All-fiber Ho-doped laser tunable in the range of 2.045 – 2.1 μm

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Abstract: For the first time to the best of our knowledge we have realized all-fiber tunable Ho-doped laser utilizing the compressed Bragg grating reflector. The emission wavelength was tuned from 2.1 to 2.045 μm. The maximum output power was measured as 2 W at 2.1 μm. The variation of the output power in the obtained spectral range was of 7.5%.

All-fiber Ho-doped laser tunable in the range of 2.045 – 2.1 μm

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1. Introduction

Fiber lasers for a spectral range beyond 2 μm can find a number of important applications in medicine, spectroscopy, eye-safe lidars, sensing, nonlinear optics etc. Ho-doped fiber lasers exhibit oscillations at the longest wavelengths for lasers based on silica fiber – 2 – 2.15 μm [1]. To date, holmium-doped all-fiber laser with the output power of 10 W [2], with the quantum efficiency of 0.81 [3] was demonstrated. Also, Q-switched [4] and mode-locked [5] lasers were realized. At the same time some applications require the use of a source with the tunable emission wavelength. Such lasers can be useful for the gas analysis, study of the atmosphere transparency, etc.

There are several methods to tune the laser emission wavelength. One of them used tunable optical filter [6]. Disadvantage of this method consists in the absence of selective reflectors which define the lasing wavelength. It depends not only on properties of the filter but also on active medium length, pump power and other laser parameters. Other methods apply tunable reflectors closing the laser cavity. Tunable Tm-doped fiber laser with a reflector...
based on diffraction grating was presented in [7]. The operating wavelength could be tuned over 202 nm from 1859 to 2061 nm. The obvious disadvantage of similar schemes is the use of bulk optical elements. Therefore, a practical application of the laser is difficult.

Another approach consists in the application of the tunable Bragg grating closing the laser cavity. The fiber Bragg grating (FBG) resonance wavelength can be tuned due to the mechanical stress that causes a variation in the grating period. Axial loads applied to the fiber lead to a variation in the resonance wavelength by \( \Delta \lambda = \lambda_0 (1 - P_e) \varepsilon \), where \( P_e = 0.22 \) is the photoelastic coefficient, \( \varepsilon \) is the relative elongation of the fiber, and \( \lambda_0 \) is the FBG resonance wavelength without a stress. Note that the tuning range related to the strain is limited by the relatively low strength of the fiber (the typical value is \( \varepsilon \sim 0.01 \)). In the case of compression, a significantly wider tuning range is limited by the limiting strength of the fiber (\( \varepsilon \sim -0.2 \)) [8].

Using the grating compression tunable Yb-, Er-doped and Raman fiber lasers were demonstrated [9–11]. In this paper we demonstrate all-fiber Ho-doped laser tunable in the spectral range above 2 \( \mu \)m. Tuning of the operation wavelength is achieved due to a compression of Bragg grating closing the laser cavity. Power characteristics of the laser are studied.

### 2. Experimental setup

Scheme of the tunable Ho-doped laser is shown in Fig. 1. To build Ho-doped lasers we used the holmium-doped fiber with the concentration of active ions of \( 1.6 \times 10^{19} \) cm\(^{-3} \), and the length of 10 m. As the input coupler we used tunable Bragg gratings with a reflection close to 100% having the resonance wavelength at 2.1 \( \mu \)m without stress. The grating was photoinscribed at an \( \text{H}_2 \)-loaded SMF-28 fiber by means of the holographic technique [12]. The transmission spectrum of the grating was controlled by measuring the grating properties in the second order diffraction. The cleaved fiber end was used as the output reflector Holmium-doped fiber laser was pumped by double-clad Yb\(^{3+} \)-fiber laser operating at 1.125 \( \mu \)m based on the GTWave active fiber and two Bragg gratings. Yb-doped fiber laser was pumped by two semi-conductor sources emitting at the wavelength of 0.91 \( \mu \)m. Maximum power of the Yb-doped fiber laser was of 7.5 W.

To realize the grating compression a piece of the fiber with Bragg grating was placed in ferrules and fixed to the ends with epoxy glue. A linear translation of the one of the ferrules caused the axial compression of the fiber to decrease the grating period and resonance wavelength. A range of the ferrule translation was of 0.8 mm.

### 3. Results and discussion

Fig. 2 illustrates the laser characteristics based on the grating without a compression. Ho-doped laser had the maximum output power of 2.1 W with the slope efficiency of
0.31 at the wavelength of 2.1 µm. That corresponds to the quantum efficiency of 0.58. Some loss of efficiency is caused by the optical losses in the wing of a vibration absorption band of SiO₂. It should be noted that the laser power is almost unchanged when Bragg grating was installed in the compression device.

Compression of the Bragg grating allowed us to change the lasing wavelength. Dependence of the emission wavelength on the deformation value is shown in Fig. 3. For the deformation range of 800 µm the operation wavelength was tuned from 2.1 to 2.045 µm. The tuning range is of 55 nm. Fig. 4 shows the emission spectra for several values of the deformation. The emission linewidth was measured as approximately of 0.4 nm. This value corresponds to the resolution of the used spectrometer. Dependence of the output power vs. emission wavelength is presented in Fig. 5. One can see that the output power grows when the emission wavelength is increased. Total variation of the output power is of 0.15 W or 7.5%. The main reason of the power variation consists in a dependence of the optimal length of the active fiber on the emission wavelength. It is typical for three-level scheme. In the paper [1] it was shown that for Ho-doped fiber laser the optimal length is decreased when the emission wavelength shortens.

4. Conclusion

For the first time to the best of our knowledge we have realized all-fiber tunable Ho-doped laser utilizing the compressed Bragg grating reflector. The emission wavelength was tuned from 2.1 to 2.045 µm. The maximum output power was measured as 2 W at 2.1 µm. The variation of the output power in the obtained spectral range was of 7.5%.

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