Pure Air for the Ultra-Short Pulse Laser

Process Research to characterize the Particle Phase in ultra-short pulse Lasers

The ultra-short pulse laser provides a precision and quality that have been previously unknown. This is a fact. And because of new applications, this relatively young technology is becoming more and more established in industry. What has been mostly ignored, however, is the question of which particles are entering the environment using this laser. ULT has found the underlying cause of this issue.

Laser processing can be found in many different industrial areas. Process methods are additionally developing very fast. But new processes and developments in processing technologies must be critically assessed in terms of current and future resulting harmful air-borne substances.
This “looking ahead” has resulted in a series of developments, for instance in process safety in the structuring of silicon wafers in the photovoltaic industry, or, more recently, in the large-scale production of high-power battery cells.

In the case of the ultra-short pulse laser, the question arises about the type of particles that are created through the specific ablation process, and which then enter the environment. Plant operators are of course subject to the Ordinance on Hazardous Substances (GefStoffV). This stipulates that hazardous substances are to be captured directly at the point of generation and discharge, and disposed of without posing any risk to persons, machines or the environment. This forces the assumption that the more focussed and higher frequent the energy used in processing is, the tinier the particulate components of an aerosol are.

A whole series of laser systems have confirmed this tendency, and require specially adapted filter systems so that process, employees and the environment are not negatively impacted. Claims for damages against operators could also be prevented, though these might be justifiably asserted at future points in time. Besides protecting people from hazardous substances, pure air is also a condition for the smooth running of machines and the production of high quality products.

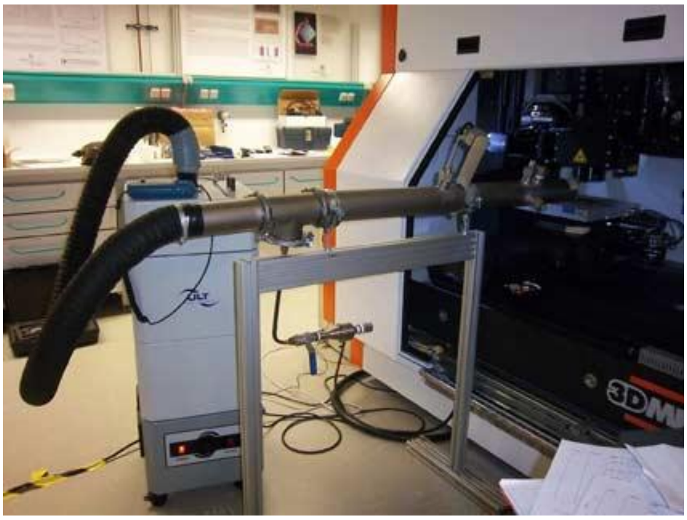

Image 1: *To investigate the characterization of the particle phase in an ultra-short pulse laser, a measuring structure consisting of exhaust pipe, measuring path, and LAS 200 exhaust device was installed*

The investigation's remit: to scrutinize everything closely

The goal of the investigation was to characterize the particle phase in an ultra-short pulse laser. The question was what influence different process parameters have on particle size distribution and furthermore what concentration of released particles is exhibited at a laser structuring system – a picosecond laser. The influence of the material (stainless steel, silicon, ceramic) on the particle size distribution was also examined. The objective for the engineers of the extraction and filtration system vendor ULT AG was to reach conclusions that would aid the construction of process-secure systems, which purify air, so that ultra-short pulse lasers can be operated in a way that is environmentally acceptable.

The investigation examined repetition rate, laser performance, distance and position of capturing equipment, separation efficiency of the filter device, and the influence of the removed material. These parameters and their influence on particle emission when processing different materials with the ultra-short pulse laser were scrutinized closely. In doing so, the influences on particle number, concentration and distribution were determined. To carry out the investigation, the Fraunhofer IWS and the Institute of Air Handling and Refrigeration (ILK) installed a measuring structure onto an ultra-short pulse laser, consisting of exhaust pipe, measuring path and exhaust device.

Image 2: During the first step, the influence of repetition rate on particle size distribution, and the number concentration of emissions during processing of stainless steel were investigated.

Hazardous substances have to be captured at the place they are generated
The first step taken by the experimenters was to investigate the influence of repetition rate on the particle size distribution and the number concentration of emissions during the processing of stainless steel. Up to a repetition rate of 500 kHz, this affects particles with a size of around 70 nanometers at medium to high number concentration, and demonstrably, at a frequency of 200 kHz that is usual in industry. A particle size of around 100 nanometers represents the maximum in the rising particle spectrum when processing stainless steel with the short-pulse laser.

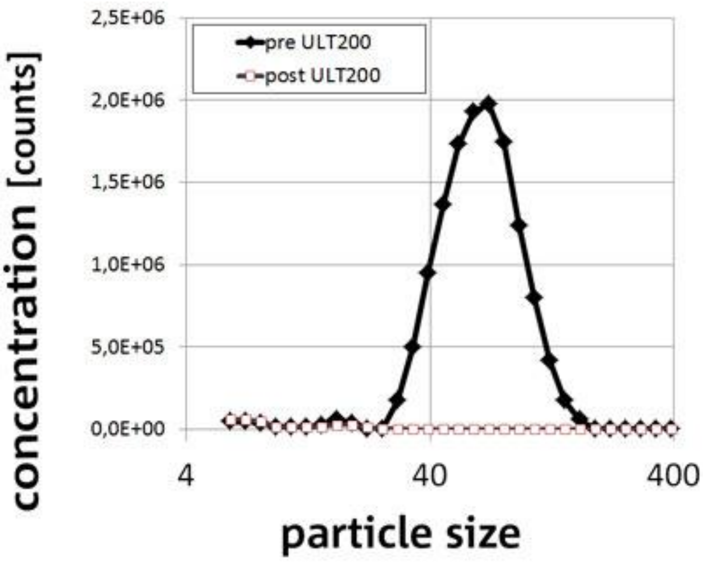

Image 3: A particle size of around 100 nm represented the maximum in the rising particle spectrum during processing of stainless steel with the short-pulse laser.

Ultra-fine particles of 100 nanometers or smaller are viewed as respirable. This means that they can penetrate into alveoli. Nanoparticles can permeate through the natural barriers of the human body and can cause severe damage over a long period. For this reason, it is necessary to keep them out of the biosphere.

An increase by 5 cm in the distance to the emission source leads to an approximately 60 percent lowering of particle concentration in the exhaust. An increase in the distance by a total of 20 cm leads to a lowering of 95 per cent compared to a distance of 0 cm. Therefore, the requirements for construction are that hazardous substances must be captured directly at the place where they are generated. The capturing equipment also has to follow fast-moving and changeable processing points. The utilization of the proper capturing element (suction pipe, hood, cabin etc.) depends on the application − if required, with specially constructed capturing elements.

Capturing the particles

The height of the vertical central axis of the intake manifold above the processing point was changed in addition to the distance. Because the scanner head was arranged near the work piece surface, the capturing height influenced the position of the maximum particle size distribution only slightly. It had to be ensured that the capturing equipment was positioned very close to the place where the hazardous substances were generated, and if required, automatically tracked for locally changeable processes.

The flow conditions cause the achievable capture efficiency for the entire system to have the same level of importance as the actual effectiveness of the filter device. Extreme filter efficiencies remain without effect on the air pollution control unless the hazardous substances are captured at a high level. Capturing also has a fundamental influence on an exhaust system’s energy consumption. Even a doubling of the distance could lead to four times the volume flow, thus resulting in eight times the energy consumption. The correct choice of capturing element improves its range and ensures high exhaust quality while minimizing running costs.

In terms of the separation efficiency of the filter device, the investigation concluded the following: after passing through the filter device, air with clearly reduced particle concentration is released on the pure gas side. The separation efficiency of the ULT filter device with specific high-performance filter materials for particles >34 nm is almost 100 per cent. Surprisingly, the tests also show that during the operating process of short-pulse lasers, small proportions of thermally influenced components can appear in the form of molten particles.

Regenerable cartridge filters and downstream storage filters

Much more critical when it comes to air cleaning, is the depositing of particles in the form of a “nano wool”. This is caused by the binding force of removed particles to one another that leads to a “cohesive sintering process“. The deposits quickly reduce the efficiency of the exhaust system and significantly increase energy requirements. The filters can become clogged if selected incorrectly, and in extreme cases, they may even become breached. For this reason, the filter system has to demonstrate a self-cleaning function. The solution by the ULT engineers was to combine regenerable cartridge filters and downstream storage filters.

The cartridge filter has a special automatic self-cleaning regime. The subsequent fine cleaning is executed using HEPA filters with very large surfaces. In this way, even for ultra-short pulse processes, basic energy efficiency can be maintained, and operating costs reduced. When laser performance increases, the particle concentration does not rise to the same degree. The maximum particle size distribution shifts slightly across the different performance ranges from 80 to 69 nm. The influence of laser performance on the particle distribution therefore has little meaning. The type of filter does not need to be changed. Naturally, the capacity and size of the filter, as well as the device for capturing particles, have to be adapted to the process conditions. The number of particles released at the processing location and their size depend on the material.

Danger of the emission of respirable fine dust particles

At a repetition rate of 200 kHz, ULT discovered similar concentration levels during the processing of stainless steel and silicon. In contrast, when ceramic was being processed, an 80 per cent smaller particle concentration occurred compared with stainless steel processing. When stainless steel and ceramic are processed, particles of a similar size spectrum are released. Conversely, larger particles are discovered when silicon is processed. At a repetition rate of 4,000 kHz, ceramic and silicon processing releases a similar number of particles, while for stainless steel, less particles are generated.

Image 4: 3D-Micromac provided a system with ultra-short pulse laser as experimental object.

3D-Micromac AG is a leading manufacturer of highly efficient machines for laser micro-processing. To ensure the environmental and health compatibility of the process, 3D-Micromac has been working successfully with ULT AG for a long time. For these investigations, they allowed us use their new ultra-short pulse laser structuring system. The results have shown that the parameter repetition rate and distance between capturing device and processing location are the decisive factors for the emission of particles and their removal. The tests clearly show that while the danger of the emission of respirable fine dust particles does exist, effective capture and filtration prevents this. The maximum particle size distribution lies at around 100 nm. With increasing laser performance, the number of particles rises as expected. The filter combination of cleanable cartridge filter and large surface area H13 pocket filters is very suitable for separating particles that are released during the processing of stainless steel. The separation efficiency for particles >34 nm is almost 100 per cent.

Safe process – clean atmosphere

Selection and construction of the capturing devices, as well as how they are mounted or tracked, are decisive when it comes to achieving a safe process and a clean atmosphere. Depending on the type of material being processed, the maximum particle sizes differ in the spectrum of the complete particle, which nonetheless has little influence on the configuration of the filter device. Processing ceramic and silicon allows a larger particle number to be generated than stainless steel, which should be considered during the measuring and servicing of the filters.

With the results of the investigations and the conclusions regarding construction, ULT have made a technical advance towards the safe equipping of short-pulse laser systems with air cleaning systems.

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