UV-Curable Hybrid Polymers Enabling Multiple Manufacturing Schemes for Complex (Micro)optical Components

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Inorganic-organic hybrid polymers, which consist of both inorganic and organic functional units and thus combine contrasting material properties in one superior material class, have already been widely applied for photonic applications \cite{1,2}. Due to their excellent optical transparency as well as high thermal and climate stability, UV-curable hybrid polymers have been successfully implemented in the industrial manufacture of optical components and micro-optical systems, such as microlenses or 2D and 3D waveguides, from the wafer-scale down to the chip level by various fabrication methods (Figure 1). Several hybrid polymers have been designed to allow various coating methods like spin coating, droplet dispensing or inkjet printing, i.e. OrmoComp\textsuperscript{®}, OrmoClear\textsuperscript{®}, Ormocore, and InkOrmo (Figure 2). In order to meet the constantly growing expectations towards the material’s optical performance as well as to further improve the adaptability to emerging industrial production technologies, the materials can be particularly tailored, i.e. regarding their optical properties or their applicability to fabrication methods (e.g. UV molding or two-photon absorption lithography (TPA)) \cite{3}. In this context, firstly we report on two newly developed UV-curable hybrid polymer materials with focus on high refractive index and PDMS compatibility. Secondly we present the extension of OrmoComp\textsuperscript{®}’s processability from 2D to 3D by the employment of TPA. By the employment of surface-modified ZrO\textsubscript{2} nanoparticles a high refractive index OrmoClear\textsuperscript{®} prototype with a RI of 1.6 was created. Despite the addition of nanoparticles the excellent transparency as well as the micro- and nano-replication capability (i.e. UV molding) of the base material OrmoClear\textsuperscript{®} was maintained. Furthermore, we report on the evaluation of a second OrmoClear\textsuperscript{®} prototype (OrmoClear\textsuperscript{®}FX) with enhanced curing behavior enabling the compatibility with the replication using PDMS molds (Figure 3), as they are highly used in high volume production environments. Aside from the applicability in 2D, we further present the evaluation of hybrid polymer materials for the manufacture of advanced 3D optical components, in particular by TPA. Hybrid polymers such as commercially available OrmoComp\textsuperscript{®} are highly suitable for the fabrication of arbitrary shaped structures via TPA as shown exemplarily by a prism array with complex topography (Figure 4) \cite{4}. In order to provide the best possible compromise between laser writing speed and shape accuracy we investigated the influence of photoinitiator and stabilizer concentration. From extensive experiments, we concluded that a higher stabilizer ratio in OrmoComp\textsuperscript{®} leads to an improved shape accuracy and a sharper contour between substrate and structure. To demonstrate the significance of TPA for mass production of complex 3D structures, we utilized TPA for the fabrication of an OrmoComp\textsuperscript{®} master mold on a glass substrate. By subsequent replication into OrmoStamp\textsuperscript{®} on a metal plate and further high throughput replication by injection molding, we successfully integrated TPA into a valid industrial production chain. To conclude, we will present the broad applicability and manufacturing capabilities of hybrid polymers not only for generic processes but also in the scope of emerging technologies for micro- and nanofabrication purpose.

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