Femtosecond direct laser writing of active photonic components in glasses.

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Femtosecond laser inscription in dielectric materials enables the fabrication of compact, robust and self-aligned multi-dimensional photonic structures. The integration of active components allows for the modulation of optical properties such as optical phase or optical power, which is highly demanded since it can expand the versatility of these photonic devices.

In this context, my Ph.D. research, conducted at the ICMCB laboratory supervised by Yannick Petit and Lionel Canioni, aims to develop active components in photosensitive materials through highly localized energy deposition in both space and time. The ultimate goal is the realization of an integrated micro-laser embedded in a glass material, emitting in the near-infrared (NIR) for applications in medical diagnostics, space technology, and/or telecommunications.

Thus far, we have demonstrated the ability to fabricate high-contrast Bragg gratings in photosensitive glasses, achieving state-of-the-art first-order coupling coefficients with record backward coupling coefficients up to 5 mm^{-1}, leading to more than 99% attenuation with 500 µm length gratings [1]. Additionally, we have observed 3D-localized energy transfers between laser-created silver molecular clusters Ag_{m}^{n+} (also responsible for the refractive index contrast) and rare-earth ytterbium (Yb) elements, making such acceptor/donor pair compatible for indirect-pumping laser gain amplification [2]. Moreover, the development of a dedicated characterization setup has also enabled the study of various laser-created waveguides including waveguides produced by 3D-printing in inorganic resins via two-photon polymerization under femtosecond laser irradiation [3]. Furthermore, investigations of novel photosensitive materials have highlighted the suitability of bismuth (Bi) in phosphate glasses for the fabrication of integrated laser gain medium and associated laser active waveguides in the NIR range [4].

These findings help refine the research scope and pave the way for the development of the all-optical laser manufacturing of an integrated laser in zinc-phosphate glasses containing Ag and Bi ions, with femtosecond-laser-inscribed Bragg gratings serving as cavity mirrors. This device would enable laser emission in the NIR around 1300 nm, within the O-band of optical telecommunications.

[1] L. Loi, M. Carpentier, Y. Petit, and L. Canioni, *Opt. Mater. Express* **14**(7), 1837-1848 (2024).

[2] F. Alassani, G. Raffy, M. Carpentier, J. Harb, V. Jubera, A. Del Guerzo, L. Canioni, T. Cardinal, and Y. Petit, *ACS Applied Materials & Interfaces* **17**(1), 1770-1781 (2024).

[3] R. Hazem, M. Carpentier, Y. Petit, and L. Canioni, *Advanced Optical Materials*, **under submission** (2025).

[4] M. Carpentier, F. Alassani, T. Cardinal, L. Canioni, and Y. Petit, *Optics Letters*, **under submission** (2025).