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Wavelength Tunable High Power Laser Using a Double-Clad Er:Yb Doped Fiber[1]

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Abstract—We experimentally demonstrated a stable, wavelength-tunable fiber laser using a polarization-maintaining, double-clad Er:Yb doped fiber amplifier in the cavity. The output wavelength is tunable over the range from 1535 to 1567 nm using a fixed grating and the dichroic mirror placed on a rotational mount; under rotation of the dichroic mirror the tuning ratio of 50 nm/deg was found. We studied the wavelength tuning range dependence on the amplifier fiber length and achieved a maximal output power of 850 mW. This configuration can be Q-switched for high peak power and its narrow bandwidth is suitable for nonlinear optics applications, such as parametric teraherthz generator.

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1. INTRODUCTION

Wavelength-tunable sources are important for applications such as fiber optics sensing, medical instrumentation, nonlinear parametric optics, and optical communication. Several configurations of a tunable source have been reported inserting filter elements in the cavity, such as, rotating intracavity gratings or a mirror in combination with a grating, acousto-optic tunable filters, a Fabry–Perot (FP) interferometer, a bandpass filter (TBF), a Lyot filter, a sampled chirped fiber Bragg gratings (SC-FBG), a Mach–Zehnder interferometer, a fiber Sagnac filter interferometer, using a Graphene mode locker, and a Diffractive Grating (DG) [1–18]. In recent years the interest in high power fiber lasers has been growing. Initially these fiber laser configurations were demonstrated using Yb double-clad fibers, but recent studies are using Er:Yb double clad fibers to generate light in the "eye-safe" 1550 nm wavelength region. One additional attraction of these sources is the broad transition line width that enables considerable flexibility in the operating wavelength. Recent papers have reported on high power fiber lasers operation using multimode and single mode Er:Yb double clad fibers [5, 19–26]. For a single mode fiber, the authors in [19] demonstrated a tunable source from 1588.6 to 1622.6 nm with maximal output power of 200 mW and with a spectral line width of 0.15 nm. The authors in [22] demonstrated a tunable fiber laser with 1.1 W output power over a 28 nm spectral range and a spectral line width of 0.7 nm.

In this paper we experimentally demonstrated a wavelength-tunable fiber laser with a polarization maintaining (PM) Er:Yb double-clad fiber placed in a FP cavity formed by two Dichroic Mirrors (DM). Wavelength tuning is achieved by inserting a DG with 600 l/mm in our laser cavity. Our maximum output power was 850 mW and the measured spectral line width was less than 0.1 nm. A Q-switched extension of this source, with its tunability and compact footprint, would be useful in nonlinear optics and active remote sensing applications.

2. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 1. We used a Visotek laser at 976 nm to pump the fiber laser. The pump laser output was connected to 3 m of fiber length with SMA fiber connectors whose core diameter is 400 μm with a numerical aperture of 0.22. We used the lenses f_1 and f_2 to introduce the pump signal into the Nufern PM-Er:Yb double-clad fiber with a clad diameter of 130 μm and a 0.46 numerical aperture. The core has a diameter of 7 μm and a numerical aperture of 0.17. The core of this fiber has a peak Erbium absorption of 30 dB/m at 1535 nm, the cladding of the fiber has Ytterbium absorption of 0.6 dB/m at 915 nm. The diameter of the polymer coating is 245 μm.

After some trial and error combinations of several lenses f_1 and f_2 (limited to available lenses in the laboratory) we found the best result was obtained with the focal length of f_1 equal to 25 mm and the focal length of f_2 equal to 8 mm. The diameters of f_1 and f_2 are 25 and 10 mm, respectively. With this combination the

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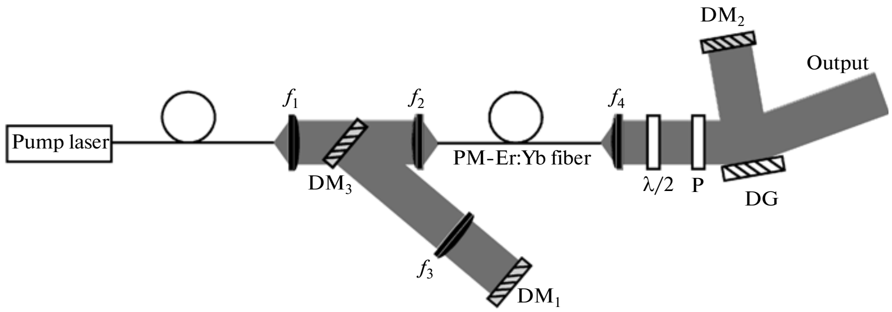

Fig. 1. Experimental setup of the wavelength tunable fiber laser cavity, f_1 = 25 mm, f_2 = 8 mm, f_3 = 250 mm, f_4 = 15 mm.

maximal pump power that we can couple into the PM-Er:Yb fiber was 14 W. The focal lengths of the lenses needed to be carefully chosen for mode matching, otherwise a significant amount of the pump power dispersed in the first cm of the Er:Yb fiber causing the coating of the Er:Yb fiber to burn. The collimated beam between the f_1 and f_2 has a diameter of 6 mm. A dichroic mirror (DM_3) reflecting the signal and transmitting the pump was inserted between these lenses. The linear cavity is formed by the dichroic mirrors DM_2 and DM_1. We included the lens f_3 with long focal length (250 mm) to improve the stability of the laser and also to better collimate the signal beam. Without this lens the laser operation stability was degraded by higher cavity losses.

The fiber output beam was collimated using the plano-convex lens f_4 with a focal length of 15 mm. For wavelength tuning we inserted a diffractive grating (DG) with 600 l/mm in our laser cavity. The first order of the diffracted beam is launched toward the dichroic mirror DM_2 and retro-reflected back on itself and thus back into the fiber, while the zero order (specular) reflection beam forms the output of the laser cavity. The tuning is accomplished by rotating DM_2. We inserted a half wave plate (λ/2) and a polarizer (P) in the cavity to increase the stability of the cw laser and also to impose linear polarization at the laser output.

A great deal of attention was devoted to determining the focal distance and position of the lens f_4 because we found certain tradeoffs had to be made between the laser efficiency, laser power stability and the potential for damaging the fiber end. We found that the fraction of the signal coupled back into the fiber end, after it has been reflected from the DM_2 is smaller for a lens with longer focal length. For example, if we measure the backward amplified spontaneous emission (ASE) we can increase the output signal by 50% by careful alignment of DM_2 with a 15 mm focal length lens, while we achieved only a 20% increase of the output signal when we used a 25 mm focal length lens. However, the lens with much shorter focal distance caused the fiber end to burn due to the reflection from the lens surface. On the other hand a longer focal distance lens allowed more stable cw generation. As a result of trade offs between laser efficiency, laser stability, and possibility of fiber damage, we choose the lens f_4 focal distance to be equal to 15 mm.

With this cavity configuration we can tune the wavelength from 1535 to 1567 nm by rotating the DM_2 at a rate of 50 nm/deg. With our configuration, wide tunability was possible only for amplifier fiber length between 2.5 and 3.6 m. When the fiber lengths are shorter than 2.5 m or longer than 3.6 m the wavelength tuning range decreases.

3. EXPERIMENTAL RESULTS

When DM_2 and the DG were replaced by a mirror with 80% reflection and 20% transmission for 1550 nm we obtained the spectra of the laser shown in Figs. 2 and 3 for 2.5 and 6.0 m of PM-Er:Yb fiber length, respectively. The lasing wavelength for this cavity configuration depends on the fiber length and we found that lasing wavelength is 1543 nm for 2.5 m amplifier fiber and is 1562 nm for 6 m amplifier fiber. The effect of the wavelength shift was also reported in [27] and it was attributed to the higher signal reabsorption in longer double-clad fiber length, which causes the laser to operate at longer wavelength. The maximum output power for 2.5 m was 200 mW and for 6 m it was 250 mW. The measured spectral line width is less than 0.1 nm, and the measurement resolution was limited by the monochromator's spectral resolvability, which is equal to 0.1 nm.

For wavelength tuning we used the experimetal setup illustrated in Fig. 1. Figures 4 and 5 are examples of spectra for different angles of the DM_2 for 2.5 and 3.6 m of the PM-Er:Yb, respectively. In Fig. 4 the DM_2 was adjusted to have a wavelength of 1536, 1544, 1552, 1558, 1562, and 1566, and in Fig. 5 the DM_2 was adjusted to have a wavelength of 1536, 1545, 1550, 1555, 1560, and 1567 nm. In our configuration it is possible to tune the wavelength from 1535 to 1567 nm by rotating the DM_2 mirror with a tuning rario of 50 nm/deg. From our experiments wide wavelength tuning was possible only when we used fiber lengths between 2.5 and 3.6 m for the PM-Er:Yb. The wave-

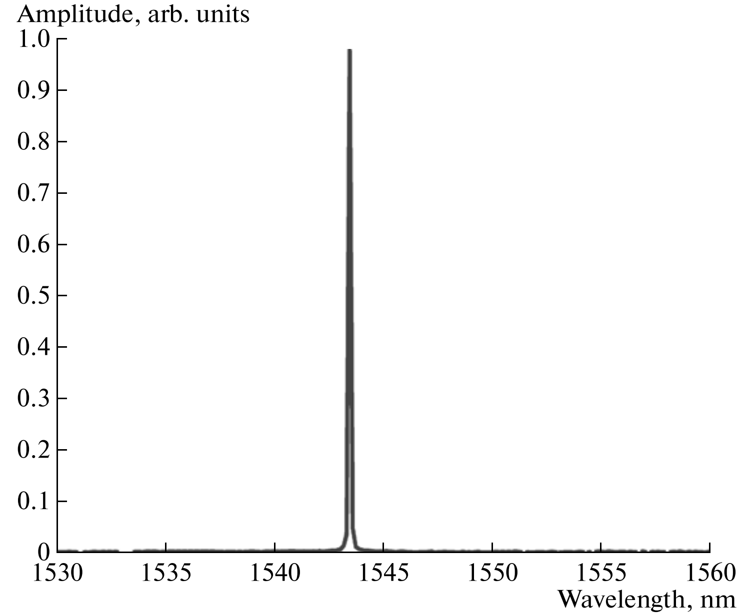

Fig. 2. Output spectrum using 2.5 m of the Er:Yb doped fiber when DM_2 and DG are replaced by a mirror. The output power was 200 mW.

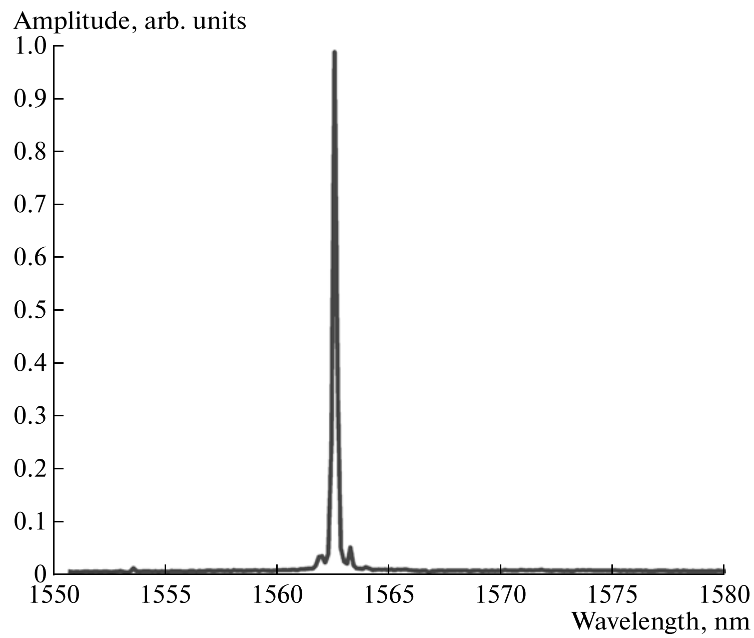

Fig. 3. Output spectrum using 6 m of the Er:Yb doped fiber when DM_2 and DG are replaced by a mirror. The output power was 250 mW.

length range for different fiber lengths is shown in table. In the case of a 6 m long PM-Er:Yb fiber wavelength tuning was possible only over a few nm range.

A small secondary peak at 1544 nm was observed in the output spectrum, which we attribute to the ASE reflections from the fiber ends, since it is fixed in wavelength and independent of the output coupling elements. When we cleaved the fiber ends at an angle of 2° the amplitude of this secondary peak at 1544 nm decreases and the output power of the laser cavity increases. Comparing the spectra in Figs. 4 and 5, the secondary peak at 1544 nm is stronger for shorter fiber lengths than for longer fiber lengths and the amplitude of this secondary peak at 1544 nm is much higher when the wavelength of the principal peak is shorter

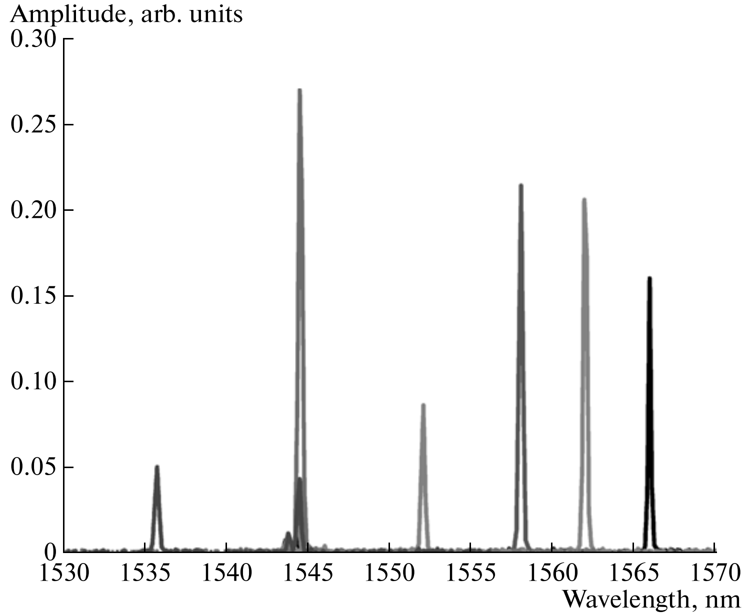

Fig. 4. Output spectrum using 2.5 m of the Er:Yb doped fiber for different angles of the DM2, this mirror was adjusted to have into the laser cavity a wavelength of 1536, 1544, 1552, 1558, 1562, and 1566 nm.

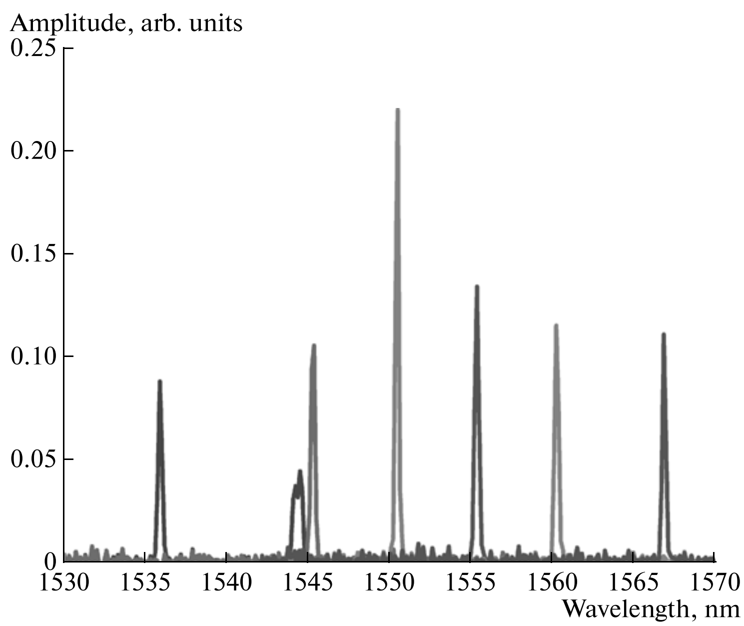

Fig. 5. Output spectrum using 3.6 m of the Er:Yb doped fiber for different angles of the DM2, this mirror was adjusted to have into the laser cavity a wavelength of 1536, 1545, 1550, 1555, 1560, and 1567 nm.

than 1544 nm, see for instance Fig. 4 (first line) and Fig. 5 (first line); however its power is almost reduced when the wavelength of the principal peak is longer than 1544 nm, see for instance Fig. 4 (third, fourth, fifth, and sixth lines), and Fig. 5 (third, fourth, fifth, and sixth lines). We believe that this problem would be resolved by increasing the fiber cleaves angle to eliminate the back scattered light from the amplifier end. The maximal output power was 700 mW for 2.5 m and 850 mW for 3.6 m using a pump power of 14 W.

The tunability range for different PM-Er:Yb fiber length

Fiber length, m	Minimal wavelength, nm	Maximal wavelength, nm
2.5	1535	1566
3	1535	1566
3.5	1535	1567
3.6	1535	1567
3.7	1541	1566

4. CONCLUSIONS

We demonstrated a double-clad Er:Yb wavelength-tunable fiber laser. With this configuration we can tune the wavelength from 1535 to 1567 nm using a diffraction grating. The amplifier fiber length was studied and optimized for the widest wavelength tunability, but further cavity optimization is required, such as the grating design and pump laser coupler design, to fully optimize the performance (tunability, line width, pulse width, etc.) of the fiber laser. The optimal tuning range was obtained by using 2.5 to 3.6 m of double-clad Er:Yb fiber length. The maximal output power was 850 mW.

This source should be suitable for high power laser applications, where narrowband linewidths are required. We envision uses of this source for parametric nonlinear optical processes to generate both shorter and longer wavelength and active remote sensing, such as lidar. In the frame of THz wave generation a pair of independently tunable fiber lasers designed with complementary wavelength spans would be used to generate narrow-band, tunable THz radiation over a wide range. Multiple versions of our fiber laser could also be phased together for higher power coherent outputs.

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