Study of three-dimensional ordering of liquid crystal molecules induced by nanogrooves fabricated with two-photon polymerization for application in tunable photonic microdevices

Liquid crystals are a unique type of material that act like liquids but keep some degree of molecular order like crystals. Due to the elongated rod-like or disc-like shape of the molecules, liquid crystals exhibit anisotropic properties, meaning they have different physical properties in different directions, e.g., refractive index, electric and magnetic susceptibility. This anisotropy gives rise to the unique optical and electrical properties of liquid crystals, making them useful in various technological applications. The liquid crystal molecules respond to external stimuli such as voltage, temperature or light, that change their orientation. It opens up the possibility for construction of tunable devices. In such devices, apart from the precise control of the molecules orientation, there is a demand of anchoring the molecules onto the orientational layers that will give them the initial alignment direction. Recently, two-photon polymerization has been introduced as a novel method for liquid crystal anchoring. In general, two-photon polymerization is an advanced technique used in additive manufacturing, commonly known as 3D printing, to create intricate and highly detailed three-dimensional structures at the nanoscale level, as illustrated in the examples in Figure 1 a) and b). Unlike traditional 3D printing methods that rely on layer-by-layer deposition of materials, two-photon polymerization utilizes a laser to selectively solidify a liquid resin in a precise manner. By printing nanogrooves, the geometrical morphology will give rise to molecules alignment along the direction implied by the grooves. This represents a significant advancement by combining the design flexibility of 3D printing with the tunability of liquid crystals, what opens up new paths for the development of advanced photonic devices.

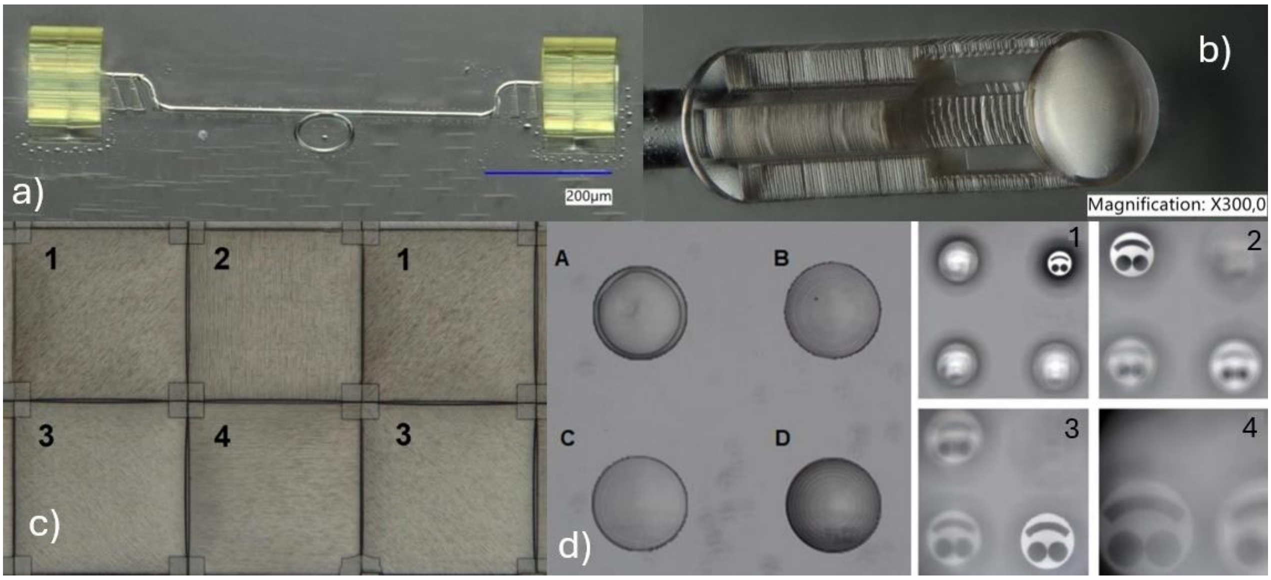

Figure 1. a) A ring microresonator coupled by a waveguide with thickness of a few micrometers, b) a lens with high-quality surface printed on optical fiber tip, the supporting structure is 1 mm long (printed with low resolution), c) anchoring layers printed with different hatching angles in four distinct areas, d) microlenses with different curvature radius and images produced by the lenses (unpublished results, recently obtained in Laboratory of Nanophotonics, Faculty of Physics WUT).

The fundamental scientific goal of this study is to develop and investigate a new method allowing for repeatable creation of stable (and multistable) three-dimensional topologies of liquid crystal molecular alignment in complex surface geometries. The research will begin with systematically varying the parameters of 3D micro- and nanostructures to understand their influence on the anchoring mechanism. Then, the feasibility of constructing of a few exemplary devices with this method will be assessed. This will include isolated waveguides for polarization, birefringence, or attenuation tuning; directional couplers; periodic waveguides; optical fiber-integrated structures; tunable microlens arrays; tunable axicons; prisms; and diffractive elements for beam steering. Numerical modeling will provide a theoretical analysis of their performance. The final phase will focus on optimizing the most promising designs and creating durable demonstrators. **The proposed project may bring new knowledge into expanding the design freedom of tunable devices, which may be useful in emerging technologies such as 3D micro-displays used in smart-glasses, augmented reality (AR), mixed reality (MR) or virtual reality (VR) sets or even new type of smart windows and small-scale soft robots.**