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# Processing and wetting behavior of hierarchically microstructured polymer foils

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**Abstract**

The demand for surface functionalized plastics is constantly rising. Therefore, industrial-scalable methods capable to provide surfaces with new functions are necessary. In this study, we demonstrate a strategy to apply hierarchical microstructures to transparent polyethylene terephthalate (PET) foils by plate-to-plate hot embossing. To that end, a stainless-steel stamp was patterned using two laser-based processes, namely Direct Laser Writing (DLW) and Direct Laser Interference Patterning (DLIP). Several single scale and multi scale structures with feature sizes in the range 3 µm up to 50 µm and depths between 0.1 µm and 10 µm were processed on the metal master and transferred to the PET surface. The topography characterization by confocal microscopy and scanning electron microscopy revealed a satisfactory replication of the microstructures from the stamp to the polymer, even for the smallest features with lateral sizes of ~100 nm. The patterned surfaces showed an increased hydrophobic behavior characterized by static water contact angles up to 105°.

Keywords: direct laser writing; direct laser interference patterning; hot embossing; hierarchical structures; stainless steel; polymer; water contact angle; polyethylene terephthalate

## 1. Introduction

Nature provides many examples of hierarchical structured surfaces with outstanding properties. For example, due to its self-cleaning and superhydrophobic behavior, the lotus leaf became an object of interest for engineers in recent years. Several attempts were made to mimic this effect on technical surfaces. For

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polymers, comparable structures could be achieved using techniques like electrochemical etching or lithographic processes [1-3]. Unfortunately, the industrial usage of these processes is limited, due to their high complexity and dependency of chemical agents with high toxicity for human health and the environment. A cost efficient and scalable alternative is hot embossing. In hot embossing, the surface of a master tool is transferred to thermoplastic polymers by applying pressure at temperatures close to the glass transition temperature of the chosen material. The main challenge is the design and production of the inverted texture on the master tool. When it comes to large area texturing of metals, laser processing has become one of the most efficient techniques in the last decades. In this study, we demonstrate the suitability of employing laser techniques the production of a lotus-like, multi-scaled surface on polyethylene terephthalate foils by means of plate-to-plate hot embossing with increased wettability performance.

## 2. Results and Discussion

Periodic structures with single- and multiscale features were created on stainless steel plates by using two laser-based processes namely Direct Laser Writing (DLW, Fig. 1a) and Direct Laser Interference Patterning (DLIP, Fig. 1b). The setup shown in Fig. 1a, was also used improve the surface quality of the stamps by eliminating defects based on Laser Polishing (LP). The metal plate served as master for plate-to-plate hot embossing (Fig. 1c) in order to transfer the textures to polyethylene terephthalate (PET) foil. Finally, the water contact angle on the structured surfaces was investigated.

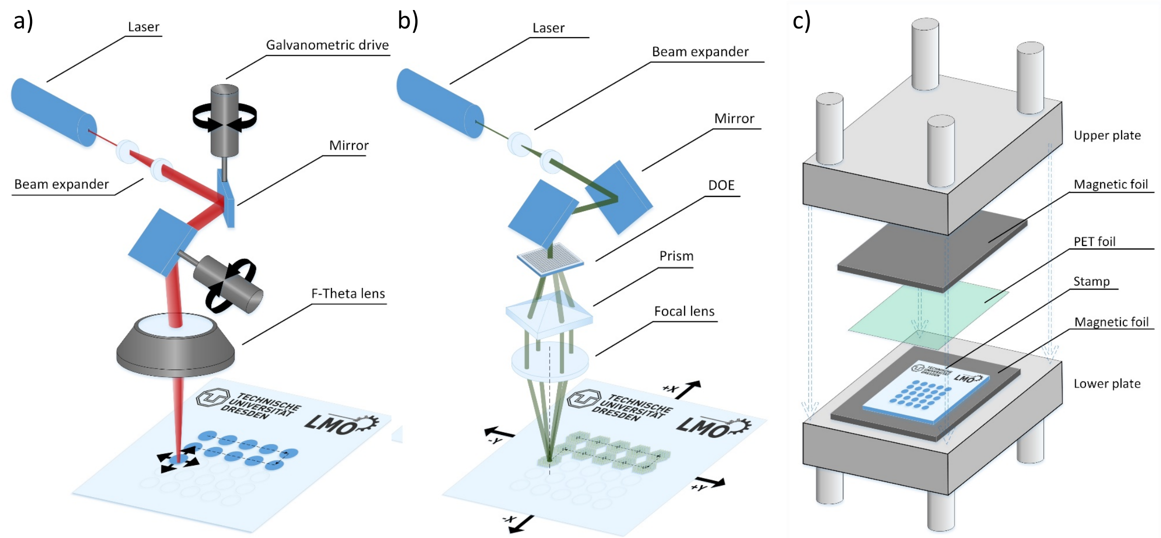


Fig. 1 Experimental setup for (a) Direct Laser Writing and Polishing, (b) Direct Laser Interference Patterning and (c) plate-to-plate hot embossing of single- and multiscale structures on stainless steel plates and polyethylene terephthalate foils. [4]

In a first step, arrays of hole like structures were created on the metal master using DLW (Fig. 2a) or DLIP (Fig.2b). By varying the process parameters such as the laser spot distance and the number of applied pulses per position, different structure depths and thus different roughness, could be achieved. Confocal microscopy measurements revealed depths of up to 10 µm for the DLW structures and up to 3 µm for the smaller DLIP features. Combining DLW and DLIP as well as a polishing step in between, complex multi-scale textures were fabricated (Fig. 2c). The processed metal plate served as master for hot embossing on 200 µm thick PET foil, operating with a pressure of 40 MPa at a temperature of 85°C. As a result, arrays of single scaled dimple like structures with diameters from 50 µm (DLW, Fig. 2d) down to 3.1 µm (DLIP, Fig. 2e) as well as dimple-covered-dimple structures (DLW + DLIP, Fig. 2f) were produced.

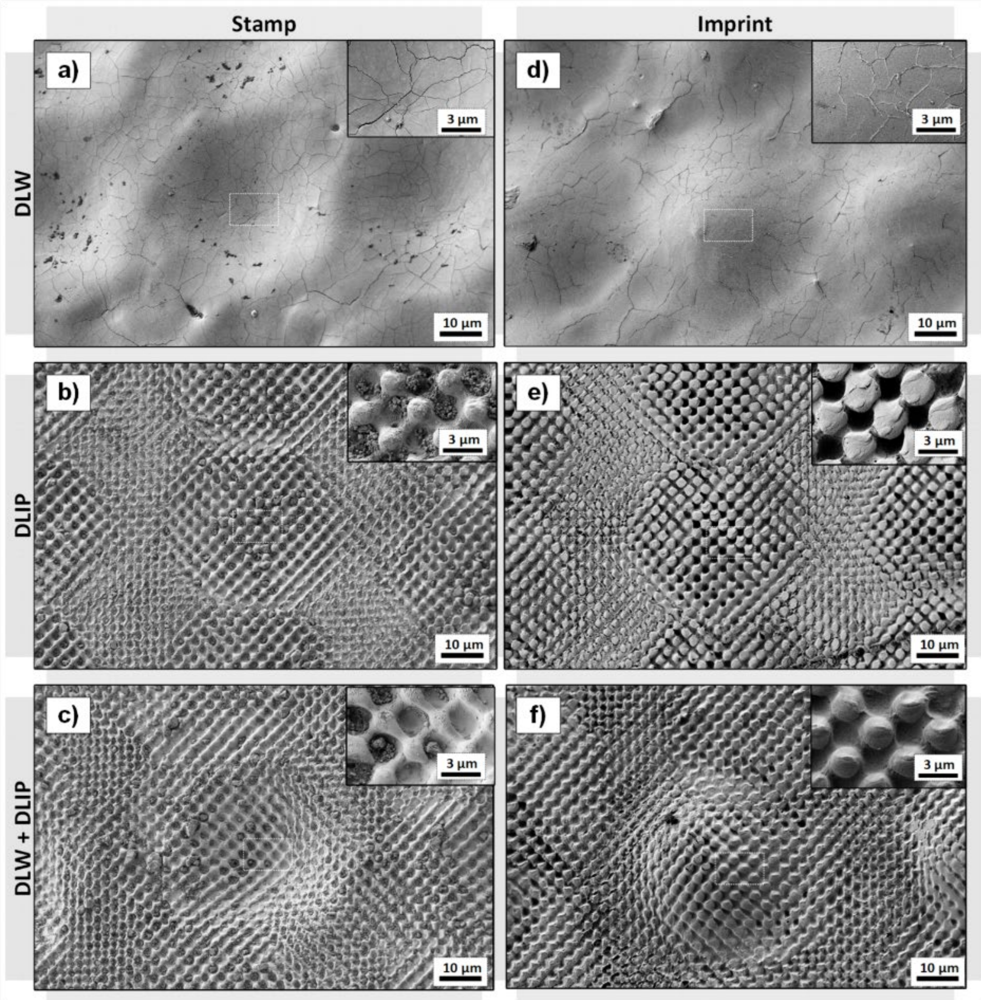


Fig 2 SEM images of single- and multi-scale structures on (a-c) stainless steel master and (d-f) corresponding imprint on hot embossed PET foil. The textures on the master were fabricated using (a) DLW, (b) DLIP and (c) combined DLW and DLIP textures [4]

The influence of the structure depth and geometry on the wetting behavior was investigated by measuring the static water contact angle (WCA, Fig. 3). Therefore, 4 µl sized droplets of deionized water were placed on the textured PET-surfaces. Compared to untreated PET with a WCA of 77°, the WCA raised up to 89 ° for DLW-only and up to 99° for DLIP-only textured areas. In all cases, the multiscale structures showed higher WCA than corresponding single scaled ones, up to a maximum of 105°.

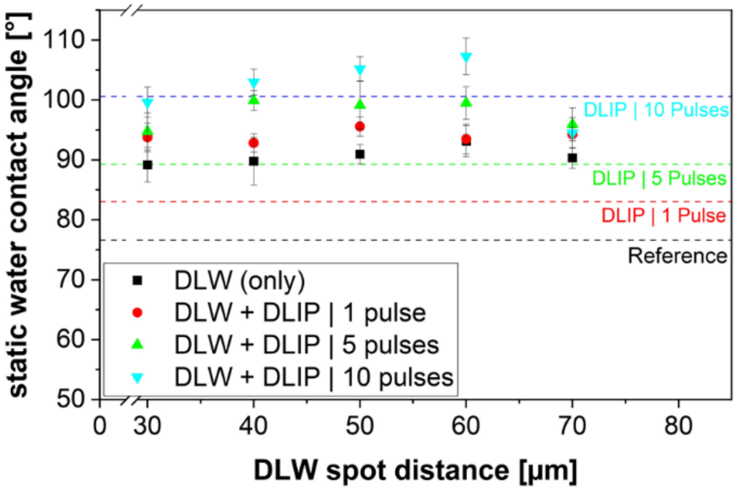


Fig 3 Static water contact angle measurements as a function of the DLW-spot distance for various combinations of DLW- and DLIP structures.

## 3. Conclusions

In this work, we demonstrated the suitablity of laser based processes to pattern hierarchical textured tools for plate-to-plate hot embossing. Several textures were transferred to polyethylene therepthtalate foils and it could be shown, that multiscale structures provides higher water contact angles than single scaled ones. Further research needs to be conducted to optimize the geometrical properties on the PET surface that maximize the water contact angle.

## References

[1] El-Saftawy, A.A., Elfalaky, A., Ragheb, M.S., Zakhary, S.G., 2014. Electron Beam Induced Surface Modifications of PET Film. Radiat. Phys. Chem., 102, 96–102.

[2] Carneiro-da-Cunha, M.G., Cerqueira, M.A., Souza, B.W.S., Carvalho, S., Quintas, M.A.C.; Teixeira, J.A., Vicente, A.A., 2010. Physical and Thermal Properties of a Chitosan/Alginate Nanolayered PET Film. Carbohydr. Polym., 82, 153–159.

[3] Samipour, S., Taghvaei, H., Mohebbi-Kalhori, D., Rahimpour, M.R., 2020. Plasma Treatment and Chitosan Coating: A Combination for Improving PET Surface Properties, Surf. Innov., 8, 76–88.

[4] Bouchard, F., Soldera, M., Baumann, B., Lasagni, A.F., 2021. Hierarchical Microtextures Embossed on PET from Laser-Patterned Stamps, Materials, 14, 1756.