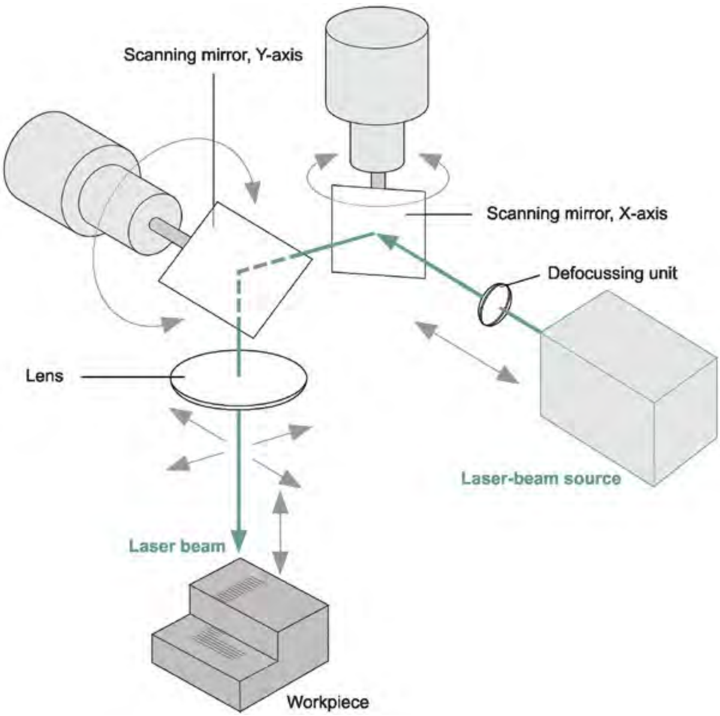
Beam expansion for focus position adjustment.

How much the beam is widened is a balancing of two goals: On the one hand, it should be widened as broadly as possible, because in the end it can be focused all the smaller. On the other hand, it should not get too wide that you can use as small — and thus quickly adjustable — mirrors as possible.

The two lenses of the beam telescope can be displaced against each other. Combined with the focusing optics, this is how the position of the focal point can be changed.

BEAM DEFLECTION

After expansion and collimation, the beam is deflected by two mirrors attached to a galvanometer drive and directed towards the focusing lens. This deflection scanner unit, or scanner for short, is controlled by the marking program and ultimately provides fast beam guidance over the workpiece without the workpiece or laser head having to be moved. With ordinary scanners, deflection speeds of more than 10 m/s on the workpiece are possible, allowing more than 100 characters per second to be applied. For optimum marking results, it is essential to match the pulse frequency and deflection speed.

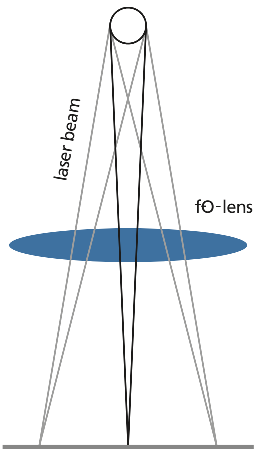


Principle of scanner optics.

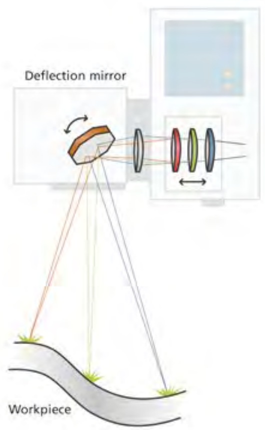
CONTENT

FOCUSING

The focusing lens focuses the laser beam onto the marking field by means of a lens system in order to achieve a high irradiance there and to enable material processing. In marking laser systems for 2D applications, a so-called plane-field lens with F-theta characteristic after the scanner is usually used, which focuses the laser beam on a flat surface — and not on a spherical surface like standard lenses. Focusing lenses for marking laser systems are available in different focal lengths. The **focal length** determines the following parameters:



Planefield correction of a F-theta lens.



Focal point adjustment with fast z-axis on a three-dimensional workpiece.

- **Marking field size:** The longer the focal length, the larger the marking field or marking volume.
- **Working distance:** The longer the focal length, the greater the working distance.
- **Depth of focus:** The longer the focal length, the larger the depth of focus range and the range in which the focus can be shifted internally.
- **Focus diameter:** The longer the focal length, the larger the focal diameter and the lower the power density on the workpiece surface.

3D focusing

With small height differences on the workpiece, the depth of focus is often sufficient, or the focus position can be adapted to the surface geometry of the workpiece with the usual adjustable focusing. For markings on workpieces with large height differences, for a long time either the workpiece or the optics were moved on the z-axis. Thanks to a different lens configuration, newer optics can also cope with markings on three-dimensional workpieces without moving the workpiece at all: Another lens, which functions as a beam telescope, is positioned in front of the focusing lens. It can be moved highly dynamically via a coil, so that the focal point can be adapted simultaneously to the movement of the scanner mirrors and moved freely in space. This turns the marking field into a marking volume.

2.8 MARKING SYSTEMS

The spectrum of laser marker systems ranges from mobile laser devices to automated processing stations. Small, cost-effective solutions and fully equipped, high-end systems offer the right solution for every requirement, depending on the marking task, the component volume and the lot size. The laser marker systems do not differ significantly in their basic structure. The following describes which components belong to a marking laser system and which equipment is necessary for different applications.

LASER CLASS 1

Marking lasers must be certified according to laser class 1 so that they can be used without additional safety measures. Sophisticated safety concepts with intelligent monitoring sensors ensure this at all times. The work area is secured by a safety door that closes during marking and guarantees safe working. A coated safety window, specially designed for the corresponding wavelength, can be installed in the housing to provide viewing.

EXHAUST SYSTEM

Particles that damage the lungs when inhaled can occur, especially during ablative engraving. That is why exhaust systems are required in laser marking systems. The filter system consists of a prefilter and a particle filter with activated carbon. The exhaust nozzle sucks in vapors and particles, which are then fed into the filter pack via a hose. Using suitable software, the exhaust system can be switched on with the marking system and switched off again after the control program has ended.

AXES

The z-axis supports the positioning of the laser head and the setting of the exact focus position. The machining process can be adapted to the component requirements by using other optionally available axis systems. For example, when marking larger surfaces, it may be necessary to move the part in two directions—this is referred to as surface segmentation. The workpiece holders are mounted on linear axes. Optional rotary axes allow for marking, even on cylindrical workpieces (rotary axis segmentation).

WORKPIECE HOLDER

With workstations for small series, the workpiece is usually inserted and removed manually. For larger systems, this is usually done automatically. A T-slotted plate or perforated plate mounted in the work area serves to receive workpieces or fixtures. Workpieces can be displaced and rotated with an optional rotary axis mounted on the axis system. When integrated into a production line, it is possible to remove the lateral housing if the laser is not to be integrated directly into a production line. The marking processes run automatically in conjunction with the workpiece movements.

2.9 PROCESS RELIABILITY

It is important to observe the marking process and adjust it if necessary in order to achieve a constant marking quality over the entire lifespan of the laser system. Several technical solutions are available for this purpose, some of which are presented below.

IMAGE PROCESSING

Image processing recognizes the component position and ensures that every marking is exactly in the right place. Usually integrated into the position monitoring system, the inspection system reads out the markings immediately after they have been applied and evaluates their quality and content. This also avoids accidental double markings. The quality inspection results can be recorded in a database for documentation purposes.

The integrated camera checks the position and the marking.

LASER POWER MEASUREMENT

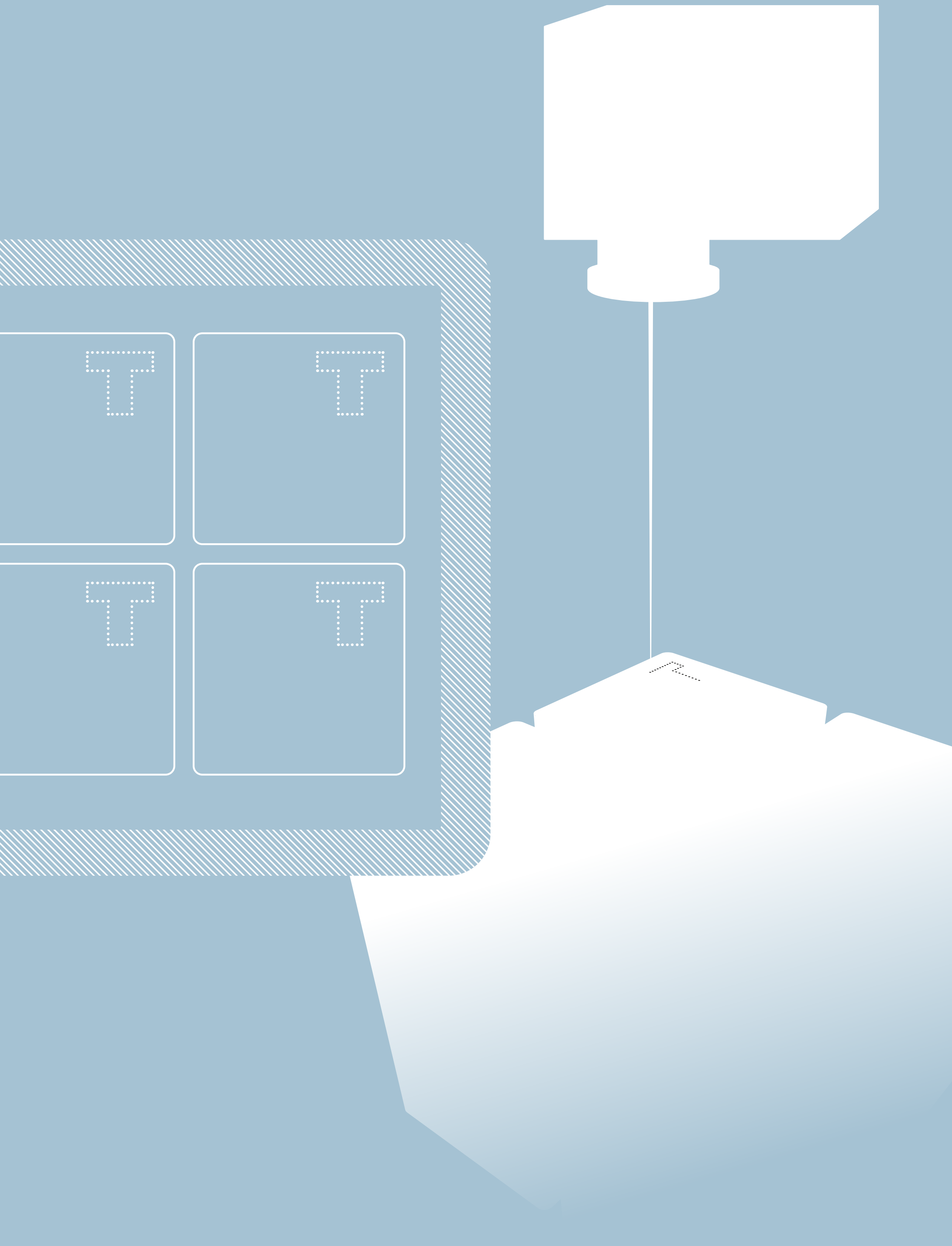
A constant laser power over the lifespan is an important factor for a qualitatively consistent marking result. A transparent mirror in the internal beam path can be used to always check the current power status. For physical reasons, the laser power always decreases slightly over a long period of time. With diode-pumped solid-state lasers, this can easily be readjusted by adjusting the current supplying the pump diodes. This is usually done automatically or semiautomatically.

LASER POWER CONTROL

If the ambient temperature fluctuates, this can also have an effect on the laser power and thus on the marking result. A modern laser power control therefore decouples a defined percentage of laser power from the beam path inline and measures it using photodiodes. A control circuit then automatically adjusts the pump power of the diodes, so that marking quality stays constant for the entire service life.

CONDITION BASED MONITORING

Sensor systems and the appropriate interfaces for reading out various information, such as the TruMark OPC/UA interface Condition Based Monitoring, are used to achieve a continuous and comprehensive status analysis of the laser and marking process in the sense of Industry 4.0. This information includes laser condition data and process parameters such as laser power or air temperature during cooling. Warning messages indicate the need for action at an early stage, and error messages become visible immediately — in this way, failures can be rectified quickly or even avoided altogether, preventing unexpected interruptions in production.



3. PRACTICAL MARKING

So you have chosen your materials and decided which marking process you need to use. Now comes the practical stage: when switching on your TRUMPF marking laser system, the TruTops Mark control software starts up automatically via the control computer.

The intuitive user interface makes it easier to access the following:

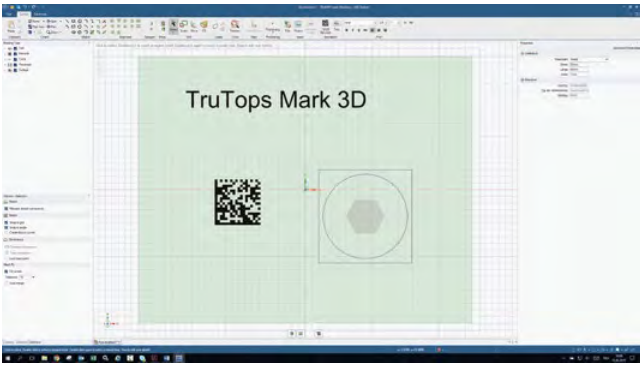
- CAD editor
- Setting and management of laser parameters
- Interfaces
- Easy marking on the fly
- Sequence programming
- Diagnostics tool

This set of tools enables you to carry out all of the steps required for applying the marking content to the workpiece.

3.1 DEFINING THE MARKING CONTENT

3D CAD EDITOR

The first thing that the laser needs to know is what the marking should consist of and where it should be placed on the workpiece. This is what the 3D CAD editor is for. It has both all the functions for the designing of components, fixtures and assemblies, and all the functions for drawing and arranging graphic objects that you find in complete CAD programs. The 3D CAD editor is used to create components and drawings, which are transformed into a marking program by the marking module, and then executed by the marking laser system. You can create both simple geometric shapes, such as rectangles, circles and texts, as well as complex programs with a number of different drawing elements. It is also very easy to create specific markings such as serial numbers and bar codes, and to import STP files as finished assemblies. Furthermore, corresponding convertors allow CAD drawings and components or image formats to be read in as vector or pixel files which can be modified and reworked as desired. The program also features graphic data for controlling the deflection unit of the marking laser system as well as the necessary laser parameters.



The markings are created in the CAD editor — both simple and complex ones.

FONTS

For the text, you have the option of using any TrueType font, and you can also import new Windows-based fonts. Fonts can be formatted in whatever way you wish — whether in mirror image, curved, or italicized. The hatching possibilities are also very versatile: you can fill in texts, logos and objects, and even work with multiple hatching in different angles if you want a higher material removal rate.

FILE FORMATS

Rather than defining and drawing the marking content yourself, you can import numerous file formats, such as DXF and STP files.

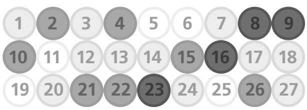
Kompatible Dateiformate sind derzeit:

ACIS (.sat/.sab/.asat/.asab)
AMF (.amf)
AutoCAD (.dxf/.dwg)
Image files (.bmp /.gif/.jpg /.jpeg/.pcx /.png/.tif/.tiff)
CATIA V4 (.model /.exp)
CREO Parametric (.prt/.xpr/.asm/.xas)
DesignSpark (.rsdoc)
ECAD (.idf/.idb/.emn)
Fluent-Netz (.tgf/.msh)
ICEM CFD (.tin)
IGES (.igs/.iges)
Inventor (.ipt/.iam)
JT Open (.jt)
NX (.prt)
OBJ (.obj)
OpenVDB (.vdb)
Parasolid (.x_t /.xmt_txt/ .x_b /.xmt_bin)
PLM XML (.plmxml/.xml)
PLY (.ply)
Punktkurve (Text) (.txt)
QIF (.qif)
Rhino (.3dm)
SketchUp (.skp)
Solid Edge (.par/.psm /.asm)
SolidWorks (.sldprt/.sldasm)
STEP (.stp/.step)
STL (.stl)
TruTopsMark 3D Templates (.scdot)
VDA (.vda)
VRML (.wrl)

MARKING BITMAPS, GRAPHICS AND IMAGES

With the Imager tool, it does not take long to mark grayscale images that are high in both quality and resolution. You can mark complex graphics and designs at very high speeds, and the resulting gray shadings are of excellent marking quality and high contrast. Each pixel is only scanned once, each one with a specific laser parameterization.

The Imager can be used to create high-quality grayscale pictures.



VARIABLES

The text or value used in the data object can be defined as a fixed and invariable object ("static object") or as a variable. Variables (e.g., serial numbers) are not filled with the content until the marking stage. When you run the marking program, the variable text is generated from constants, a keyword (such as the current date), a serial number, or a variable that has already been created. You can either merge several objects together (keywords, constants, variable), or transfer the variable directly to the marking system via the external interface.

BAR CODES

The variable data can simply be coded as a one- or two-dimensional bar code. Bar code types differ in terms of the symbols that can be used, the coding, and the length of the desired text. With TruTops Mark, it is possible to generate numerous different bar codes, square and rectangular Data Matrix Codes and DMRE codes (also in accordance with the GS1 standard), and QR codes. Together they form a sequence of different symbol sizes, with which you can code small and large amounts of data efficiently. The laser can select the formats automatically, and scanning devices are able to differentiate between them automatically.

CONTROL WITH EXTERNAL DATA COMMUNICATION

TruTops Mark can be controlled via different interfaces using external data communication. The integrated interface can be used to incorporate variable production data online into a predefined marking program. With TruTops Mark, you have the following options for the control-side integration of the marking laser system into existing manufacturing systems:

- TLV
- Digital I/O
- TCP/IP
- Profibus
- Profinet
- EtherNet/IP
- EtherCAT

ACTIVEX TRUTOPS MARK COMPONENT

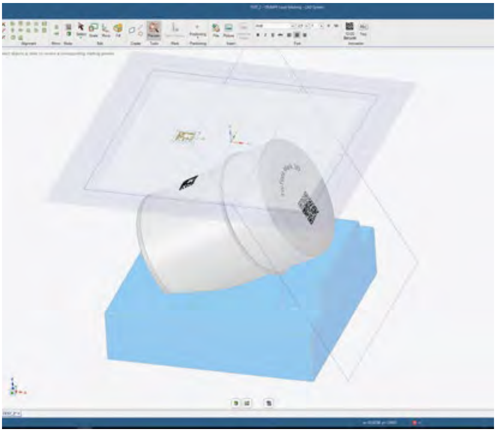
The ActiveX software component for TruTops Mark facilitates integration by means of ActiveX data exchange. Predefined tag-length-value commands can simply be integrated into the customer's process environment.

CONTENT

3.2 ALIGNING THE POSITION

The **marking field** is the area that the laser is able to mark, i.e. the area that is covered by the scanner. The size of the marking field depends on the machine configuration and is set in the marking interface according to the chosen optics.

Using 3D hardware (TruMark 6030), it is possible to generate markings on 3D surfaces—in this case, a marking field becomes a marking volume with an additional z-component.



Wrapped marking content for a 3D marking.

A suitable **workpiece holder** for the components ensures that these are always in exactly the right position. However, this type of fixture is not needed every time, as the marking application is noncontact and thus, does not apply any force to the component.

With the **pilot laser,** it is very easy to align the marking. The pilot laser emits a low-power red light via the laser optics. For the positioning, the marking processes are simulated on the workpiece using the pilot laser, before the actual marking is applied.

For the positioning, the pilot laser simulates the marking.

A **marking preview** in the CAD editor provides an indication of the result, whereby you can also view the variable content, hatching, as well as the 3D wrapping or projection.

The **VisionLine** camera system makes it very easy to position the marking and align it optimally. The marking is projected onto the surface of the component, thus enabling the marking to be positioned perfectly from lot size 1. A marking field camera with angle correction displays a camera image in the CAD editor, and the marking can be superimposed and positioned on the image.

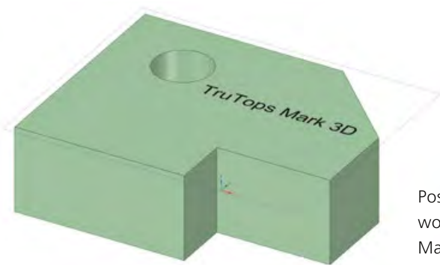
CONFIGURING THE FOCUS POSITION

It is important that the laser always operates in the optimum focus position. Users can choose to set the working distance either manually with a simple ruler, via Focus Finder with two projected crosshairs, or semiautomatically using a sensor with triangulation measurement or with the image processing VisionLine adjusting the focus position using the sharpness of the camera image.

Focus Finder

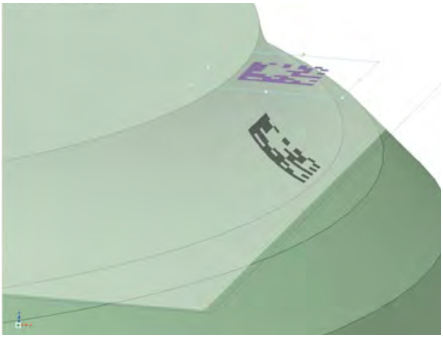
POSITIONING THE WORKPIECE IN TRUTOPS MARK 3D

In TruTops Mark 3D, the laser can identify the position and the geometric characteristics of the component due to the workpiece-based design of the software. The focus position and z-steps are also determined automatically. This 3D workpiece positioning tool saves time and is very convenient to use. The marking geometries are automatically set to the correct height in relation to the workpiece and the laser.



Positioning of the workpiece in TruTops Mark 3D.

In the **marking of 3D surfaces**, the marking geometry lies above the workpiece and can be either unfolded onto the surface (i.e. stuck on like a sticker), or projected onto it like a cast shadow.



DMC projection
on a 3D surface.

Through its automatic position recognition, the **VisionLine image processing software** guarantees increased process reliability and more productivity. It recognizes the position of the component, ensures that every marking is in exactly the right place, and checks it immediately. The system reports missing components and actively prevents markings from being applied twice. Time-consuming setup, expensive fixtures, and unnecessary rejects are things of the past. The feature that you want the system to detect is simply selected from a comprehensive library of predefined features and entered with the code that is to be read in, along with a few parameters—and you're all set to go. The functions can also be integrated as a standard process into an automated marking process.

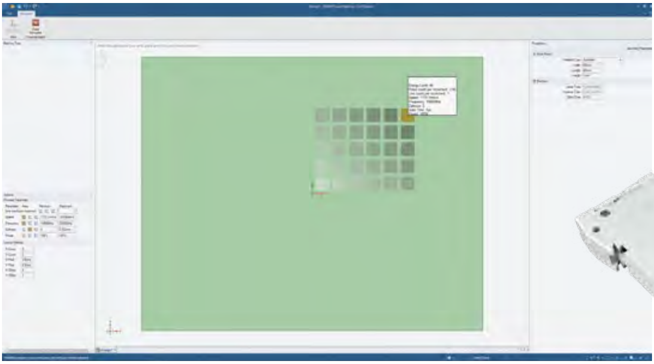
VisionLine for
positioning:
measurement of
workpiece position
and correction of
marking position.


Station 5000
TruMark Station 5000
TruMark Station 5000

3.3 SELECTING THE PARAMETERS

NAVIGATOR

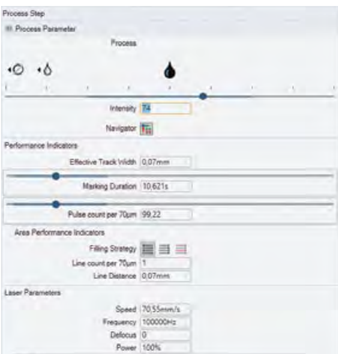
The Navigator assists users in finding the right laser parameters for their marking task in the fastest way possible. The only thing left to do is to choose the material that you want to mark. Each type of material is assigned to one or more different processes (e.g., engraving, annealing, color change). The objects that are marked as a test field are freely selectable objects in freely selectable dimensions. The test field is marked onto a workpiece. In this way, you can select the parameter with the required contrast or desired quality for subsequent markings.



The Navigator helps users to find the right laser parameters.

MAGIC 5

In the case of the Magic 5 option, the software already knows the physical characteristics of the laser, and the configuration is stored automatically. This means that inexperienced operators do not need any knowledge of lasers to apply markings. There is a slide control bar that enables you to apply light-dark contrasts onto metal or plastic, without having to adjust the individual laser parameters manually.



Simple light-dark contrasts using the slide control bar in Magic 5.

The software also features a **parameters library/global parameters table** via which parameters that have been used once can be transferred to new marking files. This is also possible for different types of hatching and variables, and accelerates the processing.

APPLICATION SERVICE

Processes are influenced by a host of different parameters, and knowing how to adjust these parameters means you can optimize your processes accordingly. TRUMPF provides users with personal assistance in this respect—either in our application centers, over the phone with the Technical Service or on-site.

3.4 DEFINING THE PROCESSES

SEQUENCE PROGRAMMING

The sequence program can control all of the machine functions in connection with a TruMark Station. These sequence programs can be written or changed via the editing mode.

The visual software program **QuickFlow** was developed so that the process routine is easy to create. Using a simple pick-and-drop system, you can create programs that control the entire marking cycle from start to finish. You can also take advantage of even more flexible and comprehensive possibilities, by using the **WSTX sequence programming** used for the TruTops Mark Module Interface.

TRUTOPS MARK MODULE INTERFACE (TTM-MI)

This human-machine interface enables you to make specific adjustments to the software, and is how communication is programmed between the laser (TruTops Mark) and other systems, databases, tools, and robots.

Standardized module interfaces for different requirements are easy to incorporate into any production process. These include:

- **Basic module** for basic functions such as loading, saving, marking and axis commands, variables, marking preview, status/errors, cycle time
- **Scanning module** for scanning input data, multiple scan inputs, GS1 standard check
- **Database module** for connecting to databases using the database assistant and for running database commands (available: SQL Server, OLEDB, Oracle, MySQL, SQLite, PSQL)
- **Camera module** for the VisionLine functionality, autofocus function, reading out function, etc.
- Specific **UDI module** for marking medical devices, which enables the configuration of the device identifier (DI) and production identifier (PI). This makes it possible to produce UDI-Codes according to standards as GS1, HIBC oder ISBT 128.
- If the standardized modules are not suitable, new modules can also be programmed that are perfectly customized to your requirements.

In this way, users can use fully automated processes and profit from the elimination of error sources. The entire process, including the process results, can be stored in a database.

For more information about this process please see chapter 1.4 “Medical technology”.


Station 5000

3.5 MARKING

WORKSTATIONS

When a laser marks products that are produced on a mass-scale and in an automated way, it (i.e. the processing station) is integrated into the production system. The system is usually a solution that has been customized for the customer. The types of systems that are most practical in this sense are systems that are modular and can be adapted to specific requirements. The ideal systems for both small series and a wide component spectrum are independent **workstations** in which the workpiece is often inserted and removed manually. They comprise the laser, a self-contained working area with a workpiece holder and exhaust system, and the operating interface with a screen, keyboard and mouse via which the process is controlled.

Marking machines are available in many different versions to cater for workpieces of different shapes and sizes. The workpiece holder is movable, in the event that you need to mark large surfaces. The holder can move the workpiece along one or two axes (area segmentation) and also rotate it (rotary axis segmentation), if required.

IMAGE AREA SEGMENTATION

Workpiece pallets can be marked in one go—including any variable data that is applied to every component. You can also use short focal lengths to create fine line widths at a high throughput. For this, the marking field is moved along, segment by segment, by the x- and y-axes.

For the image area segmentation you can choose from two options:

- The **segmentation for the x-/y-axes** allows you to mark large workpiece areas beyond the marking field (i.e. the palletization of workpieces). The size of the segment can be freely defined, row by row and column by column.
- With the **segmentation for a rotary axis,** it is possible to apply circumferential markings on cylindrical workpieces. The size of the segments and the angle can be defined freely. The program is created in the editor interface.

Through the image field segmentation, pallets can be marked in one go.

MARKING PREVIEW

The marking preview enables you to check the marking content before the actual marking is applied. The display field depicts the marking program that is running in a smaller rendition of the CAD editor.

MARKING TREE

The order and grouping of objects in the marking tree determines the order in the processing. After the initialization of a marking file, created geometric objects are first marked in the order of creation in the marking tree.

MARKING TIME

The order in the marking tree influences the marking time. Jumps in the marking field should ideally be minimized as much as possible. Both the marking time simulation for individual objects and a marking time preselection help in this regard. It is not necessary to provide estimated values for checking the runtime of an application task beforehand. This decreases the throughput time. When specifying the cycle time, you can even adjust the parameters automatically via the Magic 5 option.

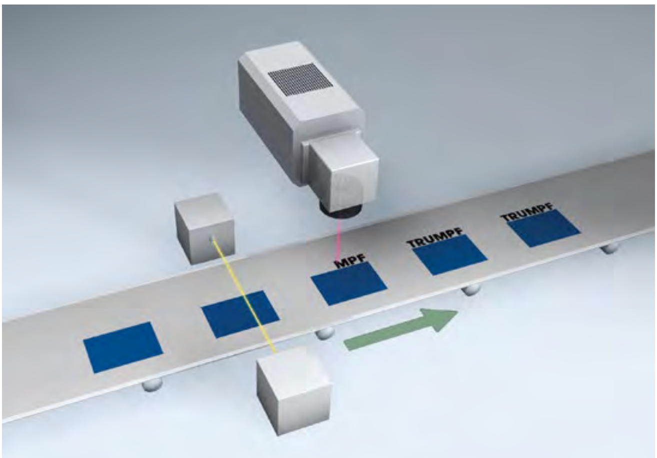
PRODUCTION MODE

In production mode, the file name is displayed during the marking process, as is a live display of the marking content in the preview window. Once the marking is complete, the cycle time, the number of parts that have been (or still have to be) produced, and the mean cycle time across x marking processes are displayed.

Every important information at a glance in production mode.

MARKING ON THE FLY (MOF)

With MOF, users can mark workpieces within ongoing production processes, without having to halt the production line. MOF superimposes the movement of the object that requires marking with the movement of the laser beam, so that the marking is not blurry. The transportation of the workpiece is continually measured via encoder signals, so that the marking can be applied with consistent quality during start-up and deceleration processes.



Marking on the fly.

3.6 CHECKING QUALITY AND READABILITY

Quality is a flexible concept and laser marking is often subject to predefined cycle times. Very short cycle times require a compromise between the required cycle time and feasible marking quality.

QUALITY OF LASER MARKINGS

The following attributes provide an indication of the quality of a laser marking:

- Contrast and color — considerable distinction compared with the base material
- Homogeneity and uniformity across the entire typeface
- Resistance (including against acids, alkalis, and corrosion), scratch resistance, and abrasion resistance
- Contour precision and sharpness of detail (important for decoding of codes)
- Positioning and dimensional accuracy; shape and size according to specifications
- If relevant, engraving depth, e.g., to achieve a particular level of wear resistance
- If relevant, track width of symbols
- Absence of burrs, e.g., in the case of medical devices, or markings on mating surfaces

You can use a commonly available colorimeter or a luminance measurement to quantify the contrast, although in practice users often resort to a visual evaluation. As many of the effects are contrary (e.g., a higher contrast is only possible by accepting an increased surface roughness) — the relevant application and individual requirements play a decisive role.

QUALITY OF CODES

The readability of bar codes and Data Matrix Codes should be checked using a suitable camera system straight after the marking has been applied, and the quality of the code should be verified.

The following points make for the ideal code:

- The highest contrast possible
- High level of edge sharpness of the cells
- Depending on the background, an additional quiet zone (light field all the way around, at least twice as wide as the size of the module)
- The ratio between the lasered cells and the gaps should ideally be 1:1
- High degree of homogeneity of the lasered cells
- ”Closed border“ and ”broken border“ are consistent

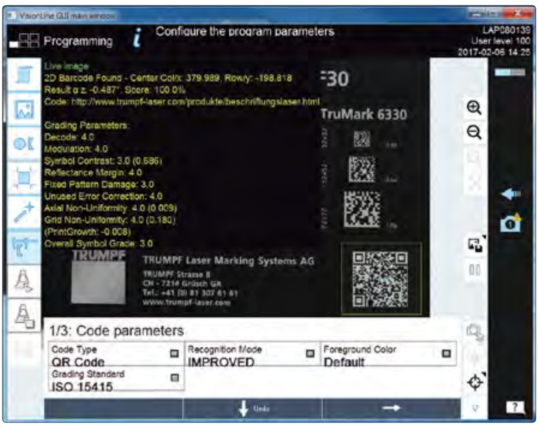
Camera systems check the quality of codes.

Video: “Image processing with VisionLine for marking — keeping an eye on everything” www.trumpf.info/ltnhea

The **VisionLine** image processing system also assists in determining the quality of 2D codes (Data Matrix or QR). The software obtains information from files or databases, turns this into codes, and marks them.

Straight after the marking process, a camera scans the generated code on the component, and compares the content with the received information. This way, you can immediately determine whether a code is actually readable and whether the content matches the initial information. The quality grading option assesses the quality of the marked code based on the standard for the direct marking of Data Matrix Codes, and then documents the result.

The VisionLine software automatically checks the readability and content of codes via a camera system.



3.7 APPLICATION SUPPORT AND SERVICE

TRUMPF LASER APPLICATION CENTER

Our service starts before users have even decided on a particular laser, as the TRUMPF application labs located across the globe assist with the decision-making process. This is where engineers work with the customer to establish processes and equipment, with the help of prototype components and a requirements catalog. For this, we carry out tests with lasers from the entire product range, so as to establish the best combination of marking quality and processing time.

The following are possible in the TRUMPF Laser Application Center:

- Full access to the TRUMPF machinery
- Tests with all types of lasers
- Tests with all focal lengths
- Machine demonstrations
- Application tests and process development
- Checking of processing quality, e.g., the verification of codes

TRUMPF TRAINING COURSES

TRUMPF offers users a variety of different training courses, so that they understand how to operate their laser in the best way possible. There are training courses for all qualification levels — from beginner through to seasoned laser users.

Advantages of TRUMPF training courses:

- Take a course directly on the machine
- Theoretical and practical content — depending on your requirements
- Novice through to expert level
- Global network of training centers

REMOTE SERVICES

With TRUMPF's monitoring and analysis products, users can maintain an overview of their equipment and processes at all times. Statuses and processes can be monitored in real time, thus enabling you to avoid instances of machine and production standstill. They can also assist in identifying opportunities for improvement that could enable you to reduce your production times and costs.

GLOBAL SUPPORT

TRUMPF has a global service network that offers everything from installation and maintenance through to repairs. Many problems can be solved via Remote Diagnostics. However, in the event of a more serious problem, a service engineer can address it on-site.

TRUMPF is certified to ISO 9001
(Find out more: www.trumpf.com/s/quality)

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TRUMPF

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