Rare-Earth Doped Phosphate Glass Fibers

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Abstract: We report on the fabrication and characterization of phosphate fibers doped with Yb and Yb/Er ions. Optical amplification and laser operation are demonstrated in short-length devices.
OCIS codes: (160.2750) Glass and other amorphous materials; (160.2290) Fiber materials; (060.2280) Fiber design and fabrication

Among various non-silica based glasses used in optics, rare-earth doped phosphate glasses have been attracting growing interest. Indeed, the optical and physical properties of phosphate-based glasses are particularly well suited for numerous applications going from optical communications, microsurgery or high-power laser applications. For instance, Nd-doped phosphate glass was selected as laser cavity medium for high-energy (10^3-10^6 J) and high-peak-power (10^{12}-10^{15} W) solid state laser for the nuclear fusion reaction tests [1]. Yb-doped phosphate glasses with an emission wavelength at around 1 µm have shown to be good candidates for high power fiber lasers thanks to absorption and emission cross sections higher than in silica glass and relatively long lifetime of the upper laser level of the incorporated rare earth ions [2]. Er-doped phosphate glasses for "eye-safe" lasers and waveguide amplifiers at 1.5 µm have received great attention not only in optical communication applications [3] for integration with passive components in highly integrated devices but also for the fabrication of laser and booster amplifier devices.

The great interest in rare-earth doped phosphate glasses as alternative to the more traditional and employed silica based glasses is related to a large number of attractive properties: they are easy to synthesize and possess good chemical durability, excellent optical properties, ion exchangeability, very high solubility of rare-earth ions and thus a high threshold towards clustering effect [4-6]. The possibility of incorporating a higher amount of rare earth ions allows for fabricating more compact active devices that are also characterized by low nonlinearities. Another important feature of phosphate glasses is their thermal and mechanical strength, that allows for the realization of optical fibers that can be fusion spliced with commercial optical fiber components based on silicate glasses [7].

1. Glass synthesis and fiber preform fabrication

In this study, several phosphate glass compositions (P_2O5 – Li_2O – Al_2O_3 – B_2O_3 – BaO – La_2O_3 – PbO) were designed and fabricated with the aim to produce Nd-doped, Yb-doped and Yb/Er-codoped double cladding fiber lasers. The most pertinent physical properties of these glasses are shown in Table 1.

Table 1: Rare-earth concentration [RE], glass transition temperature T_g, crystallization temperature T_x, glass stability ΔT, thermal expansion coefficient CTE and refractive index at 1312 nm of the prepared phosphate glasses

	CORE Yb/Er	1st $CLAD_{Yb/Er}$	CORE Yb	1st $CLAD_{Yb}$	2nd CLAD
[RE] [ions/cm^3] x 10^{20}	2.5 / 2.5	-	8	-	-
Tg [°C] ± 3	490	485	489	481	479
Tx [°C] ± 3	673	678	672	675	669
ΔT (Tx - Tg) ± 6	183	193	183	194	190
CTE [1/K * 10^{-6}] ± 0.1	9.4	9.5	9.4	10.3	10.2
n ± 10^{-3} @ 1312 nm	1.571	1.558	1.565	1.557	1.513

The phosphate glasses were designed to provide suitable characteristic temperatures and viscosity behavior for the preform fabrication and for the fiber drawing process. A particular attention was given to the design of an adequate numerical aperture between the internal and external cladding glasses while maintaining similar thermo-mechanical properties in view of the fiber drawing process.

The cladding tubes required for the preform were manufactured by the rotational casting technique. One great advantage of this technique is that the pristine inner surface of the as-fabricated tube does not require post processing prior to the fiber drawing process. The high quality of the inner tube surface is also critical for drawing an optical fiber

featuring high quality interfaces between core and internal cladding and between the internal and external cladding. Figure 1 shows a photography of a Nd-doped phosphate glass rod and two phosphate glass tubes used for building up the preform of a Nd-doped phosphate glass fiber.
Typically the fibers reported here were drawn at a speed of 5 m/min and an onset furnace temperature of 630 °C.

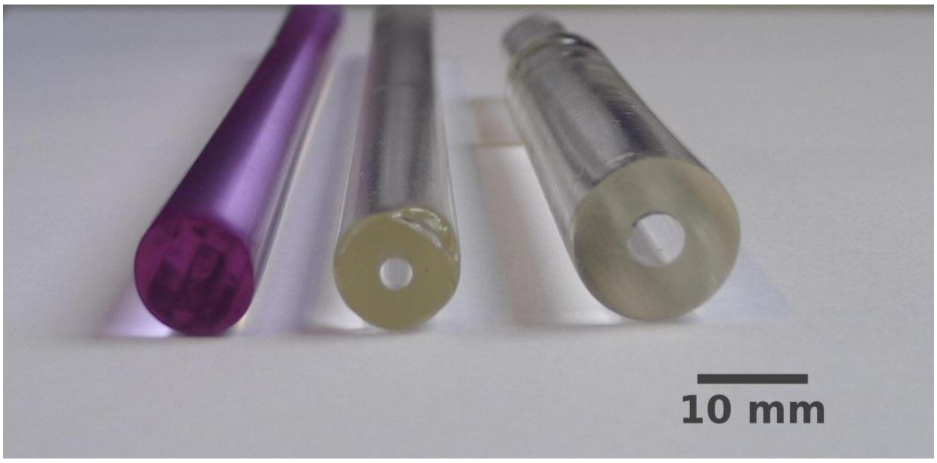

Figure 1: Glass elements of a phosphate glass preform. From left to right, core rod of Nd-doped phosphate glass, cladding tubes of passive phosphate glass

2. Fiber characterization and fiber devices

Typical losses in 40 µm core multimode fibers were measured to be 2 dB/m at 1300 nm wavelength. However, this attenuation value was found to increase to 6 dB/m for "single-mode like" fibers, although in absence of crystallization phenomena. This observation suggests that defects and impurities at the interface between core and first-clad are the main source of losses through scattering phenomenon.

2.1 Yb-doped fiber

An Yb-doped double cladding phosphate fiber was drawn as described above. The dimensions of the Yb-doped double cladding fiber are: 125 µm for the diameter of the outer cladding, 25 µm for the inner cladding and 7 µm for the core. Figure 2(a) show an optical micrograph of the fiber cross section. As shown in Figure 2(b), laser operation was demonstrated using a 25 mm long piece of Yb-doped double cladding fiber. The generation of a lasing peak of 12-14 dBm (15-25 mW) with center wavelength at 1022 nm was observed for a pump power of 248 mW operating at 976 nm.

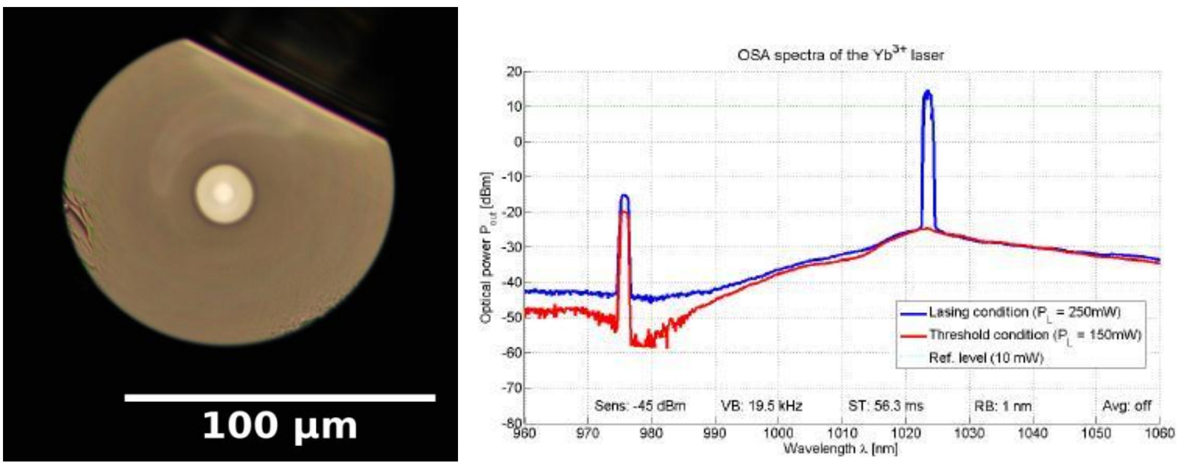

Figure (2a) Optical microscopy image and (2b) Lasing spectrum of a 26 mm long Yb-doped phosphate glass fiber

2.2 Yb/Er-doped fiber

An Yb/Er-codoped double cladding phosphate fiber was also drawn from a high quality preform. The preform and fiber fabrication parameters were set to generate a Yb/Er-codoped double cladding fiber with the following diameters: 7 µm, 25 µm and 70 um for the core, inner and outer cladding, respectively. An optical micrograph of the fabricated optical fiber cross-section is shown in Figure 3(a) where the circular and concentric core is evident. This Yb/Er-codoped fiber was tested as optical amplifier, and its performance is reported in Figure 3(b) .

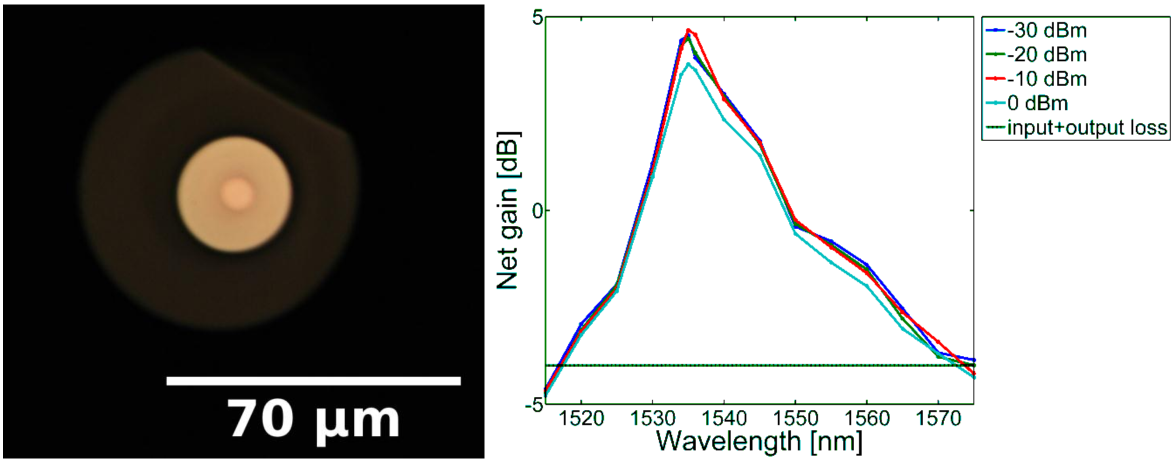

Figure (3a) Optical microscopy image and (3b) Signal net gain spectrum obtained for four different signal input powers -30 dBm, -20 dBm, -10 dBm and 0 dBm at wavelengths ranging from 1515 to 1575 nm. Injected pump power P_p = 237 mW in 27 mm long fiber.

In conclusion, this preliminary study demonstrates the feasibility to develop phosphate optical fiber devices using a simple method such as the rotational casting for manufacturing the fiber preform. Nonetheless, it is clear that further improvements of the glass material and fiber qualities are necessary towards the development of low loss and high quality phosphate glass fibers.

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