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Glückstad, Jesper

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Light-driven Nano-robotics

Jesper Glückstad

DTU Fotonik, Techn. Univ. Denmark and OptoRobotix ApS

Chair: Zhidong WANG (Chiba Institute of Technology)

Abstract

The synergy between nanotech, biotech and optics is spawning the emerging field of nanobiophotonics. Optics already hurdle the diffraction barrier for imaging with nanoscopic resolutions as celebrated by the Nobel Prize 2014 in Chemistry. However, scientific hypothesis testing demands tools, not only for observing nanoscopic phenomena, but also for *reaching into and handling* constituents in this size domain. Featured in Nature Photonics this author previously promoted the idea of fabricating a new class of Shape Optimized light robotic structures via two-photon polymerization (2PP) and pioneering their use in so-called light-driven nano-robotics. Hence, the aim of our latest R&D is to combine advanced topology optimisation, 3D printing of functionalized materials and light manipulation to demonstrate a structure-mediated micro-to-nano coupling paradigm for controlled operation of robotic tools overcoming the diffraction limit while still being optically visible and manoeuvrable. 2PP-fabrication can already today create intricate nano-features merged onto larger microstructures that, in turn, are steerable by dynamic light beams. Applying multiple independently controllable laser beam traps on these structures will enable real-time light-driven nano-robotics with six-degrees-of-freedom. This sets the stage for new discoveries using calibrated steering of optimally shaped and functionalized nano-tools at the subcellular level and in full 3D - not available in the scientific world as of today.

Highly advanced nanoscale light-based microscopy - now by experts coined 'optical nanoscopy' in celebration of the 2014 Nobel Prize in Chemistry - can already today surpass the classical far-field diffraction limit and provide optical resolutions down to a few nanometers. Strongly linked to these achievements is the rapidly emerging field of light-based 3D printing using powerful approaches offered by e.g. nonlinear photo-polymerization processes. Today it is possible to 3D laser-print nanoscopic structures with a voxel resolution down to below a few tens of nanometers. By adding a third key scientific accomplishment - namely the fascinating ability of focused light to capture, trap and manipulate tiny objects - one can approach a triangulation of new functionalities required for true light-driven nano-robotics. As Arthur Ashkin showed in pioneering experiments at Bell Labs, focused laser light is able to attract, capture and optically trap tiny refractive particles. In biological experiments, this takes best place in aqueous solutions in which living cells and other micro organisms can be sustained and thrive in a natural environment. By cleverly combining and integrating all these amazing optics breakthroughs we can create the conditions for harnessing most of the functionalities required to develop the fascinating concept of true light-driven nano-robotics.

By fully exploring 2PP, it is in principle possible to equip 3D laser-printed robotic structures with multi-functional biophotonics nanoprobes or nanotips fabricated with true nanoscopic resolution. The uniqueness of such an approach is that even if a micro-biologist aims at exploring e.g. cell biology at nanoscopic scales, the main support of each laser-robotic structure can be 3D printed to have a size and shape that allows convenient laser manipulation in full 3D – even using relatively modest numerical aperture optics. An optical robot is typically equipped with a number of 3D printed "track-balls" that allow for real-time 3D light manipulation with six-degrees-of-freedom. This creates a drone-like functionality where each light-driven robot can be e.g. joystick-controlled and provide the user a feeling of stretching his/her hands directly into and interacting with the biologic micro-environment. The light-guided robots can thus act as free-floating probes to monitor micro-biologic processes and provide spatially targeted mechanical, chemical or even optical stimuli that would otherwise be impossible to achieve in a full 3D biologic environment.

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Biography

Jesper Glückstad established the Programmable Phase Optics www.ppo.dk in Denmark more than a decade ago and currently holds a position as Professor at DTU Fotonik, Dept. of Photonics Engineering at the Technical Univ. of Denmark, and a position as 5-years Guest Professor in Biophotonics at Lund Institute of Technology in Sweden from 2006 until 2011. In 2004 he received the prestigious Doctor of Science (DSc) degree from the Technical University of Denmark for the dissertation entitled “The Generalised Phase Contrast method”. Together with a colleague he has authored a 310 pages Springer book on this topic. Prior to his achievements in Denmark, Glückstad was a visiting scientist at Hamamatsu Photonics Central Research Laboratories and in the Physics Dept. at Osaka University in Japan. Since he obtained his PhD at the Niels Bohr Institute at Copenhagen University in 1994, he has published more than 300 journal articles and international conference papers and holds around 30 international patents and patent applications. He has published papers in Nature Materials, Nature Methods and Nature Photonics. He is the year 2000 recipient of the Danish Optical Society Award and was elected as «Scientist of the Year» in 2005 by Dir. Ib Henriksen’s Foundation in Denmark. Glückstad is a 2010 elected Fellow of the OSA and a Fellow of the SPIE as the first from Denmark. In 2012-2014 he was appointed for the prestigious SPIE Fellows committee together with an American physics Nobel laurate. In 2013 he was invited to join the Editorial Board of JEOS. Glückstad is founder of the DTU Fotonik spin-out OptoRobotix originally rooted in the Silicon Valley region OptoRobotix.com. Most recently founder of the new associated tech-transfer unit GPCphotonics.com