Photonic hook switch: two photon polymerisation experiment protocol

Liyang Yue[1], Oleg V. Minin[2], and Igor V. Minin[2]
[1]School of Computer Science and Electronic Engineering Bangor University, Dean Street, Bangor, Gwynedd LL57 1UT, UK
[2]Tomsk Polytechnic University, 36 Lenin Avenue, Tomsk 634050, Russia

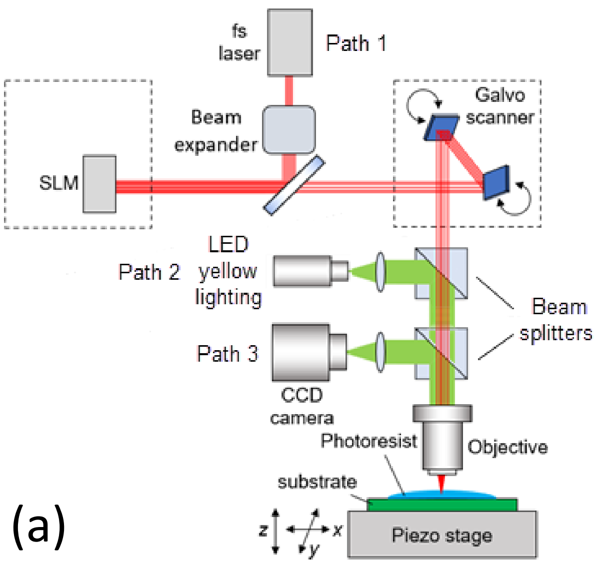
Recently, a new concept for photonic switching based on photonic hook phenomena was introduced [1,2]. When two-wavelengths beams, 1310 nm and 1550 nm, pass through a dielectric Janus particle, they were separated and guided to different routes because of different bending strengths, thus permitting effective photonic switching on microscale through a simple dielectric particle. Potential applications in photonic integrated circuit are envisaged. Experimental verification of the switch concept requires the development of an appropriate protocol.

Keywords: photonic switch, photonic hook, two-photon polymerisation

1. Optical setup

Two photon polymerisation (TPP) 3D printing is a technique to additively fabricate micro/nano features relying on the two-photon absorption process triggered by a focused femtosecond (fs) laser. The solidification only occurs at the laser focus, which results in the precise micro/nanosized dielectric photonic wires along the laser scanning path and then the dielectric particle-lens we need can be created layer by layer in an additive way.

The diagram and picture of the optical setup are shown in Figure 1 below. Three optical paths exist in this setup. The path 1, 2, 3 are for guiding fs laser beam, LED lighting, and camera image into the objective, respectively, as shown in Figure 1 (a). The spatial light modulator (SLM) and a Galvo scanner (in two dashed squares in Figure 1 (a)) would be two additional components to improve the TPP 3D printing speed and quality. The overall setup in a laser safety enclosure is shown in Figure 1 (b). The close-up views of double beam splitters, Leica infinity 1.25NA oil immersion lens objective, and Toptica Compact/780 nm wavelength/100 fs pulse width laser are in Figure 2 (a)-(c).



(a)

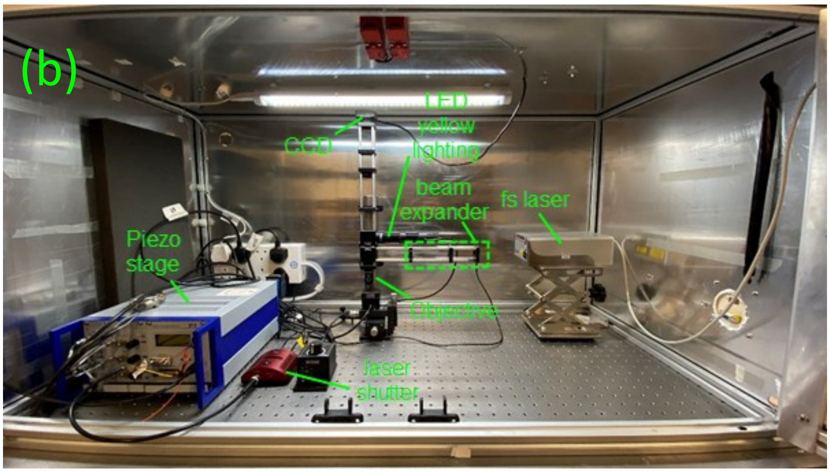


Figure 1 (a) Optical path diagram (b) Picture of the experimental setup

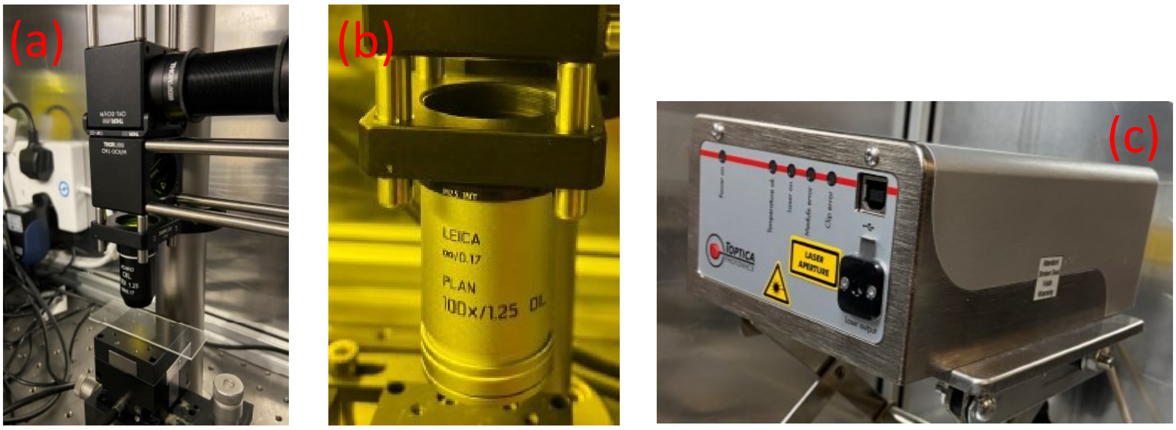


Figure 2 (a) Double beam splitter for optical path 1 and 2 (b) Objective used in the experiment Objective Leica infinity 1.25NA oil immersion lens (c) fs laser Toptica Compact 780 nm wavelength 100 fs pulse width

2. Photoresists and substrate

SU-8 is a high contrast, epoxy-based photoresist designed for micromachining and other microelectronic applications, where a thick, chemically and thermally stable image is desired. SU-8 2000 series is an improved formulation of SU-8, which has been widely used by MEMS producers for many years. After the market survey, two SU-8 2000 products – SU-8 2000.5 and SU-8 2050 are selected as the photoresist building materials of micro/nano structure in this experiment.

To obtain maximum process reliability, substrates – glass slides should be clean and dry prior to applying SU-8 2000 resist. For best results, substrates should be cleaned with a detergent followed by a de-ionized water rinse. Substrates may also be cleaned using acetone or isopropyl alcohol (IPA) depending on the surface conditions. Some devices used in the preparation are shown in Figure 2. The glass slides used as the substrate are marked by small crosses in advance using laser ablation technology to help indicate the TPP 3D printing locations under the microscope, as shown in Figure 2 (d). All experiments and preparation must be under the yellow lighting to avoid exposure of photoresist.

2.1 Development protocol of 2D mask patterns SU8-2000.5 low viscosity photoresist

Step 1: Spin coating with the speed: 2000 rpm (darkroom) for 1 min and thickness: 1 um

Step 2: Soft baking temperature and duration: 95 degrees for 7 mins (darkroom)
Step 3: TPP printing in the darkroom
Step 4: Post-exposure baking temperature and duration: 110 degrees for 5 mins (darkroom)
Step 5: Development in Propylene glycol methyl ether acetate (PGMEA, Sigma Aldrich) for 5 mins (darkroom)
Step 6: Rinse: Deionised water spray washing for 2 mins, then Isopropyl Alcohol (IPA) spray washing for 2 mins
Step 7: Drying: compressed air blowing at 25 psi for 2 mins

2.2 Development protocol of 3D short structure SU8-2050 high viscosity photoresist
Step 1: Spin coating with the speed: 6000 rpm (darkroom) for 2 mins and thickness: 40 um
Step 2: Soft baking temperature and duration: 65 degrees for 3 mins then 95 degrees for 6 mins (darkroom)
Step 3: TPP printing in the darkroom
Step 4: Post-exposure baking temperature and duration: 65 degrees for 1 min, then 100 degrees for 6 mins (darkroom)
Step 5: Development in Propylene glycol methyl ether acetate (PGMEA, Sigma Aldrich) for 7 mins (darkroom)
Step 6: Rinse: Deionised water spray washing for 2 mins, then Isopropyl Alcohol (IPA) spray washing for 2 mins
Step 7: Drying: compressed air blowing at 25 psi for 2 mins

2.3 Development protocol of 3D tall structure SU8-2050 high viscosity photoresist
Step 1: Spin coating with the speed: 3000 rpm (darkroom) for 2 mins and thickness: 115 um
Step 2: Soft baking temperature and duration: 65 degrees for 5 mins then 95 degrees for 10 mins (darkroom)
Step 3: TPP printing in the darkroom
Step 4: Post-exposure baking temperature and duration: 65 degrees for 3 min, then 100 degrees for 9 mins (darkroom)
Step 5: Development in Propylene glycol methyl ether acetate (PGMEA, Sigma Aldrich) for 15 mins (darkroom)
Step 6: Rinse: Deionised water spray washing for 2 mins, then Isopropyl Alcohol (IPA) spray washing for 2 mins
Step 7: Drying: compressed air blowing at 25 psi for 2 mins

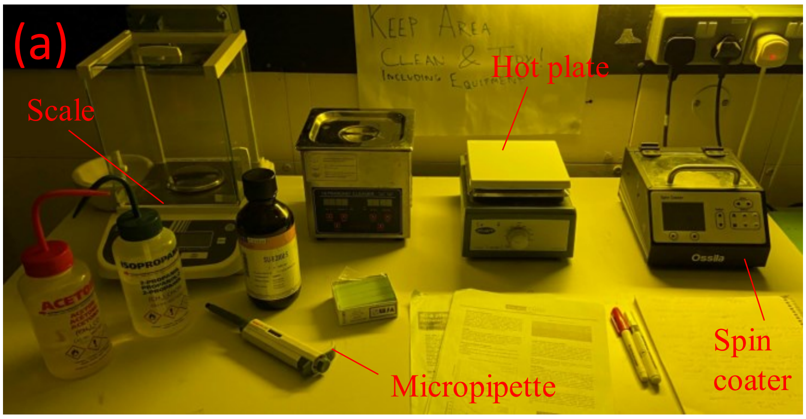
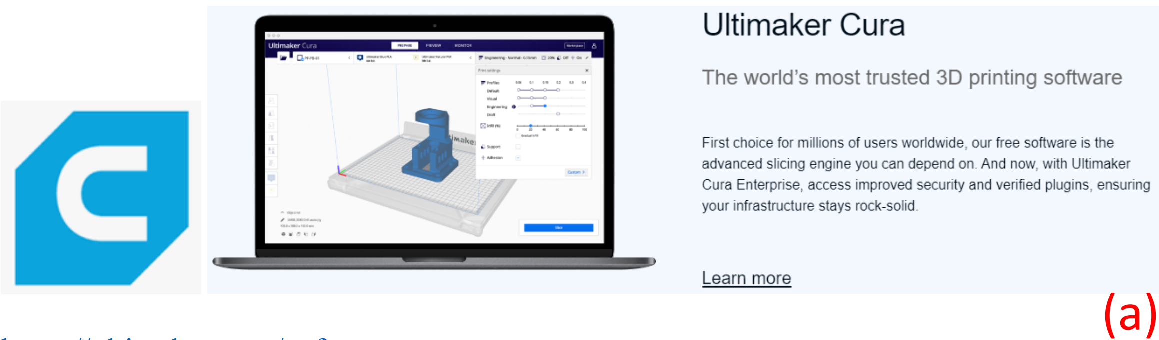


Figure 2 (a) All devices for substrate and photoresist preparation/development (b) SU-8 2050 photoresist (c) Propylene glycol methyl ether acetate (PGMEA, Sigma Aldrich) (d) The glass slides after laser cross marking and photoresist application.

3. CAD model slicing programme

The programme development for translation of CAD model slicing code to GCS code. The open-source 3D printing software CURA slices the CAD model of particle-lens into layers and generates the G-code. The developed JAVA programme translates G-code into GCS code which can be read by the piezo stage shown in the setup below - Physik Instrumente PI E-517 controller to drive the nanocube P-611.3 Piezo system.

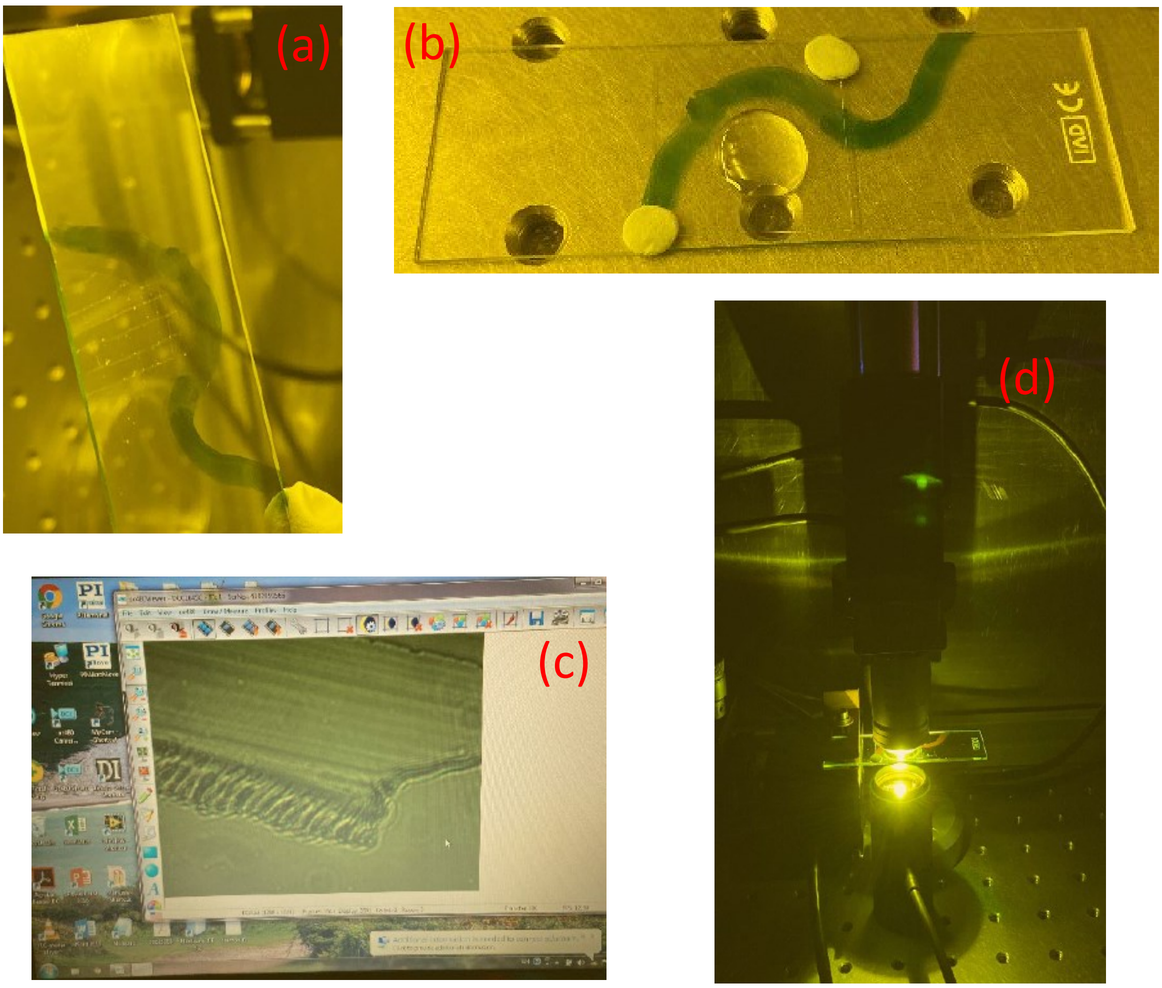


https://ultimaker.com/software

https://www.physikinstrumente.co.uk/en/products/controllers-and-drivers/nanopositioning-piezo-controllers/e-517-digital-piezo-controller-operation-module-602600/
Figure 3 (a) CURA open-source CAD slicing software G-code (b) PI E-517 controller and P-611.3 nanocube piezo system

4. TPP experiment and photonic wire measurements

The photoresist is applied to the glass slide, then several scratches will be made to facilitate the focusing, as shown in Figure 4 (a). The glass slip and immersion oil are used to get the best 3D printing quality, as shown in Figure 4 (b). When the detailed scratch images are observed through the CCD camera (Figure 4 (c)), it means the 3D printing plane is reached, and GCS TPP printing programme can start running once the printing location is confirmed. A picture of TPP printing process is in Figure 4 (d). The development procedure is introduced in the previous section. A picture of PGMEA soaking is shown in Figure 4 (e).



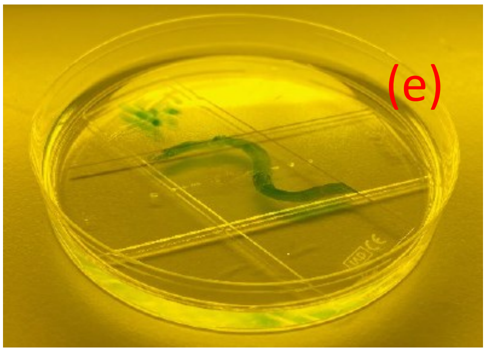


Figure 4 (a) Scratches on the dried photoresist coating to help focusing (b) Glass slip and immersion oil covered on the photoresist (c) Printing plane location with the detailed scratches image (d) TPP printing process (e) Photoresist development

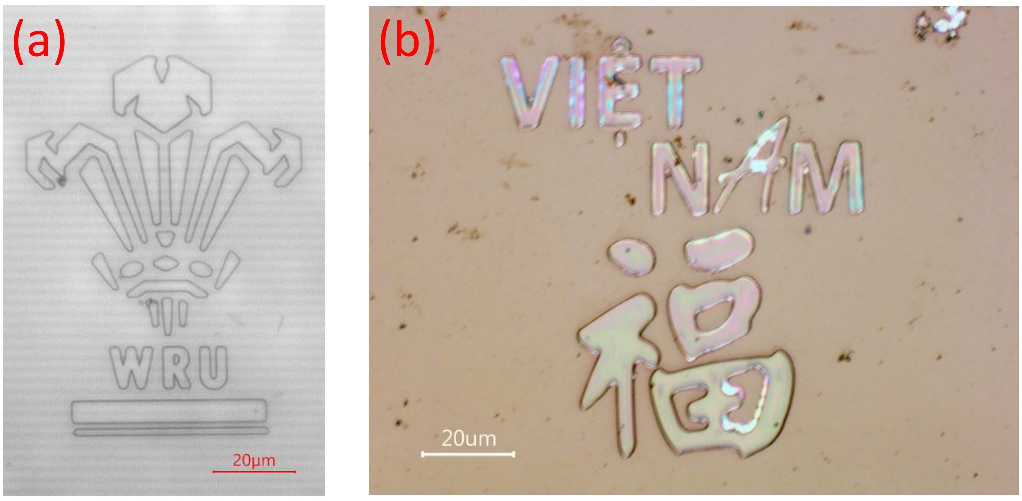
5. TPP printing results and on-going experiments

5.1 First Results

Low viscosity SU8-2000.5 2D wire can reach the minimum thickness of 0.3 um and keep straight, as shown in Figure 5 (a) and (b) Vietnam fortune and Wales Rugby union logo. High viscosity SU8-2050 wires would be curvy as shown in Figure 5 (c) because of the high viscosity of the photoresist and the following fast movement by piezo stage (need high speed to reduce the photon dose for thin wire), which causes the bad printing for the object on the scale of about 3 um that we want. This is the main issue so far, and I am trying to find a way to overcome it.

Scanning speed against photonic wire thickness:
1 micron per second 1.85um
2 2 micron per second 1.73 um
3 3 micron per second 0.81 um
4 /6 micron per second 0.59 um
5 -8 micron per second 0.42 um
6/ 10 micron per second 0.35 um

The low speed TPP printing with a large photonic wire thickness is acceptable. A large-scale fishnet structure with the height of 30 um was successfully produced, as shown in Figure 5 (d) and (e).



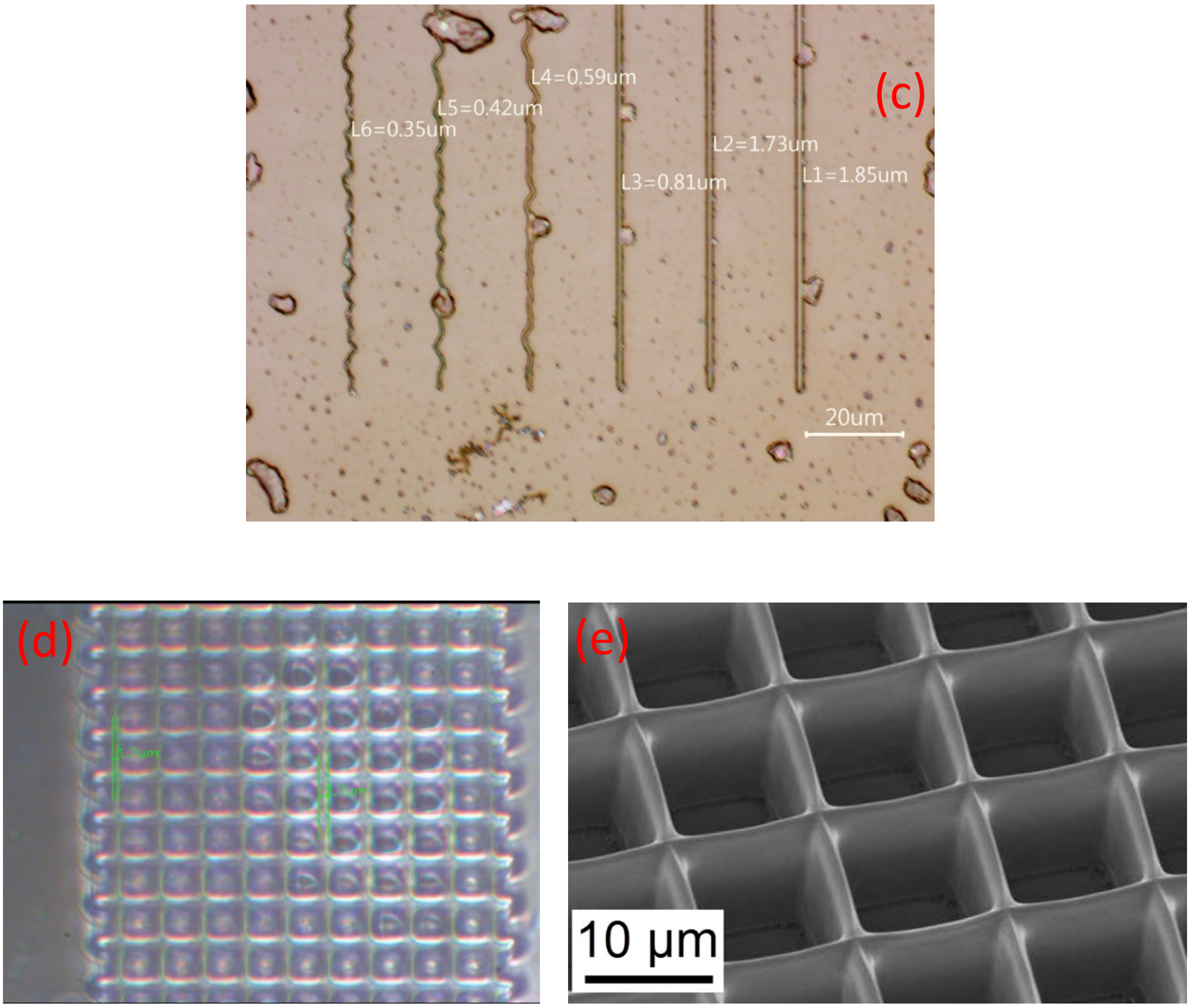


Figure 5 (a) 2D SU8 2000.5 TPP printing of Wales Rugby union logo (b) 2D SU8 2000.5 TPP printing of Vietnam fortune (c) Photonic wires thickness against printing speed (d) Picture of a low scanning speed TPP printing of fishnet structure (e) SEM image of TPP printing of fishnet structure

5.2 On-going experiments:

- Overcome the above curvy wire issue through adjustment of current piezo stage and photoresist protocols
- Attempt to test the light bending in a larger TPP printed structure, because the straight wire can be realised with a large width and low-speed movement normally, as shown in the picture. The setup is similar to that published in your paper co-authored with the Taiwanese institute.
- Add an SLM and a Galvo scanner to the setup to improve the printing quality. I am about to sort out the money for these two components and hope they can solve the problem.

Acknowledgements

This work was partially financially supported by the Russian Foundation for Basic Research (Grant No. 21-57-10001), and by TPU development program. L.Y. acknowledges the financial support by the Royal Society International Exchanges Cost Share scheme, UK (reference no. IEC\R2\202040).

References

1. Geints, Y.E.; Minin, O.V.; Yue, L.Y.; Minin, I.V. Wavelength-Scale Photonic Space Switch Proof-of-Concept Based on Photonic Hook Effect. Ann. Phys. **2021**, 533, 2100192.
2. Yue, L.Y.; Wang, Z.B.; Yan, B.; Xie, Y.; Geints, Y.E.; Minin, O.V.; Minin, I.V. Near-Field Light-Bending Photonic Switch: Physics of Switching Based on Three-Dimensional Poynting Vector Analysis. Photonics **2022**, 9, 154.