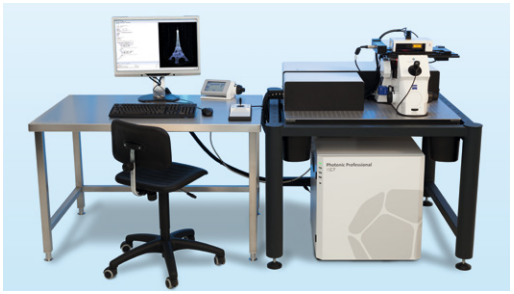
APPLICATION NOTE

nanoscribe

LIFE SCIENCES

Nanoscribe's Photonic Professional *GT* 3D printers allow to easily produce tailored and reproducible 3D scaffolds and matrices. Here, the tailoring is achieved by on one hand a wide range of processable materials and on the other hand a resolution and feature sizes which, in combination, allow to mimic in vivo physiological environments. Accessible patterning scales cover sub-micrometer features and sample volumes of up to several 10 mm³ at the same time. Samples can be produced from biocompatible, cell binding/repelling, hydrophobic and hydrophilic polymers with different mechanical characteristics as well as hydrogels.

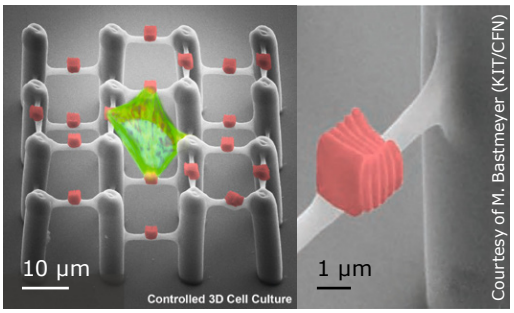


CELL / EXTRACELLULAR MATRIX INTERACTION

Challenge: Fabrication of a microstructured 3D cell scaffold consisting of a cell-repellent material (grey) and a cell adhesion promoting material (red) as per design.

Solution: First, a core scaffold made of PEG-DA mixed with PETA (grey) is additively printed. Then, a second printing step adds cell adhesion points made of OrmoComp (red) precisely at the designed locations.

Source: DOI: 10.1002/adma.201004060

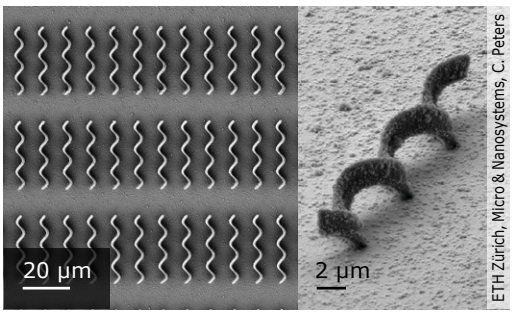


TARGETED DRUG DELIVERY

Challenge: One-step fabrication of cargo-loaded helical swimming microrobots made of biodegradable superparamagnetic hydrogel for minimal invasive intervention.

Solution: A hydrogel consisting of PEG-DA/PETA, magnetite nanoparticles and photoinitiator is 3D printed. For loading, the helices are immersed in methylene blue.

Source: DOI: 10.1002/adma.201503112

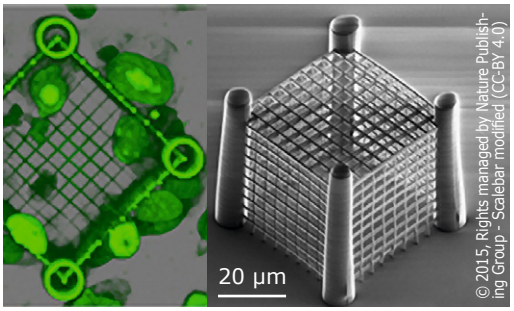


CELL MIGRATION

Challenge: Fabrication of cage-like 3D micro-structures with sufficiently small pore size to differentiate tumorigenic from non-tumorigenic human breast cancer cells based on different invasion behavior.

Solution: Cubic cages with meshes of approximately 3, 18 and 85 µm² pore size as side faces are printed in Nanoscribe's biocompatible photoresist IP-L 780.

Source: DOI: 10.1038/srep10531

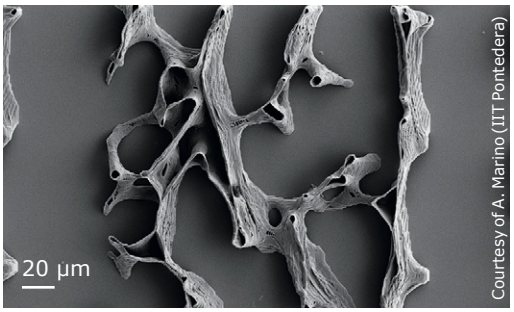


TISSUE ENGINEERING / 3D CELL CULTURE

Challenge: High-fidelity replication of a human trabecular bone structure from high resolution 3D data obtained from a µ-CT scan.

Solution: µ-CT data is transferred to the standard 3D printing workflow. The scanned 3D object is reproduced with sub-micrometer precision in OrmoComp.

Source: DOI: 10.1016/j.actbio.2014.05.032



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Photonic Professional GT

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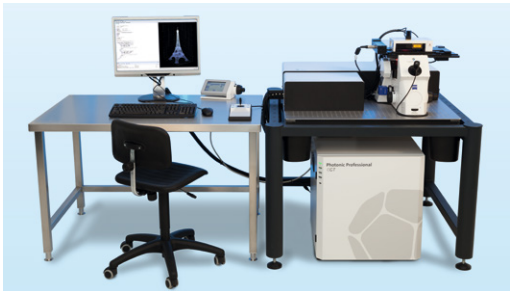
AN/LS/V03_2016

MECHANICAL METAMATERIALS

Mechanical properties of materials can be tailored by material composition but also by geometrical design. The field of mechanical metamaterials aims at exploiting exactly this twofold design freedom. Nanoscribe's Photonic Professional *GT* offers three-dimensionality (3D), submicron feature size and resolution as well as hierarchical structuring capability. Auxetics and mechanical cloaks are successfully demonstrated by polymeric structures. By subsequent post-processes such as surface coating or electro-plating, damage-tolerant lightweight materials are also made of composites, metals and ceramics.

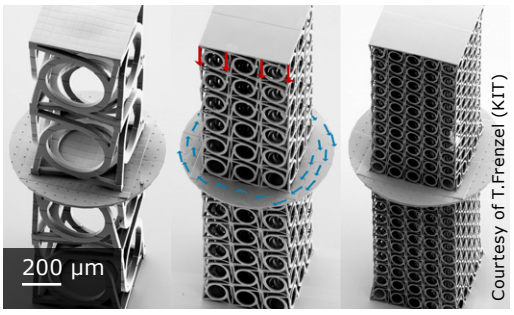


CHIRAL MECHANICAL METAMATERIAL

Challenge: Examine non-Cauchy elastic metamaterials that can respond to compression with a twisting motion (instead of buckling/ bending).

Solution: Scaling behavior is studied on several, easily printed samples with identical overall dimensions but consisting of different numbers of unit cells.

Source: DOI: 10.1126/science.aao4640

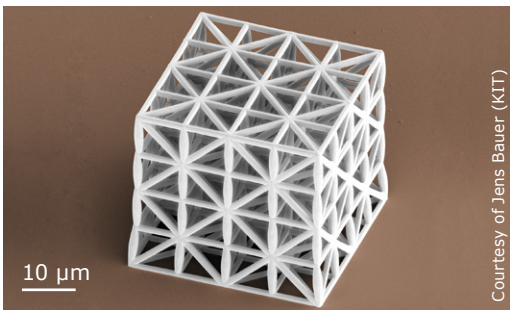


HIGH-STRENGTH CERAMIC POLYMER COMPOSITE

Challenge: Fabrication of a 3D cellular material with low filling factor built of submicron elements demonstrating size-dependent strengthening effects.

Solution: 3D polymeric structures with submicron feature size are printed. Ceramic composites are then obtained by subsequent ALD coating with alumina.

Source: DOI: 10.1073/pnas.1315147111

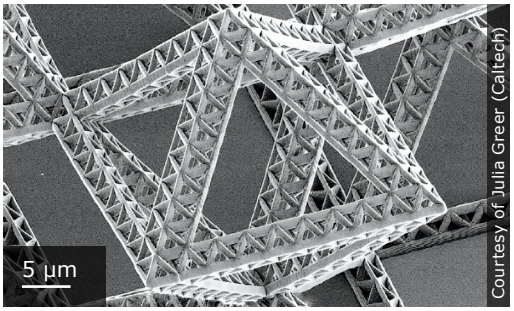


RESILIENT 3D HIERARCHICAL METAMATERIAL

Challenge: Manufacturing of 3D fractal-like architectures with features in the sub-micron regime for the attainment of various mechanical properties, e.g. ultralightweight, recoverability.

Solution: 3D hierarchical nanolattices with individual beams comprised of multiple self-similar unit cells with length scales spanning over four orders of magnitude are fabricated.

Source: DOI: 10.1073/pnas.1509120112

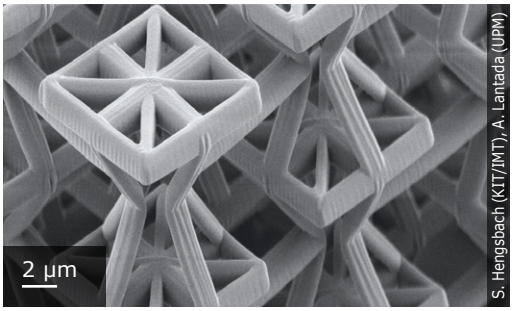


AUXETICS / NEGATIVE POISSON RATIO MATERIAL

Challenge: Micro-manufacturing of a material that laterally expands when stretched and shrinks when compressed, for applications in biomimetics or magneto-mechanical microsystems.

Solution: 3D complex geometries with submicron details are fabricated precisely, reproducibly and mechanically stably.

Source: DOI: 10.1088/0964-1726/23/8/085033



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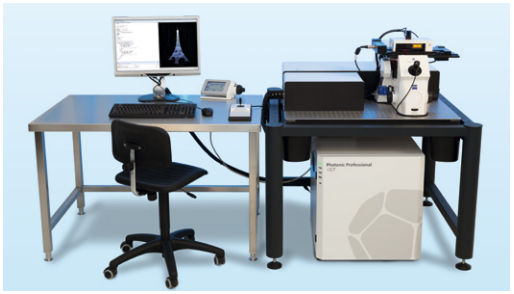
AN/MM/V04_2018

MICROFLUIDICS

The precise control and manipulation of liquids in very small volumes is the essence of microfluidics, for example in lab-on-a-chip applications. Nanoscribe's Photonic Professional *GT* offers the highest resolution available in 3D printing today, enabling tailored and smooth surfaces to be producible as desired. The additive fabrication approach overcomes technical challenges such as high aspect ratios or high surface to volume ratios. Thus, 3D intertwined compact mixers and filter elements can be achieved. By fully exploiting the design freedom even biomimetic micro-needles for painless drug delivery and customized nozzles can be printed.

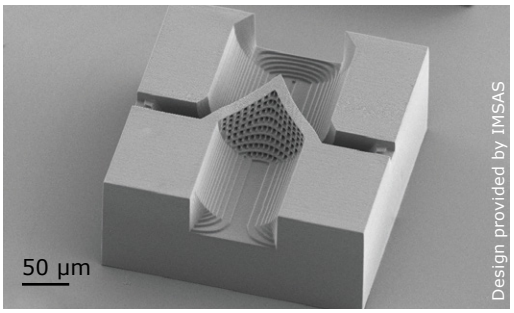


3D MICROFLUIDIC FILTER

Challenge: Fabrication of a non-clogging micro-porous 3D filter with connectors in thick-film SU-8.

Solution: The Photonic Professional *GT* allows for high resolution 3D printing over the total height of the filter element.

Source: www.nanoscribe.de/en/applications/microfluidics/

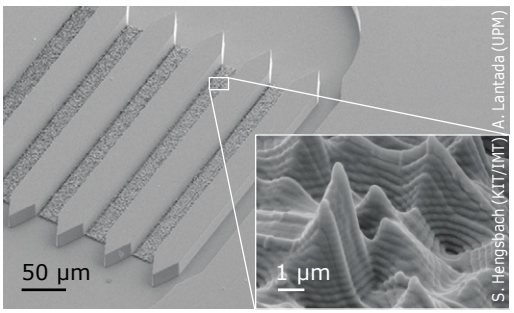


TAILORED SURFACES WITHIN MICROFLUIDIC DEVICES

Challenge: Introduction of micro-textured surfaces into microfluidic channels to study impact on cell motility or to design hydrophobic/hydrophilic characteristics.

Solution: 3D printing allows for tailor-made sub-micrometer modifications of the surface topography. For further replication, these can be used as masters.

Source: DOI: 10.1007/s10544-014-9864-2

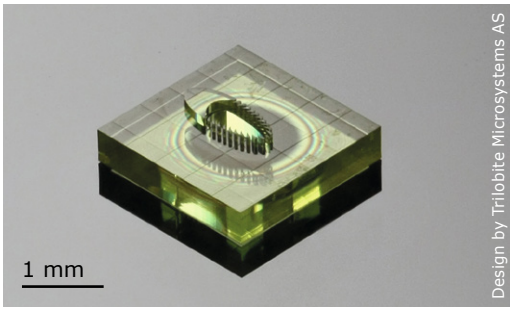


MASTER OF FILTER ELEMENT

Challenge: Rapid and precise fabrication of masters for injection molding or imprinting with heights and aspects ratios exceeding those accessible with other techniques.

Solution: Additive fabrication easily overcomes the design constraints while enabling rapid design iterations and preserving the replicability for mass production.

Source: www.nanoscribe.de/en/applications/microfluidics/

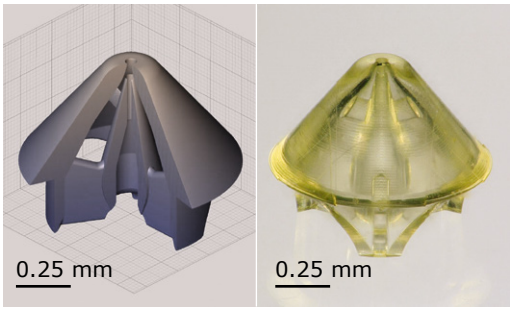


NOZZLES

Challenge: Fabrication of designer microfluidic nozzles for the precise formation of droplets, sprays or jets.

Solution: Almost arbitrarily shaped nozzles with micrometer precision can be printed. This allows for internal features and precisely structured orifices.

Source: DOI: 10.1364/OE.24.011515



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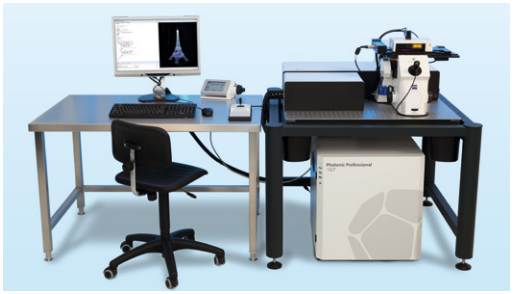
AN/MF/V03_2016

MICRO-OPTICS

Nanoscribe's 3D printer Photonic Professional *GT* allows producing almost arbitrary micro-shapes with optically smooth surfaces in an additive and tool-free way. This effectively circumvents limitations imposed by mechanical tools, and geometrical or process design-constraints often encountered with techniques such as subtractive machining, (greyscale) lithography, photoresist reflow and wet-etching. In this way, steep slopes for high numerical aperture micro-lenses, arrays with high filling factors and varying curvatures, as well as more complex 3D shapes can be achieved. Mass replication is possible by using metal replicas of these shapes.

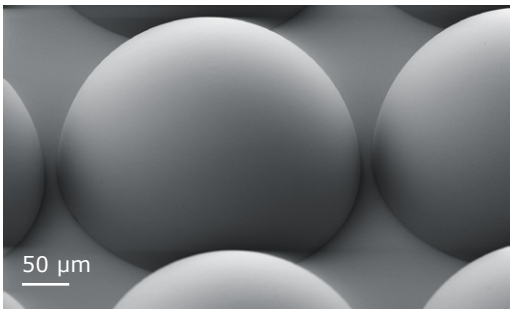


VERTICAL SIDEWALLS

Challenge: Hemispherical micro lenses with steep slopes to achieve low f-numbers in a closely spaced array.

Solution: The layer by layer writing process allows for smooth surfaces over a 0° to 90° angular range, and even for negative slopes (undercuts).

Source: www.nanoscribe.de/en/applications/micro-optics/

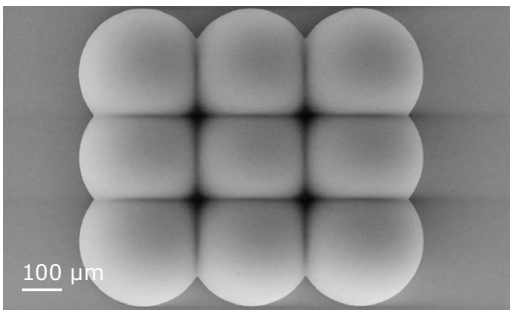


HIGH FILLING FACTOR / COMPACT ARRAY

Challenge: Microlens arrays with increased optical efficiency due to closely packed lenses.

Solution: 3D printing allows overlapping lenses, enabling designs with 100% filling factor. Arbitrary grids are possible and the lens shape can be varied throughout the array.

Source: www.nanoscribe.de/en/applications/micro-optics/

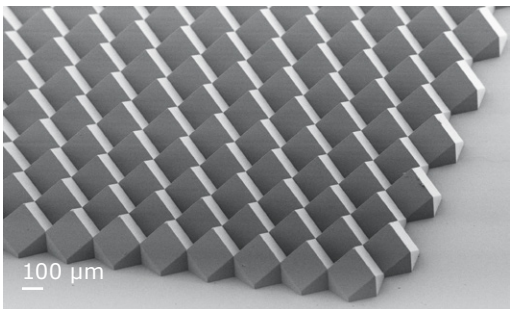


SHARP EDGES AND INTERNAL ANGLES

Challenge: Fabricate corner cube arrays on the microscopic scale with well-defined edges.

Solution: The absence of a mechanical tool and the highly localized polymerization from two-photon absorption allow for internal angles and the small feature sizes necessary for sharp corners.

Source: www.nanoscribe.de/en/applications/micro-optics/

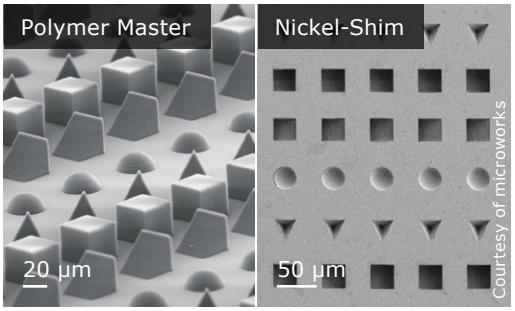


MASS REPLICATION VIA NI-SHIM

Challenge: Fast and low cost production of micro-optical elements.

Solution: A nickel shim can be fabricated from the printed polymer structures by electroforming, allowing standard replication techniques such as injection molding or hot embossing to be used.

Source: www.nanoscribe.de/en/applications/micro-optics/



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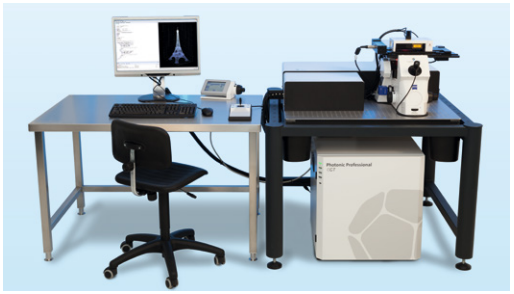
AN/MO/V02_2016

MICROROBOTICS

Nanoscribe's 3D microprinter Photonic Professional *GT* allows for microfabrication with an intrinsic capacity to build complex and custom 3D micro tools. It enables the fabrication of microrobots that interact with tissue and single living cells and conduct medical tasks at the micro scale. Remotely controlled micromachines, which can be powered by magnetic, chemical or optical actuation, are crucial for minimal invasive operations. Depending on the desired actuation mechanism microrobots can be printed from photopolymers, nanoparticle composites as well as hydrogels. Metallic coatings can be applied if required.

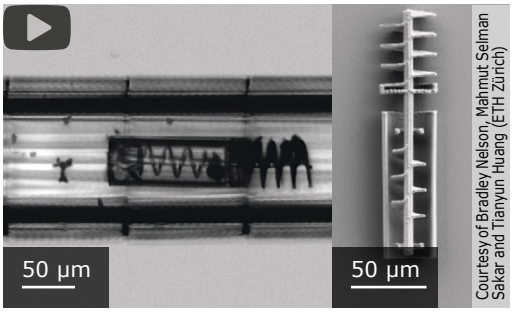


MICROTRANSPORTERS FOR TARGETED DRUG DELIVERY

Challenge: Controlled loading, transport and release of therapeutic agents in fluids by means of a microtransporter remotely actuated by a magnetic field that rotates a magnetic shaft.

Solution: The complete transporter is printed without further assembly. A sacrificial printed shell allows for selective coating of the structure with Ni/Ti.

Source: DOI: 10.1002/adma.201503095

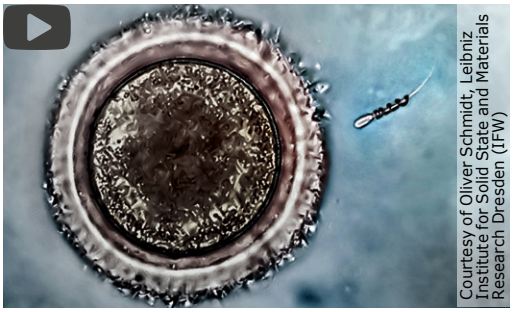


FERTILIZATION-ASSISTING MICROMOTORS

Challenge: Cell-compatible micromachine able to catch, transport and release living sperm to an oocyte overcoming low sperm motility-induced fertility issues.

Solution: Printed polymer microhelices are coated with nickel and titanium allowing the helices to act as motors in a magnetic field and providing biocompatibility, respectively.

Source: DOI: 10.1021/acs.nanolett.5b04221

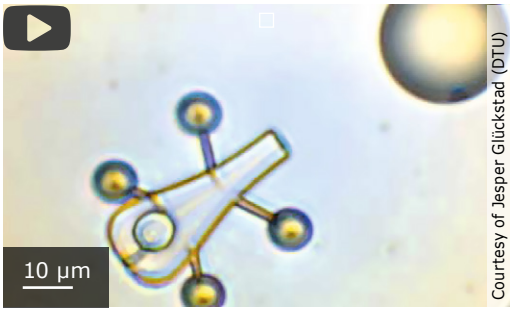


OPTICAL MICROSYRINGE

Challenge: Micro tool capable of movement with six degrees of freedom and controlled as well as precise cargo loading, transport and release.

Solution: A hollow micro vessel with several trapping handles is printed and moved by optical tweezing. Optically changing the pressure inside the vessel allows for loading and unloading of particles.

Source: DOI: 10.1038/lsa.2016.148

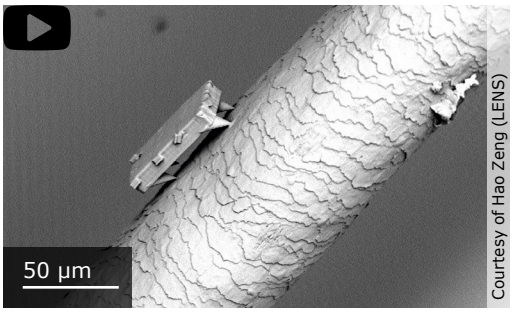


LIQUID CRYSTAL ELASTOMER (LCE) MICROWALKER

Challenge: Soft microrobot that reversibly deforms and is powered by light for walking and jumping, overcoming strong surface adhesion.

Solution: Conical legs are printed on a previously printed LCE structure to reduce adhesion. Modulated laser light contracts the robot body, changing the tilt of the legs leading to locomotion.

Source: DOI: 10.1002/adma.201501446



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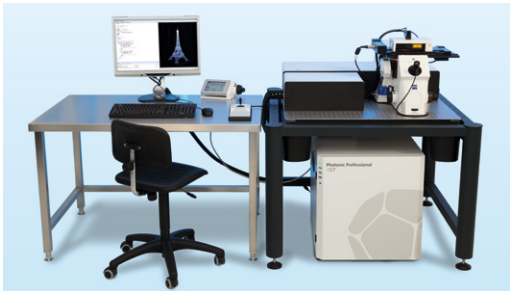
AN/MR/V01_2016

3D PHOTONIC MATERIALS

Nowadays, in telecommunication technology as well as for photonic circuits and devices, materials whose optical response can be tailored by design are being developed. Nanoscribe's Photonic Professional *GT* offers the highest resolution known in 3D fabrication and submicron feature sizes typically on or below the length scale of the wavelength of light, leading to novel optical properties proven in reflection and transmission measurements. Subsequent processes such as electroplating, and single or double inversion using ALD and CVD allow to transfer polymer templates into different materials, e.g. gold, titanium dioxide, silicon.

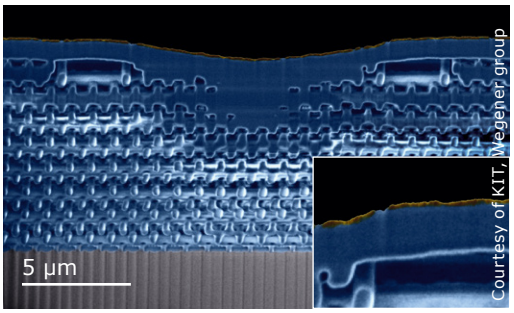


3D INVISIBILITY CLOAK

Challenge: Realization of spatially varying, tailored effective refractive index distribution in 3D for hiding a metallic bump at optical wavelengths.

Solution: 3D woodpile photonic crystal with rod distance of 800 nm and varying rod width is fabricated with the polymer material IP-L.

Source: DOI: 10.1126/science.1186351

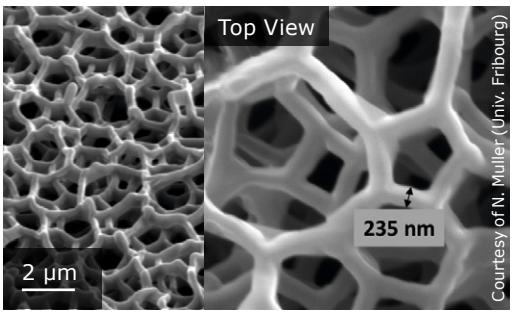


SILICON PHOTONIC BANDGAP MATERIAL

Challenge: Rationally designed aperiodic 3D structure from a high refractive index material with a photonic bandgap in the near infrared.

Solution: Polymer networks are printed, coated with TiO_2 by ALD and the polymer is removed by calcination. The remaining shrunk TiO_2 structure is infiltrated with silicon by CVD.

Source: DOI: 10.1002/adom.201300415

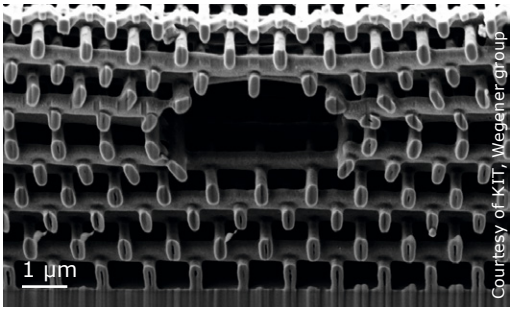


PHOTONIC PARTICLE-ACCELERATOR

Challenge: Fabrication of an air waveguide inside a 3D photonic-crystal in order to accelerate electrons using a confined optical mode.

Solution: Woodpile structure with a waveguide inside is printed. After fabrication, the silicon replica of the printed structure is generated via silicon double inversion.

Source: DOI: 10.1364/OE.20.005607

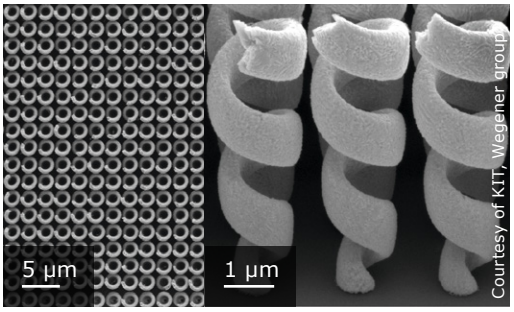


TAPERED GOLD-HELIX BROADBAND CIRCULAR POLARIZER

Challenge: Fabrication of arrays of gold-helices whose radii increase gradually along the helix axis serving as broadband circular polarizers in the mid-infrared.

Solution: Positive-tone resist template with helices is printed and then transferred to gold by LIGA processes. The resist is then removed by plasma etching.

Source: DOI: 10.1063/1.3693181



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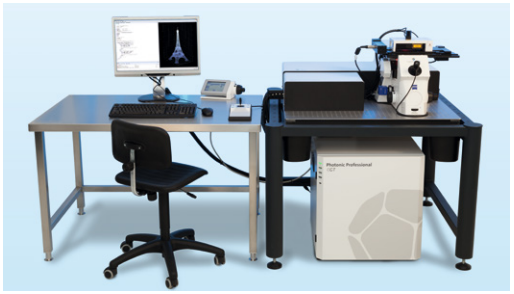
AN/PM/V02_2016

PLASMONICS

Nanoscribe's Photonic Professional *GT* system is the world's highest resolution 3D printer. It offers resolution between what can be achieved with electron beam lithography and UV lithography, providing at the same time the full fabrication flexibility for 2D, 2.5D as well as for 3D objects. Highest accuracy for high performance demanding researchers is enabled with one single instrument that can be installed in a non-clean room as well as in a clean room environment. Maskless lithography is possible on silicon wafers as well as on non-conductive substrates like glass. The four examples below show ways to achieve plasmonic behavior.

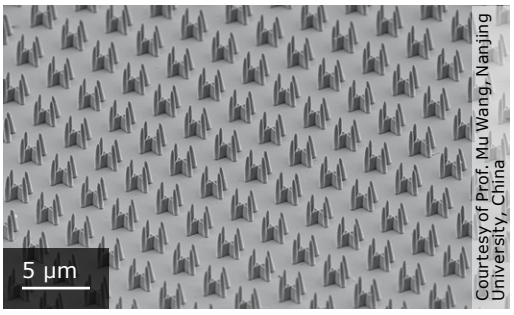


PERFECT ABSORBER

Challenge: Fabrication of a metamaterial absorber in the MID-IR range, that shows good heat dissipation.

Solution: Printing of a polymeric four-tined fish-spear-like resonator array that is covered by a continuous metallic film for excellent thermal conductance.

Source: DOI: 10.1002/adma.201300223



PLASMONIC COLOR DISPLAY

Challenge: Develop a reflective display with pixels based on a surface plasmon resonance that can be tuned electrically to modulate the color.

Solution: Fabrication of a 2.5D master pattern array of nanowells and subsequent processes like nanoimprinting, aluminum coating and placing of liquid crystals.

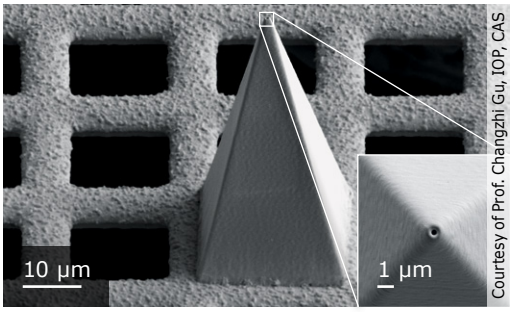
Source: DOI: 10.1038/ncomms8337

SUBWAVELENGTH LIGHT FOCUSING

Challenge: Provide a novel methodology for realization of 3D plasmonic focusing with a signal stronger than other techniques for subwavelength light focusing.

Solution: Fabrication of hollow pyramids with apertures of varying sizes and subsequent coating with a thin gold film on different substrates including a copper grid.

Source: DOI: 10.1364/OE.23.022564

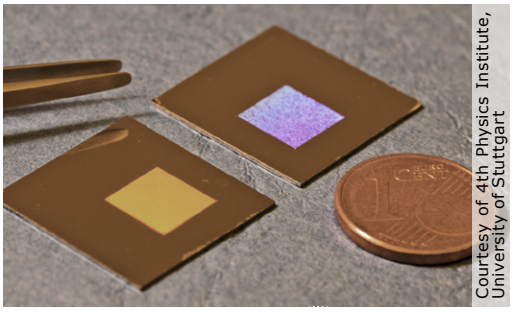


PLASMONIC NANOANTENNA

Challenge: Establish an easy-to-use alternative for electron beam lithography for fabrication of plasmonic nanoantennas with line widths down to 105 nm.

Solution: The Photonic Professional *GT* enables patterning of polymer serving as an etch mask on a gold layer covering an area of tens of mm².

Source: DOI: 10.1021/acsphotonics.5b00141



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Photonic Professional GT

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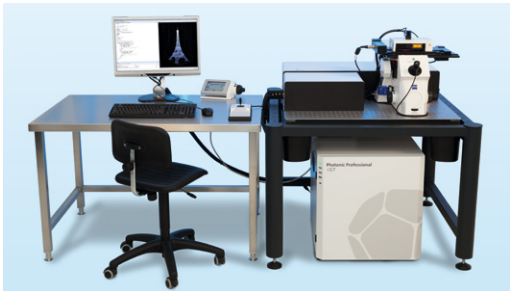
AN/PL/V02_2016

BIOMEDICAL ENGINEERING

Nanoscribe's Photonic Professional *GT* 3D printers offer full design freedom and submicron precision for the fabrication of customized biomedical devices. The high resolution of the printers is especially favorable for mimicking natural environments at sub-cellular scale for lab-on-a-chip applications. Moreover, the printer is used to develop precision instruments needed in minimally invasive operations. Biocompatibility of multiple 3D-printed parts has been demonstrated in contact with living cells and tissue. The printable materials range from photoresins to biodegradable hydrogels and functional resins containing nanoparticles.

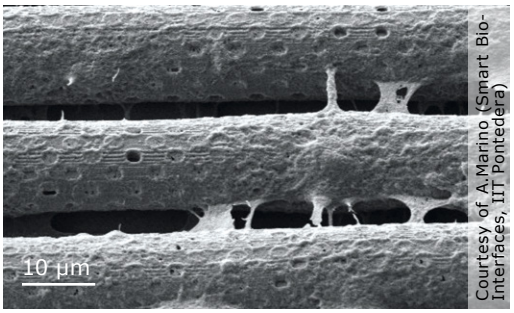


BLOOD-BRAIN BARRIER MODEL

Challenge: Fabricating a real-scale biohybrid model of the blood-brain barrier for drug screening. This model requires tubular structures of 10 µm diameter and pores of 1 µm diameter as supporting scaffold for endothelial cells.

Solution: A millimeter-long system of porous cylindrical channels is 3D printed. The cells cultivated on this scaffold build a biological barrier mimicking the blood-brain barrier.

Source: DOI: 10.1002/smll.201702959

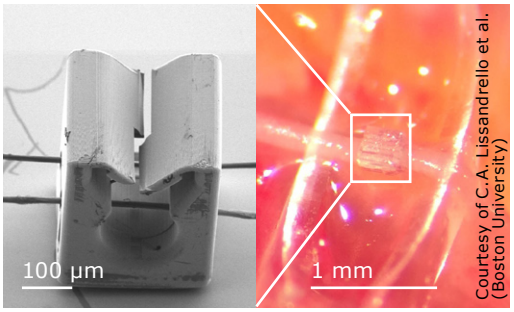


NERVE INTERFACE IMPLANTS

Challenge: Producing micro-scale implants to stimulate and track nerve responses.

Solution: Nanoclips with trapdoors for fixing nerves, slots for placing electrodes and through-holes for surgical handling are 3D printed. Transplanted into zebra finches they show healthy nerve activity post implant.

Source: DOI: 10.1088/1741-2552/aa5a5b

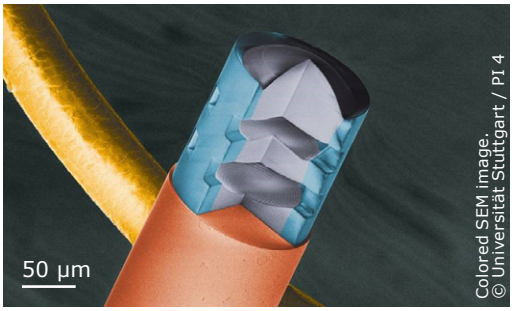


MULTI-LENS OPTICS ON A FIBER

Challenge: Fabrication of a compound lens system consisting of three objectives stacked on the tip of 125 µm diameter optical fiber. The device can find applications in endoscopy.

Solution: A triplet lens system is fabricated in one printing step without the need of further assembly nor alignment of the lenses. Printing is done in situ on top of the fiber.

Source: DOI: 10.1038/nphoton.2016.121

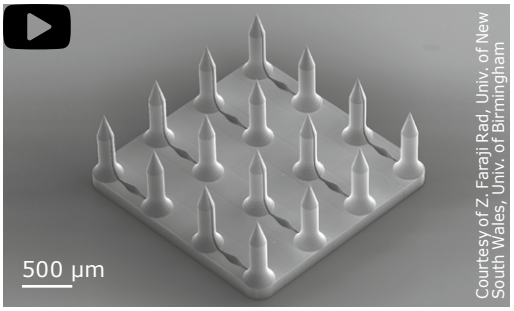


REPLICATED HOLLOW MICRONEEDLES

Challenge: Replication of hollow microneedle arrays with microfluidic channels and sharp tips. The replicas aim to be used for point-of-care collection of blood or drug delivery.

Solution: Needles are additively manufactured from a CAD model. The needles' master is cast in a negative mold. The mold is replicated by soft embossing into a thermoplastic cyclo-olefin polymer that shows agent delivery into a rabbit's ear.

Source: DOI: 10.1038/micronano.2017.34



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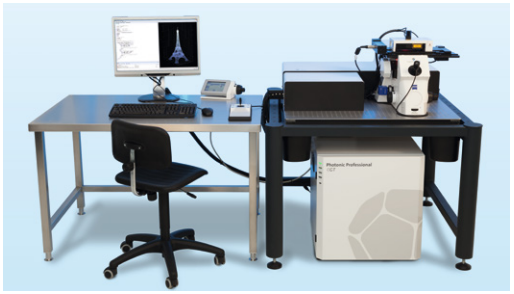
AN/MED/V01_2018

BIOMIMETICS

Natural systems with millions of years of evolution inspire technological innovation in the design and development of functional and smart materials. Nanoscribe's Photonic Professional *GT* offers highest resolution in 3D printing and geometric design freedom to emulate biological structures at nano-, micro- and millimeter scales. Shape, size and distribution of the structures can be easily changed in order to investigate and optimize materials. Due to structural design at the microscale, materials can adopt properties such as hydrophobicity, elasticity or coloration – mimicking intricate architectures and finest features observed in nature.

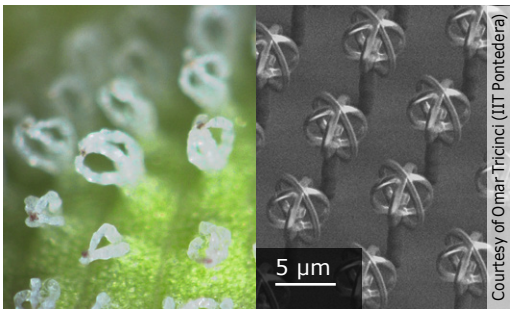


HIGHLY HYDROPHOBIC SURFACES

Challenge: 3D micropattern capable of air retention, hydrophobicity and water condensation required for fog collection inspired by salvinia molesta leaves.

Solution: Periodic arrays of crown-like hairs, hundred times smaller than the natural model, are printed. Structures are stable when submerged in water and air trapping is demonstrated.

Source: DOI: 10.1021/acsami.5b07722

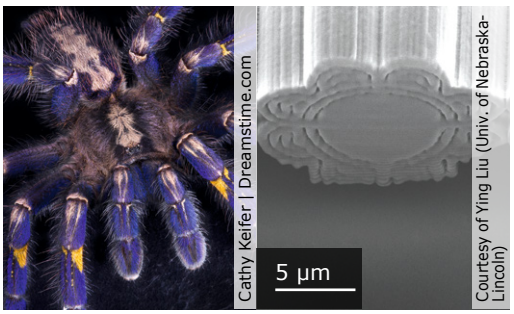


NONIRIDESCENT PHOTONIC NANOSTRUCTURES

Challenge: Tarantula hair-like nanostructured material which exhibits angle independent reflectance spectra due to microscale rotational symmetry and hierarchy.

Solution: Hierarchical multilayer cylinders are fabricated out of a transparent polymer material with layer thicknesses of 300 nm and layer spacing of 450 nm that show a green hue up to 70° incidence angle.

Source: DOI: 10.1002/adom.201600599

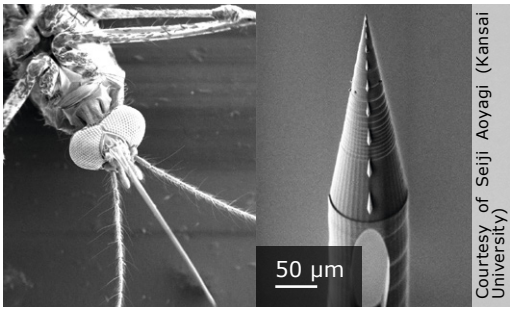


MICRONEEDLES FOR PAINLESS BLOOD COLLECTION

Challenge: Microneedles mimicking the mosquito's proboscis for painless and easy insertion into the skin without bending or collapsing due to reduced puncturing resistance.

Solution: Microneedle halves of mm-length are printed with sharp tips, spikes and small holes. Two assembled halves advance alternately and can penetrate artificial skin to suck blood.

Source: DOI: 10.1109/TRANSDUCERS.2015.7180876

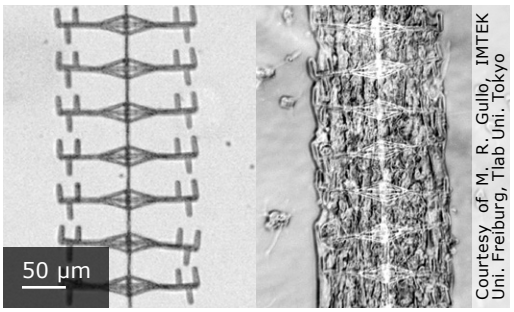


CELL-ACTUATED HYDROGEL MICROSKELETON

Challenge: Stable and deformable hydrogel scaffold that allows selective cell adhesion and differentiation of C2C12 cells into mature muscle fibers that contract and relax when voltage is applied.

Solution: The printed microskeleton is made of a PEGDA-based hydrogel mixed with PETA which promotes stiffness and protein adhesion. The cell-seeded bio-MEMS system deforms reversibly under electrical stimulus.

Source: DOI: 10.1109/MEMSYS.2017.7863350



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