# High concentration Er-doped phosphate glass optical fibers for single-frequency fiber amplifiers

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**max. 500 words abstract:**

The continuous improvement of earth-bound interferometric gravitational-wave detectors (GWDs) and the preparation for the next generation of GWDs set highly demanding requirements on their laser sources. The next generation of GWDs will likely operate not only at 1064 nm but also in the 1500 or 2000 nm wavelengths regions to cover a broader range of frequencies in which gravitational waves are detectable. A promising candidate to fulfill the challenging requirements of GWD laser sources is the hybrid master-oscillator power fiber amplifier (MOPFA) configuration that consists of a diode-pumped solid-state or semiconductor-based laser used as a master oscillator followed by fiber amplifying stage. The implementation of a MOPFA relies principally on commercial silica glass-based optical fiber technology, which has been key in the successful development of high-power fiber amplifiers. However this technology also carries limitations to scale up the output power. One of the main drawbacks is the limited concentration of rare-earth (RE) ions achievable in silica glass: it is well known that Erbium (Er) ions tend to cluster in the rigid closed structure of silica glass leading to ion-ion interactions and degradation of performance. Typically modifiers such as aluminum and phosphorous are added to the glass to increase RE solubility by creating more open sites, but with moderate effect. The limited concentration of RE ions per unit length implies a limited optical gain per unit length and thus the requirement for long amplifying fiber lengths that enforce deleterious nonlinear effects, foremost stimulated Brillouin scattering (SBS).

Numerous SBS suppression techniques have been proposed, alongside investigation of specialty optical fibers in terms of fiber geometry, morphology and glass material. One promising solution is

to use highly doped optical fibers based on multicomponent phosphate glass. Thanks to the high concentration of RE ions (up to $10^{21}$ ions/cm$^3$) achievable in the phosphate glass matrix, it is possible to reach high gain per unit length values and therefore to design ultra-compact and short pathlength-devices free of nonlinear spurious effects.

With the aim of realizing compact optical fiber amplifiers operating in the 1.5 µm wavelength range, a series of highly $Er^{3+}$-doped (2.60 x $10^{20}$ ions/cm$^3$) custom phosphate glass compositions was designed and fabricated to be used as active materials for the core of the fiber amplifiers. The synthesized glasses were thermo-mechanically characterized, then the glasses underwent optical characterization such as refractive index measurement, FTIR spectroscopy and RE emission spectroscopy resolved in time and frequency. Suitable undoped cladding compositions were investigated and final core/cladding glass pairs were selected to manufacture single-mode and multi-mode optical fibers.

Core and cladding glasses were synthesized by melt-quenching. The core glass was then cast into a cylindrical mold to form a rod, whereas the cladding tube was fabricated by extrusion using an in-house developed equipment. The core/cladding phosphate glass fibers were then drawn from a preform realized through the rod-in-tube technique.

Preliminary results of the application of the $Er^{3+}$-doped phosphate fiber as laser active medium in a fully monolithic single-mode single-frequency core-pumped MOPFA setup resonantly pumped at around 1480 nm are presented.

**max. 300 words abstract:**

The continuous improvement of interferometric gravitational-wave detectors (GWDs) and the preparations for next generation of GWDs set highly demanding requirements on their laser sources. A promising candidate to fulfill the challenging requirements of GWD laser sources is the hybrid master-oscillator power fiber amplifier (MOPFA) configuration. The implementation of a MOPFA relies principally on commercial silica glass-based optical fiber technology, which has been key in the successful development of high-power fiber amplifiers but that poses also a limitation to power scaling of these devices. It is well known that erbium (Er) ions tend to cluster in silica glass leading to ion-ion interactions and degradation of performance. The limited concentration of RE ions per unit length implies a limited optical gain per unit length and thus the requirement for long amplifying fiber lengths that enforce deleterious nonlinear effects, foremost stimulated Brillouin scattering (SBS).

Numerous SBS suppression techniques have been proposed, alongside investigation of specialty optical fibers. One of the most promising solutions is the use of highly doped optical fibers based on multicomponent phosphate glass that allows the fabrication of ultra-compact active devices with minimized nonlinearities.

To realize compact optical fiber amplifiers operating at 1.5 µm, a series of highly $Er^{3+}$-doped custom phosphate glass compositions was designed and fabricated to be used as active materials for the core of the fiber amplifiers. Suitable cladding compositions were explored.

Core and cladding glasses were synthesized by melt-quenching method. The core glass was cast into a cylindrical mold to form a rod, whereas the cladding tube was fabricated by extrusion technique.

Phosphate fibers were then manufactured by drawing the preform assembled by rod-in-tube technique.

Preliminary results of the application of the $Er^{3+}$-doped phosphate fiber as laser active medium in a fully monolithic single-mode single-frequency core-pumped MOPFA setup resonantly pumped at around 1480 nm are presented.