Ring cavity tunable fiber laser with external transversely chirped Bragg grating

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Abstract. Application of the Transverse Chirped Bragg Grating (TCBG - a reflecting volume Bragg grating with continuously variable resonant wavelength across the aperture) for the narrowband tunable ring-cavity fiber laser is presented. The main advantage of the use of TCBG is that its linear translation allows continuous tuning of emission wavelength within 5-10 nm band. Yb doped fiber laser operating in the wavelength range of 1050-1055 nm of narrowband emission up to 2.3 W is demonstrated.

1. Introduction.

Cost effective, tunable laser sources at 1 μm are important for nowadays science and technology. Combination of high output power and wall plug efficiency makes double clad Yb-doped fiber laser an attractive solution for many applications such as laser sensing, LIDARs, coherent communications, optical fiber sensors and high-resolution spectroscopy. Fiber lasers have proved to be highly attractive coherent light sources due to their high-power capability, compact and portable design, robustness, output stability, cost effectiveness, and power scalability. The applicability of such laser systems, for example as long-range spectroscopic probes of atmosphere, highly depends on the linewidth, thus narrow band operation is highly desirable in order to keep the high coherent length.

Narrowband operation of fiber lasers can be achieved by using internal selective elements such as fiber Bragg grating or external ones that include diffraction gratings, etalons, birefringent filters, etc. A new approach for solving this problem is based on spectral selectivity of volume Bragg gratings (VBGs) in photo-thermo-refractive (PTR) glass. These VBGs provide diffraction efficiency exceeding 99%. PTR glasses are transparent from 350 to 2700 nm permitting wide tunability[1,2]. With a damage threshold of ~40 J/cm2 (for 8 ns pulses), a nonlinear refractive index similar to fused silica, and multi-kW cw power loading capability VBGs are ideal components for high intra-cavity powers[1,2].

VBGs provide extremely narrow spectral and angular selectivity combined with high tolerance to laser radiation and harsh environmental conditions. These elements were successfully used as narrow band output couplers and reflective mirrors in laser resonators for spectral narrowing of solid state and semiconductor lasers with a spectral width of a few picometers[3,4]. It is important that low losses of VBGs enable spectral narrowing of laser emission by orders of magnitude with an efficiency penalty that does not exceed a few percent.

Several types of VBGs have found practical realization in many laser systems. Among them are reflection (RBG) and transmission Bragg gratings (TBG), moiré volume Bragg gratings (MVBGs). These types of VBGs have been successfully implemented in different laser systems providing considerable spectral narrowing and frequency stability in laser diodes[5], solid state[6,7] and fiber lasers[8,9], and optical parametric oscillators (OPOs)[10,11].

In this paper we report on a simple scheme for realization of compact, narrow line, tunable Yb-fiber laser source with an external Transverse Chirped Bragg Grating (TCBG - a reflecting volume Bragg grating with continuously variable resonant wavelength across the aperture) acting as tunable spectral selective element and output coupler. Application of a TCBG in a ring cavity configuration allowed continuous tuning narrow emission line (7 pm) of Yb doped fiber laser in the wavelength range of 1050-1055 nm with a constant power up to 2.3W and a minimum step of 10 pm.

2. Tunable Yb-doped fiber laser.

The TCBG had an aperture of 5x20 mm and a thickness of 2 mm. It had a transverse spectral chirp rate along the long axis of 0.25 nm/mm, a full width at half maximum (FWHM) spectral width of 160 pm and diffraction efficiency varying from 30% to 50%. It was mounted on a translation stage in order to tune the wavelength of the

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laser. The surfaces of TCBG were polished parallel to the grating planes and AR-coated for the wavelength range of 960-1060 nm.

The ring cavity configuration (Fig. 1.) was used to eliminate pulsations typical for a narrow line CW fiber laser. As a pump source we used a fiber coupled laser diode module emitting at 976 nm with maximum output power of 30 W. As a gain medium we used single mode polarization maintaining Yb-doped double-clad fiber with a core diameter of 6 µm. The fiber facets were angle cleaved in order to prevent parasitic lasing inside the fiber. The cavity was formed by a dichroic beam splitter (DBS) with a high transmission for the pump (976 nm) and high reflection for the signal wavelengths (1020-1100 nm), a broadband mirror (BM) and a TCBG. The unidirectional laser operation was provided by an optical isolator (OI).

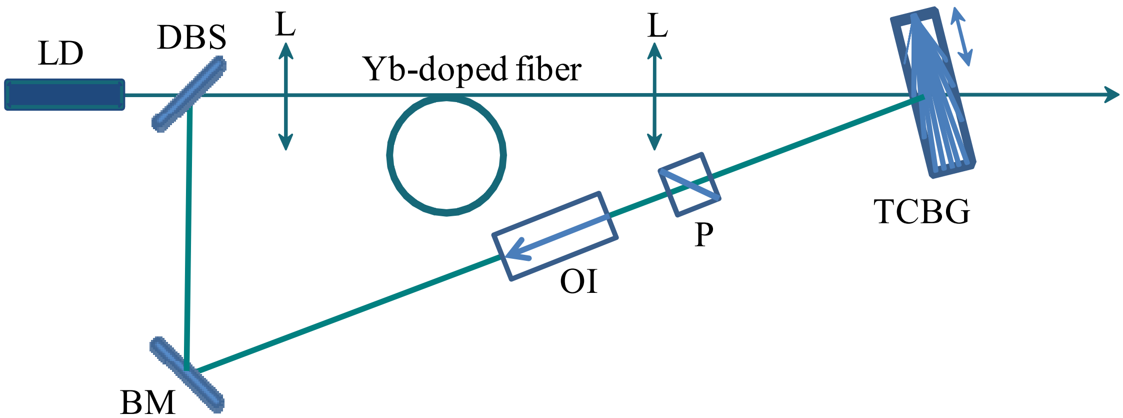

Fig. 1. Experimental setup of a tunable Yb-doped fiber laser. LD – pump laser diode, DBS-dichroic beam splitter, TCBG – transverse chirped Bragg grating, BM- broadband mirror, OI – optical isolator, P- polarizer, L –lens.

In order to demonstrate capabilities of the TCBG a comparative study of the same cavity with two different output couplers was performed: a TCBG and a broadband mirror. The corresponding spectra of the laser emission are presented in Fig. 2. For a broadband mirror, one can see (Fig. 2, curve 1) typical broadband emission with chaotic position of emission lines. However, once the TCBG is used (Fig. 2, curve 2) the narrowband emission line is generated with a spectral contrast of 25 dB.

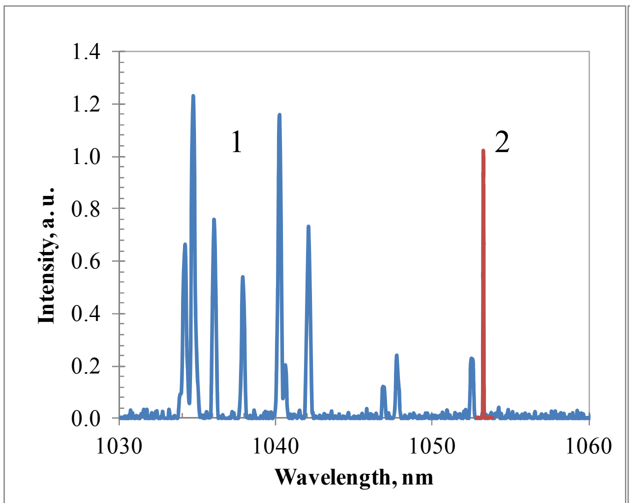

Fig. 2. Emission spectra of Yb-doped fiber laser with broadband (1) and TCBG (2) output couplers

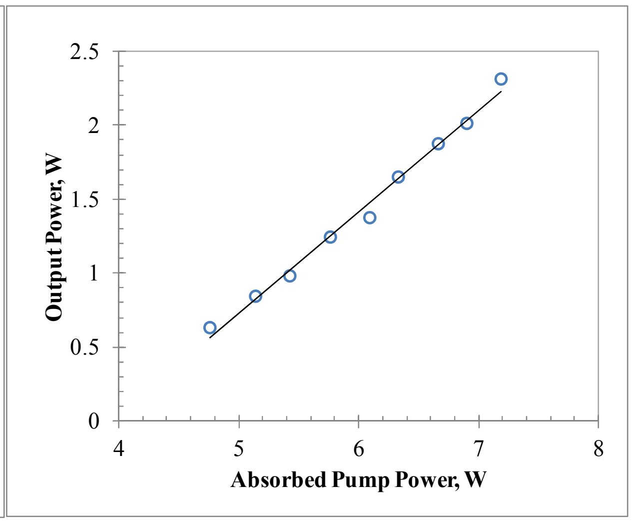

Fig. 3. Power dependence of Yb-doped fiber laser emission

The dependence of output power on absorbed pump power is shown in Fig. 3. The slope efficiency was calculated to be ~70%. Scaling of the output power can be achieved by increasing of the pump power and optimization of the fiber length and coupling efficiency.

It is well known that one of the main issues of CW fiber laser is self-pulsing effect which can cause catastrophic fiber damage. We studied the temporal characteristics of the laser emission and did not observe self-pulsing effect in our laser system at all used pump power levels. One can see (Fig. 4) that the laser operates in a truly CW mode.

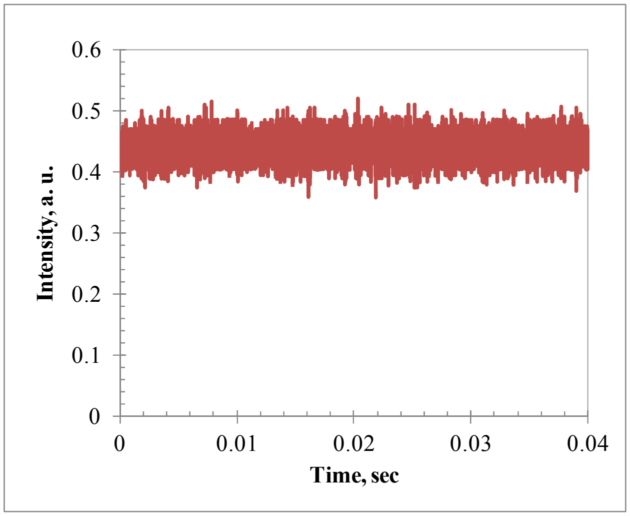

Fig. 4. Temporal characteristic of Yb-doped fiber laser emission.

Linear translation of the TCBG in transverse direction allowed continuous tuning of emission line of Yb-fiber laser in the wavelength range of 1050-1055 nm (Fig. 5a). The results of the fine tuning capabilities of the fiber laser are presented in the Fig. 5b. Spectral widths of lines are determined by the spectral resolution of the spectrum analyzer. Our measurements showed that the minimum achievable step with a linear translation stage corresponds to 10-15 pm. It is however possible to perform more accurate tuning by temperature change of the TCBG.

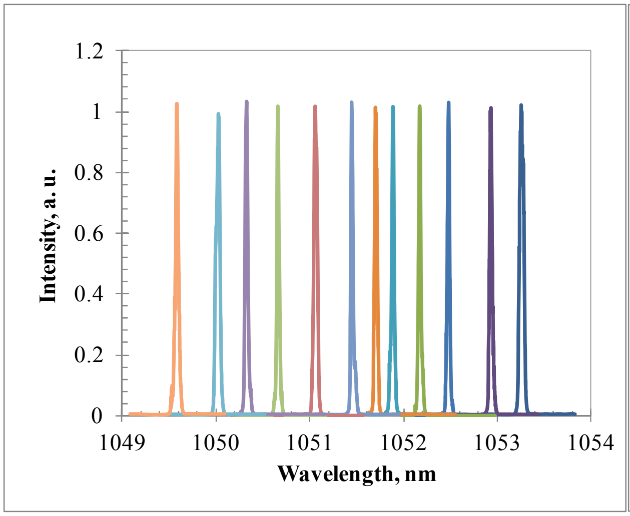

Fig. 5a. Wavelength tuning of Yb-doped fiber laser.

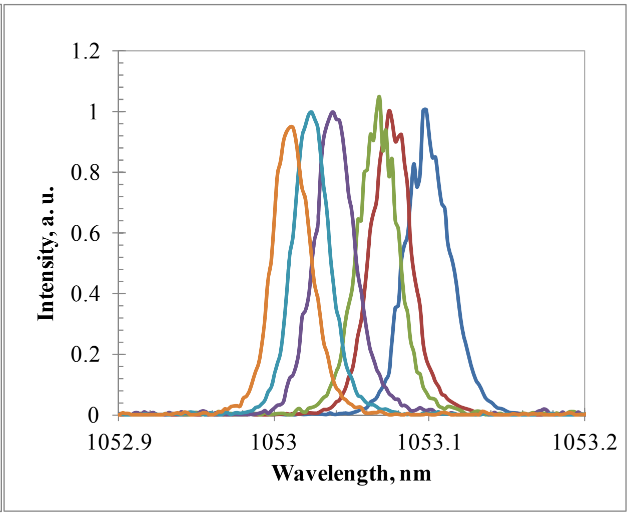

Fig.5b. Fine tuning of Yb-doped fiber laser.

The measurements of the laser line-width were also performed on high resolution spectrum analyzer (Advantest) with a resolution of 7 pm at 1 micron range. The linewidth of 7 pm, which corresponds to spectral resolution of the analyzer (Fig. 6.), was measured in the whole wavelength range of laser operation. Our measurements of far field profile of the output radiation have shown that the laser generates TEM_{00} mode (Fig. 7.).

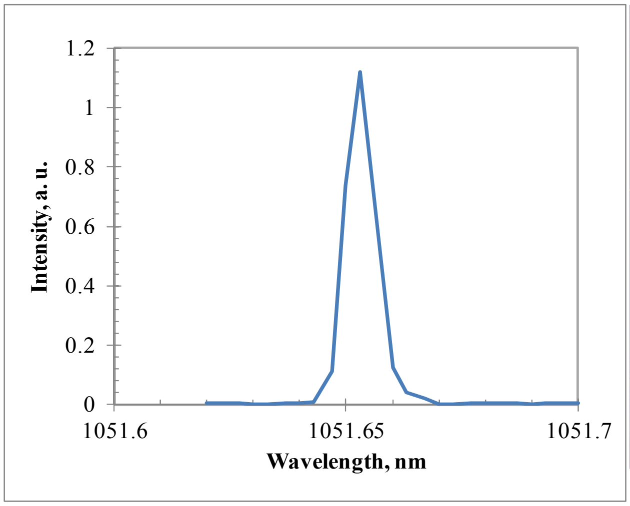

Fig. 6. Emission spectrum of Yb-doped fiber laser

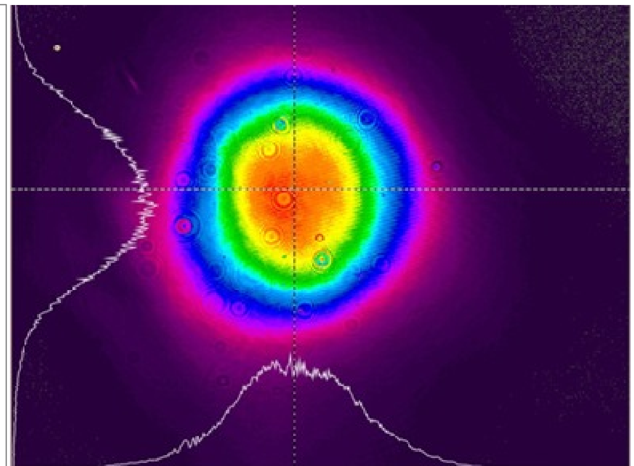

Fig. 7. Far field profile of the Yb-fiber laser

3. Conclusion

We report on a new ring cavity tunable Yb-doped fiber laser using external transversely chirped Bragg grating as an output coupler. Linear translation of the grating with respect to the incident beam allowed continuous tuning of narrow emission line (<7 pm) of Yb-fiber laser in the wavelength range of 1050-1055 nm with a constant power up to 2.3W and a minimum step of 10-15 pm. The laser system is capable to cover the whole emission band of Yb ions with integration of additional TCBGs.

4. References

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