An Erbium -Ytterbium DFB laser with a simple and compact structure

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Abstract. A distributed feedback fiber (DFB) laser operating at 1540 nm having more than 45 dB signal to amplified spontaneous emission ratio with a simple and compact structure is introduced. The DFB laser consists of 45 mm long highly Er-Yb co-doped phosphate glass fiber with a grating structure inside the gain medium. The laser emission is stable, but the power is still relatively lower due to un-optimized grating structure.

Keywords: DFB laser, Er-Yb doped fiber laser, phosphate fiber laser.

1. Introduction
A distributed-feedback laser (DFB) is a laser where the whole resonator consists of a grating structure, which acts as a distributed reflector in the wavelength range of laser action, and contains a gain medium. Typically, the grating structure is made with a phase shift in its middle. This structure is essentially the direct concatenation of two Bragg gratings with internal optical gain. Most distributed-feedback lasers are either semiconductor lasers or fiber lasers and are operating on a single frequency. Semiconductor DFB lasers can be built with an integrated grating structure, e.g. a corrugated waveguide [1]. In the case of a fiber laser, the distributed reflection occurs in a fiber Bragg grating, typically with a length of a few millimeters or centimeters. Efficient pump absorption can be achieved only with a high doping concentration of the fiber, and unfortunately it is often not easy to write Bragg gratings into fibers with a composition (e.g. phosphate glass) which allows for a high doping concentration. However, this kind of single-frequency fiber laser is very simple and compact.

Recently, a study of the photosensitive in different phosphate glass has been reported, which allows high-quality Bragg gratings to be constructed in both phosphate fibers and planar glass waveguides [2]. In an earlier work, a DFB laser has been demonstrated using phosphate Er/Yb co-doped fiber in conjunction with a multimode pump [3]. In this paper, an Er-Yb co-doped phosphate DFB laser is demonstrated using a single-mode diode laser as the pump source. The laser resonator is formed by an asymmetric grating structure that provides distributed feedback for a signal light propagating in the single-mode core of an active Er–Yb codoped phosphate fiber.
2. Experimental

The schematic diagram of the linear-cavity Er-Yb DFB fiber laser is shown in figure 1. The active fiber is fabricated from phosphate glasses that allow for high levels of rare-earth-ion doping in the active core with $1.1 \times 10^{26}$ Er$^{3+}$ ions/m$^3$ and $8.6 \times 10^{26}$ Yb$^{3+}$ ions/m$^3$. The gain fiber is 45 mm long and has a core diameter of 6 μm and a numerical aperture of 0.12. The DFB grating structure is written directly into the active fiber by exposure to 193 nm UV light through a phase mask. The grating consists of a 20 mm long section close to the pump side and a 15 mm long section at the single-mode DFB emission side that are separated by a 0.05 mm wide gap that creates the defect state inside the grating’s reflection band.

The overall ~35 mm long grating structure is located approximately at the center of the active fiber piece, and the asymmetric DFB grating design results in unidirectional DFB laser emission. The single mode pump from 976 nm laser diode is launched into the Er-Yb fiber through a single-mode fiber which is spliced into the phosphate active fiber. The total splice loss at both ends of phosphate fiber is measured to be around 6 dB at 1310 nm. The output of the DFB laser is tapped from 1550 nm port of WDM coupler and is characterized by an optical spectrum analyzer (OSA) with a resolution of 0.015 nm.

![Figure 1. The configuration of DFB phosphate fiber laser with a 35 mm long DFB grating section inside the gain medium.](image1)

3. Results and discussion

![Figure 2. Transmission spectrum for the DFB grating (Maximum reflectivity = 89%).](image2)
A transmittance spectrum of the gratings in the phosphate fiber is measured using an erbium amplified spontaneous emission (ASE) and the result is shown in figure 2. The spectrum shows a transmission dip of 9.6 dB, which translates to 89% reflectivity. The central wavelength of the grating is around 1539.5 nm at room temperature. The emission spectrum of the DFB fiber laser at different launching 976 nm pump power is shown in figure 3. The launching power is defined as the power measured right after the pump laser delivery fiber, which is fusion-spliced with the SMF. At pump power 468 mW, the DFB laser emits a narrow laser line located at the grating structure designed wavelength of 1540 nm. The width of the line is measured to be approximately 0.02 nm which is limited by the resolution of the OSA, while the true emission line-width is expected to be much narrower. A shown in figure 3, the side-mode suppression ratio (SMSR) is better than 45 dB, indicating stable single longitudinal mode operation of the DFB laser. Figure 3 also shows that no lasing is achieved at other pump powers. The laser is only achieved if both left and right grating wavelengths are matched.

The grating wavelength changes with the pump power, and therefore the DFB laser only achieved the maximum power -15 dBm after precise adjustment of pump power. The relatively low output power is a consequence of high splicing loss between the phosphate and SMF fiber on both sides of the 45 mm DFB laser. The pumping into active fiber sections that are on both sides of the 35 mm long DFB grating structure but do not contribute to the DFB cavity and the limited pump absorption within the DFB section are other factors that reduces the efficiency of the DFB laser. The efficiency can be improved by reducing the splicing loss, eliminating doped fiber segments that are not part of the DFB and also increasing the grating reflectivity.

![Figure 3](image.png)

**Figure 3.** Emission spectrum of the core pumped DFB fiber laser measured by an optical spectrum analyzer with resolution of 0.015 nm.

In order to study the lasing wavelength stability at a fixed temperature, 14 successive scans of the system output were carried out within 10 min and the results are recorded in figure 4. The variations in output power and emission wavelength were below 2% and 0.05 nm, respectively. Even though the achieved power level is relatively low for fiber laser, any improvements in grating fabrication as well as the optimization of the laser set-up are expected to give a reasonably higher output power, indicating the potential of our laser scheme for the development of high-power DFB fiber lasers.
4. Conclusions
We have demonstrated a stable and compact DFB fiber laser scheme based on the Er-Yb co-doped phosphate fiber despite the large amount of splicing loss at both ends of the doped fiber and our low reflectivity grating. A stable and narrow line-width lasing is obtained at 1540 nm with SMSR of more than 45 dB by adjusting the amount of pump power that is injected. The achieved device performance makes our DFB laser a promising candidate for the fabrication of single-frequency fiber lasers that can be optimized for high-power, simple structure, compact and low noise.

References
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Figure 4. Laser output spectrum scanned every 10 minutes.