Femtosecond laser-assisted free-form 3D printing on fiber tip for microfluidic sensing applications

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The rapid expansion of modern cities has significantly intensified heavy metal pollution in soil, the atmosphere, and particularly in aquatic environments, underscoring the urgent need for efficient pollutants detection methods [1]. Meanwhile, optical fibers, introduced nearly 40 years ago, are recognized as a cornerstone of innovation in sensing and instrumentation, driving remarkable progress in both academic and industrial research [2]. Recent progress in laser-assisted 3D printing technologies has further expanded the possibilities for a precise and dedicated patterning on fiber tips using polymer-based materials [3]. However, such materials may degrade under laser exposure. To overcome this limitation, hybrid organic-inorganic resins have been developed offering durable, cost-effective and eco-friendly solution to propose long-lasting structures [4].

This paper reports on the development of an original system designed as a probe based on light collection through a spherical mirror and entirely fabricated by 3D printing assisted by IR pulsed laser. The targeted application addresses water analysis through microabsorption spectroscopy. For the light collection, we design an optical reflective freeform device that is a hollow hemisphere with a 200µm diameter, supported by 15µm high pillars, directly printed on the tip of a fiber that operates as both the light source and the optical receiver.

A first step of this study focuses on the optimization of the morphology, roughness and homogeneity of the hollow hemisphere surface to achieve the best optical quality as possible and to ensure that the final print fits the developed 3D model obtained from a finite element modeling. A femtosecond fiber laser operating at 1030 nm is used for the 3D printing process. Considering a two-photon polymerization, the frequency is doubled using a BBO frequency-doubling crystal, shifting the wavelength to the visible range (515 nm). The resin used in this work belongs to ORMOCER® family. Preliminary fabrication results are presented in Fig. 1(a) and Fig. 1(b). In a second step, the surface of the obtained hemisphere is coated with a layer of few nanometers of gold and then an optical characterization is performed by injecting light and collecting the reflected one.

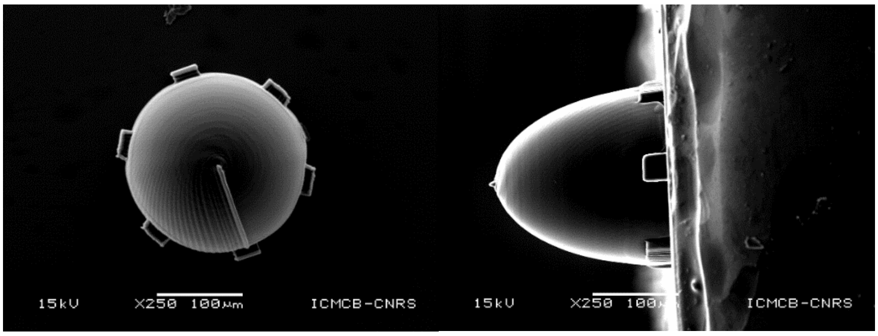

Fig. 1 SEM image of the spherical mirror coated with a gold layer after the baking process **(a)** top view **(b)** side view

In conclusion, we successfully fabricated a spherical mirror considered as a novel and rarely explored structure in literature, and we demonstrate its ability to capture the emitting light. Future works focus on the direct fabrication of such a structure directly connected on the fiber tip to propose an integrated sensor enabling water pollutants detection. We believe that this study provides a simplified approach where analysis can be conducted by directly immersing the fiber into the targeted liquid sample.

References

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