FABULOUS

FABrication of 3D metasurfaces to enable the next generation of high efficiency optical products

End-to-End Optical System Design: Metasurfaces

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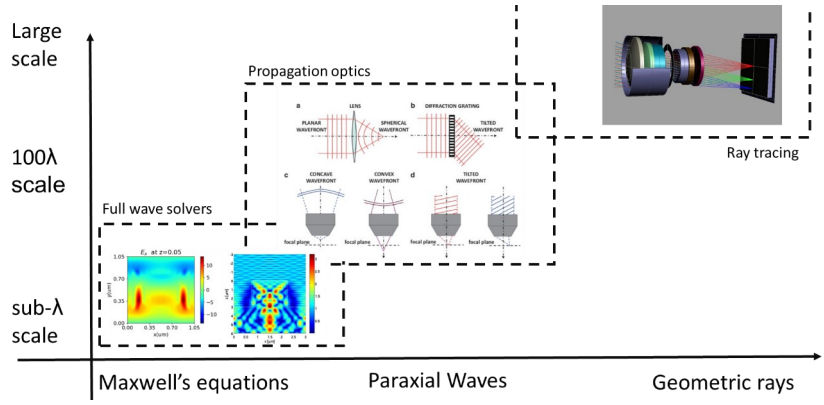
Designing optical systems with integrated metasurfaces is a challenging task due to the range of length scales involved. Practical applications such as sensing, imaging, and beam shaping, require integrating components on macroscopic scales (millimeters to meters), while precise nanometer-scale calculations are essential to design the sub-wavelength structures, or meta-atoms, that enable metasurface functionality.

The FABulous researchers tackled this challenge using a multi-scale simulation approach that combines full-wave solutions, wave optics, and ray tracing to bridge the nanoscale-to-macroscale gap. Two interfacing methods, which are grounded in physical theory and were specifically developed for FABulous, enabled seamless integration across these scales.

The FABulous team have now validated their methods through comparisons across software platforms. Successfully demonstrating that end-to-end design of meta-surfaces for innovative solutions such as automotive camera lenses, light pipes, and solar micro-optic arrays is possible. This breakthrough marks a major step forward in scalable optical system design.



The Project

FABulous will develop an industrial surface 'coating' technology that exploits breakthroughs in multiphoton lithography and process modelling to manufacture high resolution 3D metasurfaces at a throughput viable for series production.

These metasurfaces will be capable of manipulating light with unprecedented flexibility and will open the possibility of designing and manufacturing smaller, lighter, and more environmentally friendly products, through the replacement of bulky components and/or the chemical coatings currently used to enhance the efficiency and performance of optical products.

MADE IN EUROPE

Funded by the European Union

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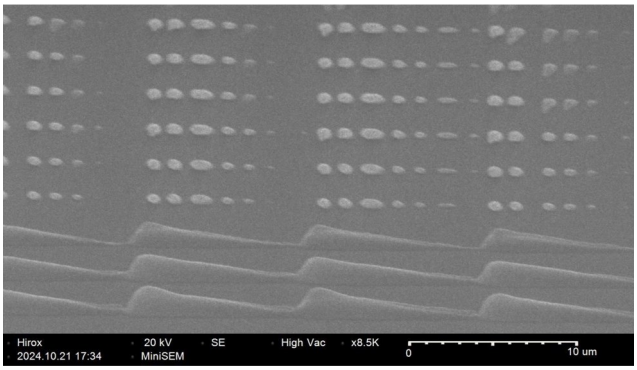
High-speed fabrication of 3D surface structures

One of FABulous' most ambitious challenges is the development of MPP printing techniques that enable fabrication of full 3D surface structures at plot rates greater than 2E7 voxels/s, while retaining the sub-micron resolution of the multi-photon process.

To address this challenge novel methods for multi-photon writing, based on the knowledge of existing parallel-write technique using Spatial Light Modulators (SLM) and Diffractive Optical Elements (DOE), have been developed with the aim of identifying the best engineering compromise for the numerous process parameters and constraints (write wavelength, available lasers, projection lens resolution and write field, resist sensitivity etc).

Robust testing found that the DOE approach was better suited to high-speed fabrication over large areas due to the energetic efficiency of the DOE, as this means that the system can withstand very high laser power. Which enables large numbers of intense write spots to be used simultaneously. However, the SLM approach, whilst slower, was also found to be an attractive process because it does not impose periodicity restrictions of the type of structures that can be plotted and in theory any 3D structure can be plotted as each SLM pixel can be individually modulated.



MEB view of structures written in parallel "on-the-fly" with a DOE. The upper structures were fabricated by binary (ON/OFF) modulation of the laser power as the write spots were scanned. In the lower part, continuous variable height structures were fabricated by grey-level modulation of the laser power during the scan.

Using the DOE approach the target plot rate of 2E7 voxels/s has now been demonstrated for the fabrication of 200nm structures. Further optimisation of the process is now planned to achieve even better performance.

Learning lessons through collaborative research

In a world driven by knowledge and innovation, collaborative research is a critical aspect of innovation and discovery. The FABulous project is an excellent example of how collaboration in research fuels progress and opens new frontiers in technology.

FABulous has united individuals from diverse disciplines, cultures, and experiences, creating an ecosystem for the sharing and development of ideas. The varied perspectives of the FABulous collaborators are challenging conventional thinking and sparking the development of innovative solutions to common problems. As a result FABulous has established a vibrant culture of mutual learning, where participants share insights into both successes and failures. This transparency accelerates the pace of discovery, offering valuable lessons in metasurface design and fabrication. For both our academic researchers and industry professionals the FABulous project is proving to be a testament to the transformative power of collaboration.

A key highlight of the latest phase of the project has been the parallel development of advanced manufacturing methods. This collaborative effort has optimized the FABulous approach towards significantly improving the resolution and throughput of the MPP write process. Resulting in advances that are not only being adopted by project partners but are also poised for exploration at an industrial scale in the next phase of the project.

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Training the next generation in metasurface manufacturing

With the digitization of European industry the demand for skilled workers is growing. Yet, many entering the workforce today face a skills gap, with limited opportunities to acquire the expertise needed to meet the demands of emerging advanced technologies. Recognizing this challenge, the FABulous project is taking steps to equip individuals with the skills they need for the jobs of the future.

A key ambition of FABulous is the development of training resources that address the specific challenges faced in the advanced manufacturing of optical products. This initiative targets the shortages of skilled staff with interdisciplinary expertise and industrial insight required for mastering multi-photon polymerization (MPP) fabrication of metasurfaces. By doing so, FABulous seeks to bridge the gap between cutting-edge technology and its practical application in industrial settings.

The FABulous training resource will be multifaceted, offering:

- Theoretical Training to deepen understanding of metasurface technologies and their applications.
- Practical Training Guides to support hands-on experience with MPP fabrication processes.
- STEM Resources for Future Generations, aimed at inspiring the next wave of skilled workers and innovators.

By combining these elements, FABulous is committed to reducing the barriers to process integration for newcomers and fostering widespread adoption of this groundbreaking technology.

Visit the FABulous website at www.fabulous3d.eu for more updates as we roll out this transformative training resource designed to shape the future of metasurface manufacturing!

Where to connect with the FABulous team in 2025

Date	Location
May 2025	20th Fraunhofer IISB Lithography Simulation Workshop, Gößweinstein, Germany
June 2025	CLEO Europe, Munich, Germany
June 2025	Laser World of Photonics, Munich Germany
June 2025	40th Mask and Lithography Conference, Dresden, Germany
September 2025	European Manufacturing Conference, Brussels, Belgium
October 2025	AIMEN Laser 2025, XIX Workshop, Pontevedra - Spain

Remember you can also follow the FABulous social media channels for more information about the project and where you can interact with the team over the next few months.