11[th] CIRP Conference on
Photonic Technologies [LANE 2020]

Industrial Paper

Hybrid additive-subtractive 3D manufacturing using femtosecond lasers

Linas Jonušauskas[a,b*]

[a]Femtika Ltd., Saulėtekio Ave. 15, Vilnius, LT-10224, Lithuania
[b]Laser Research Center, Faculty of Physics, Vilnius University, Saulėtekio Ave. 10, Vilnius, LT-10223, Lithuania

Abstract

Femtosecond laser technology was proven to be a powerful toll in laser material processing. As it matures, there is ever higher drive to apply it in the industrial setting. One of the key advantages of using amplified femtosecond laser systems is possibility to widely tune laser parameters, which allows to induce huge variety of light-matter interactions. This results in possibility to achieve both additive and subtractive structuring with a single light source. In this paper we will discuss possibilities and challenges of such approach. We show how it could be applied to produce various functional structures and devices including microoptical elements, hierarchical surface patterns and lab on chip devices. Furthermore, considerations how to realize it in one highly automated workstation is given, with the emphasis on how it can be used in both scientific and industrial setting.

Keywords: femtosecond laser; material processing; comercial workstation.

1. Introduction

Femtosecond (fs) lasers gathered substantial interest over the last two decades. Due to very short pulse duration and possibility to achieve light intensities in hundreds of TW/cm^2, highly nonlinear light-matter interactions could be realized. Furthermore, as shown in work by Chichkov et al. (1996), interaction in the focal point was shown to be fast enough to prevent substantial heat dissipation from the effected zone to the surrounding material, thus allowing to realize extremely precise ablation or, so called "cold processing". Additionally, Maruo et al. (1997) demonstrated that fs pulses can also be used to induce two-photon polymerization, meaning that it can be used for additive manufacturing as well. Indeed, the main difference between these processing regimes is laser parameters. Overall, pulse duration, wavelength, pulse repetition rate and focusing properties must be considered. Nevertheless, in simplified case, by going from nJ to hundreds of μJ in pulse energy (or from hundreds of GW/cm^2 to hundreds of TW/cm^2 in light intensity) all the processing regimes from polymerization to ablation can be achieved.

As required laser parameters needed for different processing regimes can be quite diverse, for a very long time it was considered that a special laser and setup is needed for each processing regime. However, development in amplified laser technology allowed to produce fs laser sources which can be adjusted to cover basically all the parameter range needed for any general laser material processing operation, starting from additive manufacturing and going all the way to transparent medium ablation. In this work we show how this flexibility can be exploited in a simplified and highly ergonomic workstation. We show that such setup can be used in highly specialized fields like microoptics or surface structuring. Additionally, advantages of using single setup hybrid additive-subtractive laser manufacturing in areas as microfluidics is demonstrated as well. Main considerations for using this approach in scientific and industrial settings are provided.

2. Methods and materials

In this work we used fs laser workstation "Laser Nanofactory" by Femtika Ltd. shown in Fig. 1. The main light source in this system is amplified Yb:KGW fs laser, either "Pharos" or "Carbide" by the Light Conversion Ltd. As it is commercial system, the choice of laser is dictated by the requirements set by the customer. Laser is paired with optical system capable of sustaining first three laser harmonics (1030 nm, 515 nm and 343 nm) as well as capable of dynamically tuning polarization and laser beam diameter. Fabrication is realized using synchronized linear stages and galvo scanners which allows stitch-free fabrication of cm sized structures. Other features such as real time imaging of the fabrication process is also realized. More details on the technical aspects of the system can be found in Jonušauskas et al. (2019). The system is controlled by the proprietary 3DPoli software.

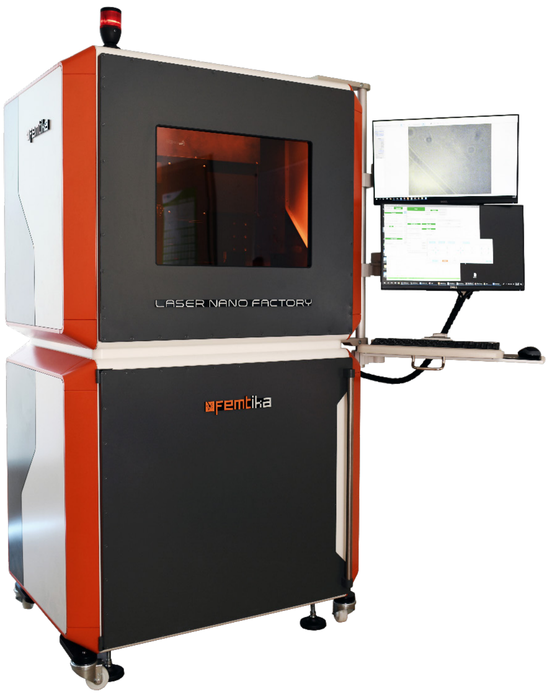

Fig. 1. “Laser Nanofactory” workstation used in this work.

Various materials were used in the work. Metals ranging from steal to titanium were used in surface structuring. Channels out of soda lime, borosilicate and fused silica glasses were produced, depending on what properties the final channel systems needed to have. For additive manufacturing hybrid photopolymer SZ2080 was used with varying degrees of photosensitization. Exact details on how polymer samples were prepared can be found in Jonušauskas et al. (2017).

3. Results and discussion

One of the key features of the “Laser Nanofactory” is possibility to realize various processing regimes in a single workstation. Additionally, everything is done using software solutions. The only component the user has to physically change is the focusing optics. This greatly reduces the workload of the operator and makes system easy to operate. It is important to stress, that it does not have adverse impact on the performance of the system. Even highly specialized structures can be produced, including free-form microoptics or hierarchical surface nano-/micropatterns shown in Fig. 2. (a) and (b) respectively. The presented 500 μm diameter microlens is consisting of multiple aspherical zones, which allows to achieve diffraction-limited focusing properties of the element. At the same time, laser created surface patterns allow to achieve either hydrophobic or hydrophilic properties, with contact angles from 160º to -160º (or even more for specialized applications) Main difference between processing regimes used to create these examples is pulse energy (from nJ to mJ), repetition rate (from 1 kHz to 1 MHz) and pulse duration (from 250 fs to 10 ps). In addition, several processing regimes can be used to produce single structure. For instance, a polymeric nanofilter with pore size down to hundreds of nm can be integrated into glass channel as presented in Fig. 2. (c). Such system can be used to filter macromolecules and/or bacteria in liquids, making it extremely attractive for fields of drug development of some types of clinical use.

The channel is produced either by ablation or selective glass etching (i.e. in subtractive fashion) while the filter integration is performed using two-photon polymerization (additive technique). As it is done with a single workstation it severely simplifies the process.

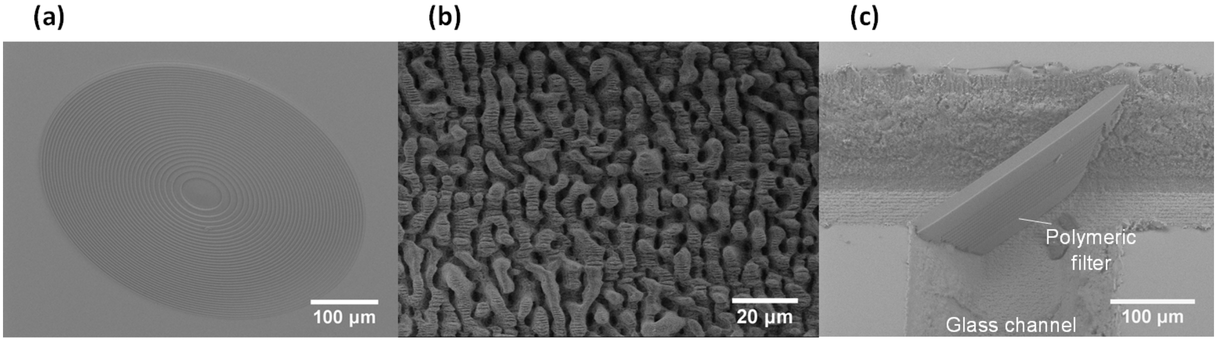

Fig. 2. SEM micrographs of Fresnel lens (a), hierarchical surface structures (b) and nanofilter integrated into a glass channel (c). First structure was produced using additive two-photon polymerization, second – subtractive surface structuring and third using both additive and subtractive fs laser processing.

The system is also highly modular. Most of the main components of the workstation can be changed and/or tuned to accommodate different lasers and/or system components. Change of the laser might be required if new, more advanced laser allows expanding the possibilities of the system. Same principle applies for additional components, such as needed for spatial light shaping. Indeed, the modularity of the system allows to expand its functionality on-demand when the customers deem it necessary. Additionally, it means that when Femtika develops novel components needed for advanced material processing all the previous systems are compatible with these solutions, allowing them to not become obsolete. This is substantial competitive edge in comparison to other, less flexible systems in the area of workstations used for academic research. Furthermore, it can work in completely different direction – when industrial system is needed, in a lot of cases, only one yet extremely well-developed processing regime might be needed. Then the modularity allows to take all the unnecessary components out without compromising it.

4. Conclusions

In this work we showed that a laser material processing workstation based on amplified fs laser can be used for both additive and subtractive manufacturing of functional devices. Changing from one processing regime to other is relatively simple, requiring operator to only change focusing optics and system parameters. Additionally, such system can be tuned to suite for both academic research and industry as it is based on highly modular design.

Acknowledgements

MicroConPu, Nr. P-MIP-19-444 (The Research Council of Lithuania) and FemtoSurf, Nr. 825512 (European Commission) projects are acknowledged for financial support. Femtika's research team is acknowledged for performing experimental work presented in this work.

References

Chichkov, B. N., Momma, C., Nolte, S., Alvensleben, F., Tünnermann A., 1996. Femtosecond, picosecond and nanosecond laser ablation of solids. Applied Physics A 63, 109–115.

Jonušauskas, L., Gailevičius, D., Mikoliūnaitė, L., Sakalauskas, D., Šakirzanovas, S., Juodkazis, S., Malinauskas, M., 2017. Optically clear and resilient free-form µ-optics 3D-printed via ultrafast laser lithography. Materials 10(1), 12.

Jonušauskas, L., Baravykas, T., Andrijec, D., Gadišauskas, T., Purlys, V., 2019. Stitchless support-free 3D printing of free-form micromechanical structures with feature size on-demand. Scientific Reports 9, 17533.

Maruo, S., Nakamura, O., Kawata, S., 1997. Three-dimensional microfabrication with two-photon-absorbed photopolymerization. Optics Letters 22(2), 132-134.