

# SINGLE-FREQUENCY Er:Yb PHOSPHATE GLASS WAVEGUIDE LASER ARRAY

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We fabricated an high-power single-frequency end-pumped Er:Yb:glass waveguide laser array by ion-exchange technique. The linear cavity 1.5  $\mu\text{m}$  laser emits 3.7-mW at 1534 nm and 2.9 mW at 1550 nm at 180 mW pump power.

**Keywords:** guided-wave laser, single-frequency laser, erbium laser, ion-exchange

## Introduction

In the recent years we had an increasing demand for compact active devices at 1.5  $\mu\text{m}$  for metro/local optical network applications. A promising solution is to fabricate array of waveguide devices on the same glass chip. In fact these devices are very promising in terms of cost, size and reliability. In particular active devices based on high-concentration Erbium doped glasses are very promising for making compact array of linear devices that are compatible with multifiber cable.

To obtain high gain per unit length (p.u.l.) Ytterbium codoping and phosphate glass base demonstrated to offer superior performance: Ytterbium codoping offers waveguide design flexibility and enhances pump absorption efficiency while phosphate glass base optimizes the energy transfer process between Erbium and Ytterbium ions [1]. Active fiber with gain up to 5 dB/cm [2] and amplifier with high gain p.u.l. and high output power have been reported [3-5]. Among various technique to fabricate such devices ion-exchange is a simply, reliable and rugged option and it was successfully demonstrated both using Ag-Na [4,7,8] and K-Na [9] ion-exchange. Active structures [10-12] and in particular optical amplifiers [3,4], lossless splitter [13] and single-frequency lasers [7-9] have been demonstrated. However laser devices were limited by low output power or by a cavity design requiring bi-directional pumping.

In this paper we report on a compact linear array of single-frequency waveguide lasers fabricated by a two-step ion-exchange technique. The laser emits about 3 mW at both 1534 nm and 1550 nm and shows robust single-frequency operation.

## Waveguide fabrication

The laser has been fabricated by using a commercial phosphate glass base (Schott, IOG-1) with doping concentration of  $2 \times 10^{20}$  ions/cm<sup>3</sup> and of  $6 \times 10^{20}$  ions/cm<sup>3</sup> for Erbium and Ytterbium, respectively. In the two-step ion-exchange technique we first make a superficial waveguide by Ag-Na ion-exchange and thermal diffusion. The second step is a field-assisted burial step. We therefore

performed preliminary investigation of glass parameters [14]. On the basis of this investigation we found that a first step with 0.02 surface refractive index variation and about 7 mm diffusion depth was the optimum to match the standard fiber mode profile after the burial step. The salt composition in the first step was 8% wt  $\text{AgNO}_3$ , 86.85% wt  $\text{KNO}_3$  and 5.15% wt  $\text{NaNO}_3$  and the step was performed at 330 °C for about 8 min. To reduce the waveguide loss the second burial step using Na-K fused salt was done, obtaining a mode-field profile compatible with standard SMF-28 telecom fiber. A set of sixteen 250- $\mu\text{m}$  spaced buried channel array was obtained.

### Single-frequency laser array

Figure 1 shows the schematic diagram of the linear laser cavity array. Two 25-GHz full-width-half maximum fiber-Bragg-gratings (FBGs) with 99.8% and 75% reflectivity, respectively, are butt-coupled by using index-matching fluid to the waveguide. By using the high-concentration glass we were able to obtain sufficient gain by using an end-pumped cavity as short as 10 mm. We thus overcame the complexity of the double pump configuration previously realized [15]. In addition the short cavity minimized mode-competition.

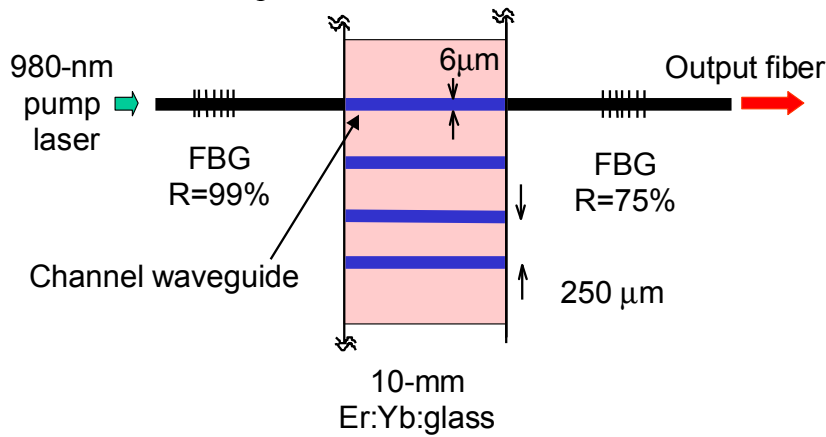


Figure 1: Schematic of the linear laser cavity

To further ensure robust single-frequency operation by inhibiting the onset of spatial hole burning, one of the two FBGs was placed  $\sim 20\text{-cm}$  apart, while the other was close to the active waveguide. The composed asymmetric cavity had a free-spectral-range of  $\sim 0.3\text{GHz}$ . The fiber-coupled 975-nm wavelength-stabilized laser pump diode was directly spliced to the 99.8% reflectivity FBG for a maximum available power of 180 mW. The single-frequency laser output was monitored by a high-finesse Fabry-Perot interferometer with resolution  $< 100\text{ MHz}$ .

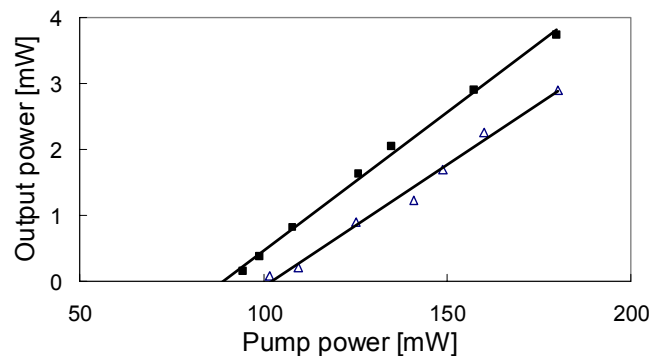


Figure 2: Output power versus pump power at 1534 nm (squares) and at 1550 nm (empty triangles).

Figure 2 shows the a typical single-frequency output power versus launched pump power curve at both 1534 nm and 1550 nm. At the peak wavelength the maximum single frequency output power was 3.7 mW at the maximum pump power with about 4.1% slope efficiency. A different channel was used as 1550 nm cavity. The laser threshold was a bit higher and the maximum output power was 2.9 mW with about 3.6% slope efficiency. By optimizing reflectivity at each wavelength we are looking for a laser array device with 3 mW output power from 1530 nm to 1565 nm. We stress that single-frequency operation was robust up to the maximum pump power however occasional mode-hopping occurred due to technical and thermal noise. To verify source suitability for external modulation we measured the relative-intensity-noise (RIN) spectra. A typical value is a RIN peak of about  $-80$  dB/Hz at the relaxation oscillation frequency of about 180 kHz. The RIN value than decreases below  $-150$  kHz for frequencies higher than  $\sim 3$  MHz

## Conclusions

In conclusion we reported on a high-power single-frequency end-pumped waveguide Er-Yb laser array operating in the C-band fabricated by the ion exchange technique using a commercial glass substrate. This device is extremely promising as compact transmission source for multi-wavelength optical network. This work was partially supported by Progetto Finalizzato MADESS II. One of the authors, G. Jose, acknowledges the support of an ICTP, Trieste Italy grant. Authors acknowledge the contribution of Daniele Costantini, EPFL-Lousanne, for measuring FBG position.

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