PDP22

Ultra-compact 52 mW 50-GHz spaced 16 channels narrow-line and single-polarization fiber laser

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Abstract: The multiwavelength laser is based on a 41 mm long distributed Fabry-Perot resonator photo-induced in Er-Yb co-doped fiber using superimposed chirped gratings. With a single pump laser, the mean power per line is 5.1 dBm.

OCIS codes: (140.3510) Lasers, fiber; (060.2380) Fiber optics sources and detectors

1. Introduction

Multiwavelength continuous-wave lasers emitting an optical frequency comb are of great interest for dense wavelength-division-multiplexing (DWDM) systems, in which they could be used as low-cost and compact multiwavelength sources feeding an array of signal modulators or as testing purpose sources. They also have great potential for the development of laser encoders for optical code division multiple access (OCDMA) systems and for optical fiber sensor networks. Such lasers should emit in single longitudinal and polarization modes with constant per-channel output power and with controlled frequency spacing. To meet these requirements, several technologies and designs have been proposed over the last decade, mostly based on semiconductor [1] or erbium-doped fiber (EDF) [2-5] gain media. For the later case, the multiwavelength regime is usually inhibited by the room-temperature homogeneous-line broadening behavior of the erbium-doped silica fiber. The simplest way to overcome this limitation is to separate the resonant cavities corresponding to the individual channels. This may be achieved by cascading [3] or by combining in parallel [4] a number of distributed feedback fiber (DFB) lasers. Recently, we introduced a more sophisticated multiwavelength spatially distributed Fabry-Perot (DFP) resonator made of two superimposed chirped fiber Bragg gratings (CFBGs) [5]. The initial results presented in [5] showed emission over 8 channels with relatively low output power and an average of 0.5 mW per channel. Also, we noticed that the polarization of the output was not aligned for all channels.

In this work, we present major improvements to the performance of the DFP fiber lasers. Using theoretical modeling of the device [6], we were able to optimize the laser design to maximize the output power. Experimentally, we increased the average power-per-peak by more than 8 dB, quadrupled the conversion efficiency, doubled the number of channels and shortened the device length by 30%. All the 16 channels were found to emit in the same polarization with linewidths less than 215 kHz. We believe that these improvements open doors to many applications.

2. Design and realization

The structure consists of two identical CFBGs, which are superimposed in an Er-Yb co-doped optical fiber but slightly shifted along the fiber axis (Fig. 1a) [5]. The two CFBGs form a distributed Fabry-Perot resonator, in which the cavities corresponding to each channels are displaced along the fiber axis. The CFBGs were written by scanning a linearly chirped phase-mask (chirp of 1.25 nm/cm, TeraXion inc.) with a 244-nm CW laser beam, and the active fiber was a deuterium-loaded Er-Yb co-doped fiber with a photosensitive inner cladding (University of Southampton, UK). From direct spectral transmission measurement, the strength of the first grating (CFBG #1) was theoretically and experimentally found to be optimum at a transmission of -25 dB. The second grating (CFBG #2) was made much stronger to get a strong unidirectional output and was found to have -50 dB transmission, which was determined from the laser weaker output-to-main output power ratio. Between the two exposures, the phase-mask was longitudinally shifted by a distance of 2.1 mm to obtain a free spectral range (FSR) close to 50 GHz. Considering the grating chirp, we estimate that the longitudinal spacing between neighboring cavities is 2.4 mm. Targeting a 16-channel laser thus requires 41 mm long CFBGs. Moreover, the fact that the cavity separation is larger than the cavity length ensures that the resonant cavities are not overlapping [5] thereby reducing unwanted gain competition.

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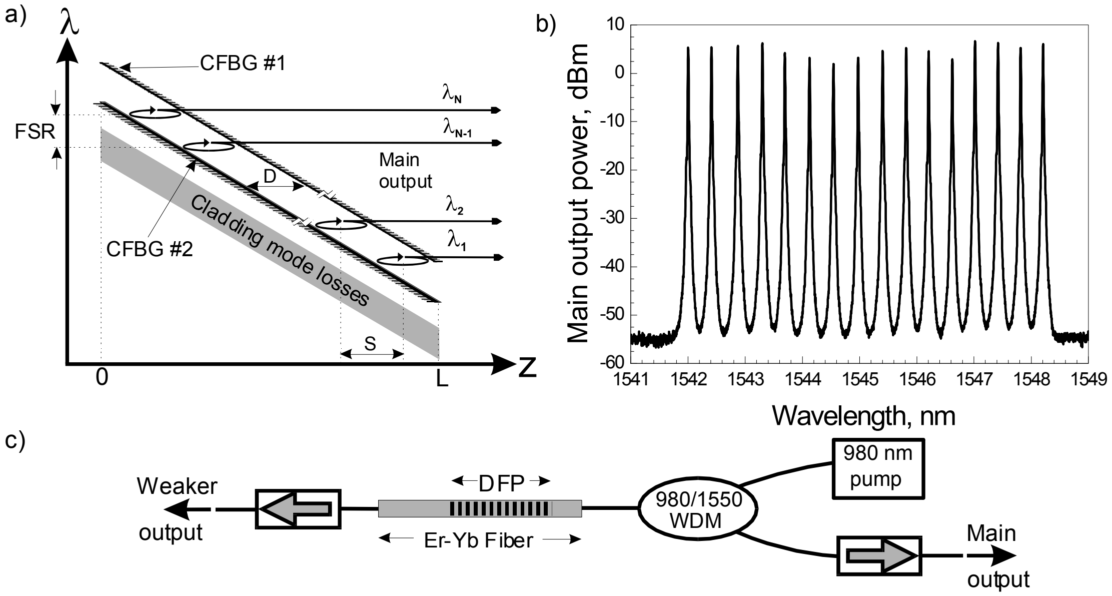

Fig 1 Principle of the distributed Fabry-Perot resonator (a); Laser output power spectrum density when pumped with 380 mW (b); Laser configuration (c).

The laser is pumped in a counter-propagating configuration (Fig. 1c) with a single 400 mW 980-nm commercial laser diode. Such high power is required to pump efficiently the active fiber along all its length, since it has very high pump absorption (2.5 dB/mm). We found theoretically [6] that the unexposed Er-Yb piece of the fiber between the CFBGs and the pump laser mostly contributes to a waste of pump power and that it should be reduced to a minimum. As shown in Fig. 1a, the cavities corresponding to the shorter wavelengths should also be placed closer to the output end to avoid losses induced by coupling to cladding or radiative modes.

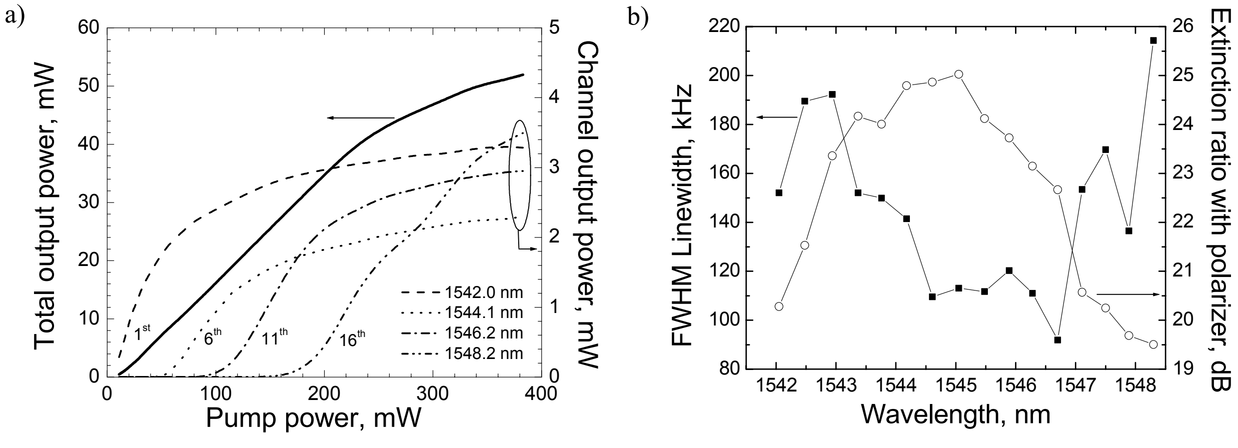

Fig. 2 Output power as a function of the injected pump power for all the channels and for individual channels (for simplicity, only the 1st, 6th, 11th, and 16th lines are shown) (a); FWHM linewidths of individual laser channels and simultaneous extinction ratio achievable using a polarizer and a polarization controller (b).

3. Results

For all the measurements, the laser was attached to a piece of aluminum metal by a thermo-conductive paste to stabilize it passively. Using an optical spectrum analyzer (OSA) with 10 pm optical resolution, we found that the average output power per peak was 5.1 dBm, with a maximum power difference among the channels of 4.5 dB and a signal-to-noise ratio of 60 dB. The total output power was 52 mW (17.1 dBm) when pumped with 380 mW (Fig. 2a). Moreover, as can be seen in Fig. 2a, the 4.5 dB power difference among the channels and 47 mW of total output power can be obtained even with 300 mW of the pump power, which corresponds to a conversion efficiency of 16%. The frequency spacing between successive laser lines was 53 ± 3 GHz.

We used a self-heterodyne measurement (40 km of delay line) to get the linewidths and the polarization extinction ratios. To analyze each laser channel separately, we used a tunable filter which suppressed neighboring channels by 20 dB. We found that, for each channel, the laser emits in a single polarization with an extinction ratio better than 45 dB. The self-heterodyne measurement also showed that the two orthogonally polarized modes were spaced by 5.4 GHz corresponding to birefringence of 4×10^{-5}. As the pristine fiber has much smaller birefringence, the measured value has its origin in the photoinduced birefringence. In order to confirm that all the channels emit in the same polarization, we placed a polarization controller followed by a polarizer between the active structure and OSA. Varying the state of polarization through the polarization controller we were able to reduce simultaneously the power of all the laser lines by more than 19 dB (Fig. 2b) thus demonstrating that all the channels emit along the same birefringence axis of the structure. We also found that lasers having stronger output couplers (CFBG#1) were more likely to emit in the two polarization modes. These results are in agreement with previous analysis of DFB structures [7]. The linewidths for all the channels, assuming a gaussian profile, are shown in Fig. 2b. We see that they vary from 92 to 215 kHz being higher at both edges of the laser structure. These linewidths are typical for distributed Bragg reflectors erbium doped fiber lasers and narrower linewidth shall be obtained with better packaging [8]. Finally, since the laser structure is short, we might think about frequency locking of the laser comb to a frequency reference by active stabilization.

4. Conclusion

We presented break-through performance improvement of distributed Fabry-Perot multiwavelength fiber lasers. Using theoretical modeling of the device, we were able to optimize the structure and reach high conversion efficiency. The increased number of laser lines, the improved output power and the single polarization emission now make this source truly attractive for many applications in optical communication and sensing systems. Further improvements of the device would include an external gain flattening filter to improve the spectral flatness, adequate packaging to reduce the linewidths and refined grating writing techniques to further improve the FSR uniformity. Frequency locking of one laser to a frequency reference could also be envisioned to stabilize the frequency comb emitted by this compact multiwavelength source.

5. References

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