Laser fumes in femtosecond laser processes – product, process and environment considerations

Introduction

Advanced laser processes find increased utilization in production processes. The later fosters an in depth understanding of laser fumes, which are a major factor of product quality, machine life and environmental/safety and health considerations. Short pulse laser processes are focused on non-melting preparations. On this basis, exciting new applications arise. Starting from hard-glass manufacturing, over thin film photovoltaic patterning to Lithium-Ion Battery electrode structuring virtually every advanced technology relies on ultra-short pulse laser processes. [1-6]

Experiment

The presented study was performed on a femtosecond laser with a wavelength of 1064 nm [3]. Correlations between type of ablated material, particle size distribution as well as particle concentration have been investigated. Especially, the difference in particle size between steel and plastic has been evaluated.

The aerosol resulting from laser material processing was captured close to the source and sucked towards a filter system. Particle size distribution was determined continuously using an Engine Exhaust Particle Size (EEPS) which measures particles sizes in the range from 5.6 to 560 nm. For this purpose, a sample was analyzed by the instrument.

Particles within the sample are positively charged and move within an electric field towards electrometers where their charge is transferred. The charge is a measure of particle-surface-area. According to their electrical mobility particles reach different electrometers. Based on current flows particle size distributions are calculated. In addition, sample were taken from the filter and investigated by Secondary Electron Microscopy (SEM) for analyzing the shape of the particles.

Figure 1: Extraction and filtration system LAS 260 for ultra-fast laser processes

The raw gas was filtered using the filtration system LAS 260, a storage filter with F9 pleat pre-filtration. This pre filter consists of high surface area with a well-defined cross flow to ensure long filter life. A secondary particle filter with the HEPA class H14 ensured cleaning capability to 0.005% of total particle count. Further down the gas stream activated carbon was located to remove eventual reminders of hazardous gases from the laser process.
Additionally, the performance of the filter system LAS260 was determined. For this, the laser was kept in stationary conditions and the particle concentrations in raw gas and purified gas were measured using the EEPS-method.

Results and Discussion

The figures 2-4 illustrate the particle shape, as seen in SEM investigations. As expected, the majority of these particles is none melted. Though, a small amount of the metal debris proved to be hemispherical, which is a sign for sufficient thermal energy to melt this material. In any case the size of these particles is very small, in the range of d=100…200 nm.
In contrast to the metal process the plastic debris seemed to be initially smaller, though it formed small, agglomerated plates on the filter. The particle shape is mostly cubic. Forming plates can be caused by thermal energy during the agglomeration phase on the filter.

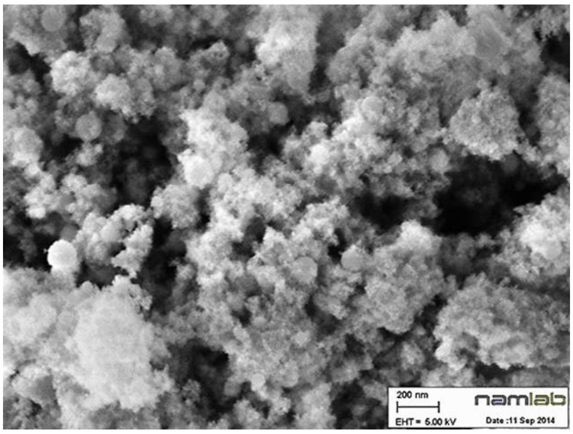

Figure 2: Particles of steel from an fs ablation process (first location)

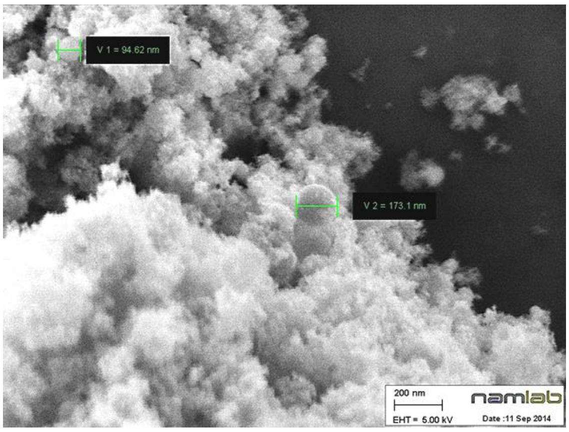

Figure 3: Particles of steel from an fs ablation

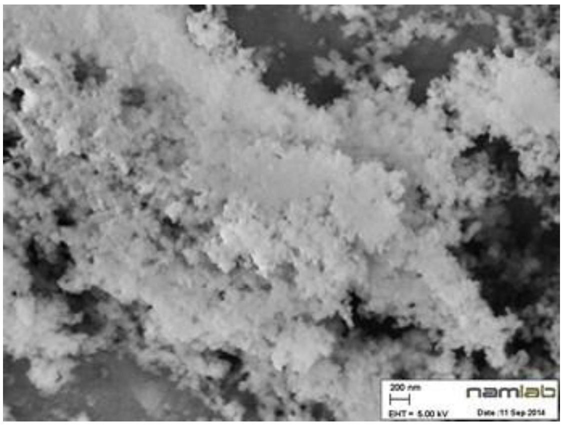

Figure 4: Particles of plastic from an fs ablation process

Based on these findings filter technology must be revised. Starting from extraction; the high kinetic energy of these particles has to be considered. Small particles are faster due to kinetic impact. The basic rule of extracting the fumes close to the source needs to be extended to another extraction point further up for capturing the small particles in the nm range as well.

As the size of these particles is mainly in the range of nm they can enter the lung-blood barrier, causing high risks on health. Therefore, standard filter technique is in many cases not suitable for air cleaning. Figure 5 depicts the basic principle of particle filtration as used in the LAS 260 extraction system as demonstrated the majority of the particles are kept in the F9 filter, ensuring low maintenance cost for the operator.

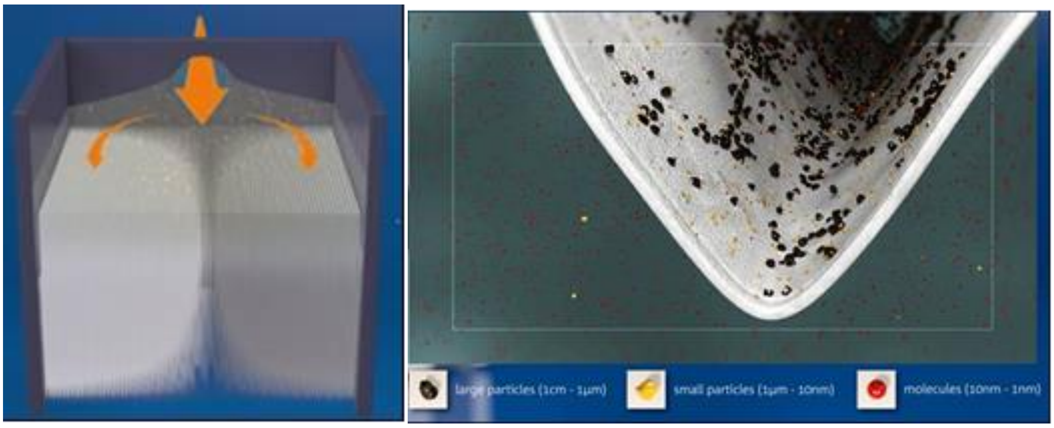

Figure 5: Filter principle of F9 pre-filtration in LAS 260

Figure 6 depicts the measurement results of EEPS during the plastic process. The statistic maximum of plastic particles was at d=90 nm with a concentration of 3...4 10^5 particles per cubic centimeter. This value is well above acceptable concentrations for high product quality and operator health. By employing the filter sandwich of LAS 260 the clean gas was on the same level as the background signal of the lab with dN <<10^2 #/cm³. Hence, a high-quality operation in terms of laser fume is possible.

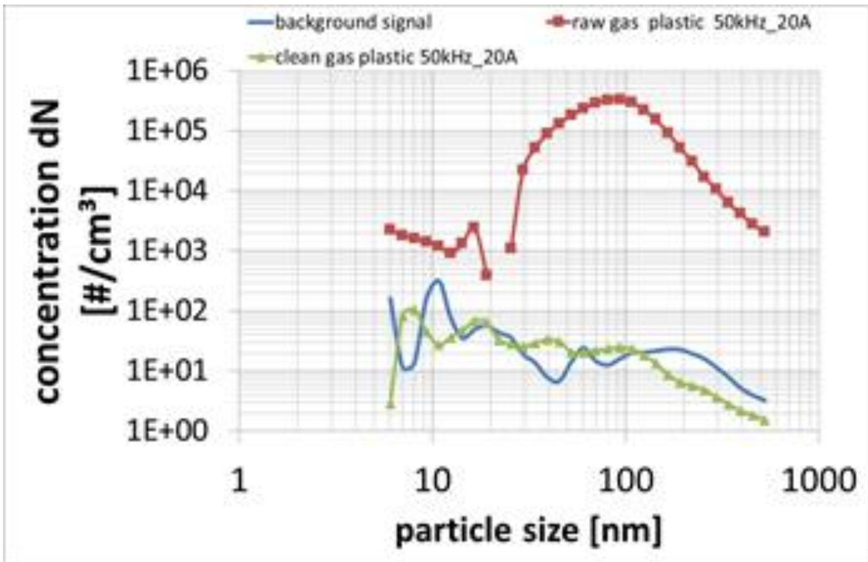

Figure 6: EEPS data of raw- and clean-gas during preparation of plastics with an ultra-fast laser. Clean gas was filtered by particle filter system LAS 260

Summary

Ultra-fast laser processes, especially in the femtosecond range have been investigated in terms of particle distribution during the operation. Particle size is found to be in the range of d=50 nm…200 nm in significantly high concentrations of up to 10^6 #/cm³. By using the new LAS260 with pleat filtration and HEPA post filtration a fractional deposition is the filter of >> 99% was demonstrated. For non-cancerous and mutagenic materials, the filtered air can be re-circulated in the working environment for saving energy cost.

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Authors:

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