Multi-wavelength fiber laser using a single multicore erbium doped fiber

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Abstract: We propose and demonstrate a simple multi-wavelength fiber laser based on a single multicore erbium doped fiber. An exemplary 7-wavelengths fiber laser was realized in a linear cavity by using 7-core EDF and an arrayed waveguide grating.

OCIS codes: (060.2340) Fiber optics components; (060.3510) Lasers, fiber ; (140.3500) Lasers, erbium.

1. Introduction

Space division multiplexing (SDM) [1] allows the simultaneous transmission of multiple spatial channels to increase the information carrying capacity of an optical network and various types of SDM fiber (e.g. few mode fibers and multicore fibers) and their matching amplifiers have been extensively investigated. Recently, these SDM amplifiers have been integrated in a fully fiberized format by employing side pump couplers and inline SDM isolators [2] and a cladding pumped 32-core multicore fiber amplifier [3] has been successfully demonstrated providing good gain characteristics and low inter-core crosstalk. One can apply these SDM technologies in other research fields beyond optical communications, for example for 3-dimensional shape sensing and the coherent beam combination of fiber lasers. In particular, the independent multiple spatial amplifier channels provided by multicore erbium doped fiber offer attractive opportunities for new types of fiber laser supporting multiple laser outputs.

In this paper, we introduce a new type of multi-wavelength fiber laser based on multicore fiber (MCF) technology. Each laser beam (at a different wavelength) is generated/guided along an individual core within the MCF and stable multi-wavelength laser operation is guaranteed. Use of MCF enables the wavelength competition (or longitudinal mode competition) caused by the homogenous gain broadening with erbium doped fiber (EDF) in a conventional multi-wavelength, single-core fiber laser to be avoided. As a proof of concept, an exemplary 7-wavelength fiber laser was realized with a linear cavity using a 7-core multicore erbium doped fiber as a multiple spatial channel gain medium and an arrayed waveguide grating (AWG) as a wavelength selective element.

2. Fiber laser configuration and optical performance

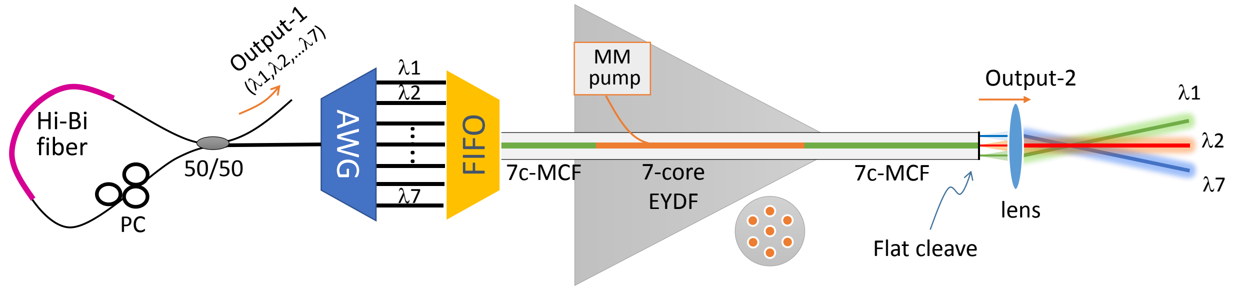
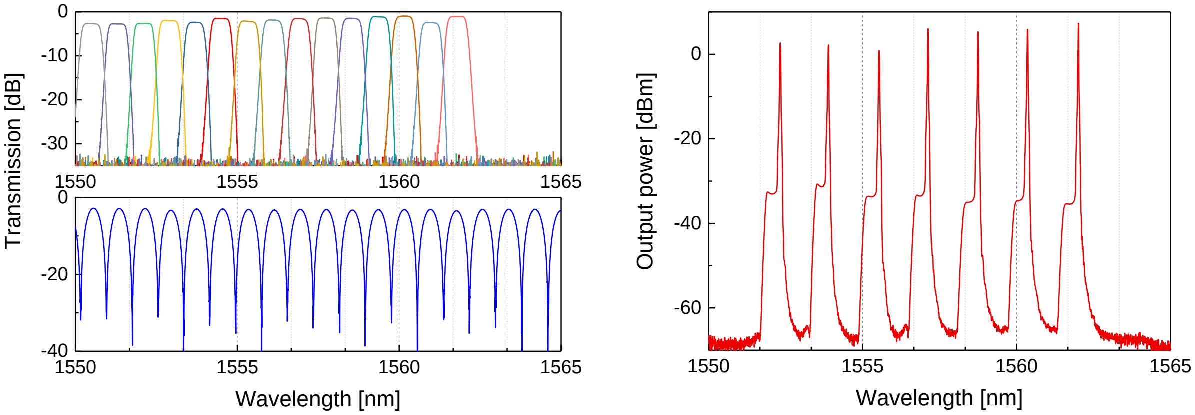


Fig. 1. Schematic of the proposed multi-wavelength fiber laser. FIFO: fan-in/fan-out device, AWG: arrayed waveguide grating, 7-core EYDF: 7-core multicore erbium/ytterbium doped fiber, Hi-Bi fiber: high birefringent fiber, PC: polarization controller.

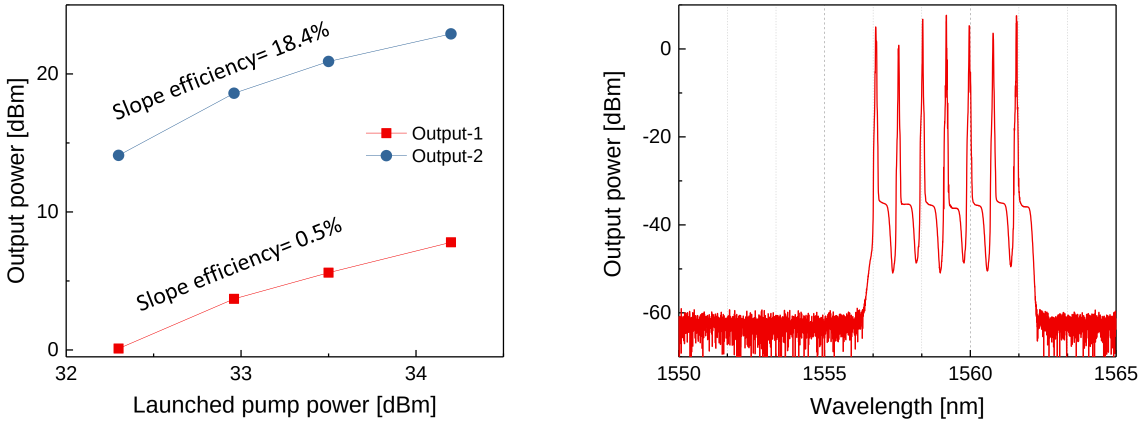
Fig. 1 shows a schematic of the proposed multi-wavelength fiber laser. The laser is composed of a 7-core multicore erbium/ytterbium doped fiber (EYDF), a fan-in/fan-out (FIFO) device, an arrayed waveguide grating (AWG) and cavity mirrors. A 6m long, 7-core EYDF was used as the optical gain medium and was directly spliced to matching passive 7-core multicore fiber (MCF) [4] at both ends. The outer diameter and core-pitch of the 7-core EYDF used in our experiment was about 198 μm and 50.1 μm, respectively. The core diameter of each core was ~5 μm and the cladding absorption at the pump wavelength of 975nm was ~1.2dB/m/core. A fully fiberized side pump coupler was integrated to couple the pump light from a multimode pump laser diode to the active 7-core EYDF in a cladding pumped configuration and >60% of coupling efficiency was readily achieved using this approach. One end of the 7-core MCF was connected to a 3D waveguide based FIFO device to access the individual cores of the MCF followed by an arrayed waveguide grating (AWG), operating on a 100 GHz channel spacing, which acted as a wavelength selective element for each individual core. A linear laser cavity was constructed using a Sagnac loop mirror on the AWG side and 4% Fresnel reflection from the flat cleaved fiber end of the MCF. Two laser output ports are available in our laser configuration. Multi-wavelength laser output can be obtained from a single mode fiber (*output-1*) and multiple-core (single-wavelength per core) can be obtained from the multicore fiber (*output-2*).



(a) (b)

Fig. 2. (a) Transmission spectra of the AWG (top) and Sagnac loop filter (bottom) and (b) a typical spectrum of the proposed multi-wavelength fiber laser with a 1.6 nm (200 GHz) channel spacing.

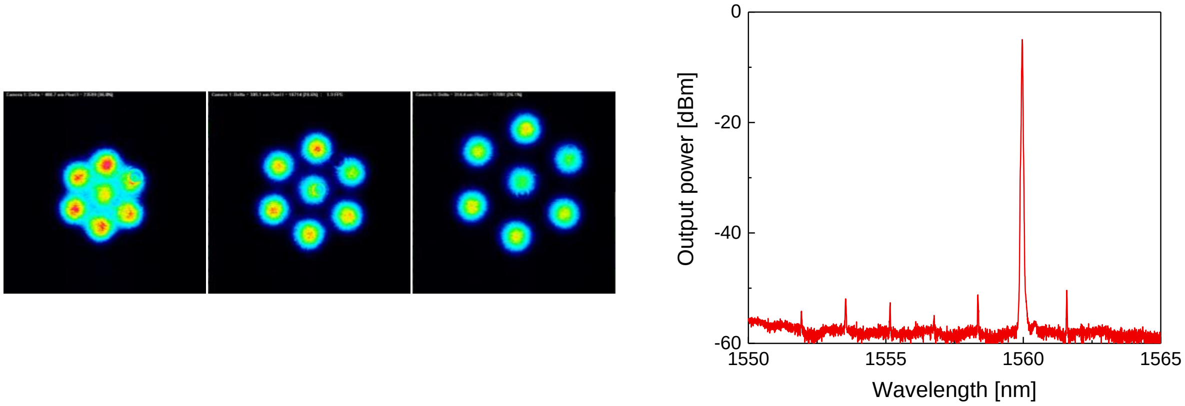
A 16-channel AWG module with a channel spacing of 0.8 nm (100 GHz) was used to determine the lasing wavelength of the individual cores in our laser cavity and the top plot of Fig. 2(a) shows the measured transmission spectra of the device around 1550nm. The average insertion loss of the AWG was ~1.8 dB and output power uniformity over all 16 channels was about 1.7dB. In our experiment, 7 output channels of the AWG were connected to a FIFO with a regular channel spacing of 1.6 nm from 1552.1 nm to 1561.8 nm. However, given that the AWG has quite a flat spectral passband, it proved difficult to obtain single wavelength operation within a single passband of the AWG (not between different channels), due mainly to the homogenous broadening of rare-earth ions in the glass host. To avoid multi-wavelength operation, a Sagnac loop filter was employed to provide a much sharper passband for each channel. A 7.5 m length of highly birefringent fiber was spliced in to the loop mirror to provide a 0.8 nm free spectral range as shown by the bottom plot of Fig. 2(a). A polarization controller (PC) was placed inside the loop to vary the effective reflectivity of the fiber loop mirror. Fig. 2(b) shows a typical spectrum of the multi-wavelength laser output (*output-1*) measured using an optical spectrum analyser (OSA) with a minimum resolution setting of 0.02 nm. Seven distinct lasing wavelengths are clearly observed with a wavelength spacing of 1.6 nm. The small pedestals ~35 dB below the lasing peaks could be eliminated by using a much sharper wavelength selective element and pump injection point. The 3dB linewidth of each wavelength was measured to be less than 0.02 nm (OSA resolution limited) and 20dB bandwidth of the laser was ~0.07 nm.



(a) (b)

Fig. 3. (a) Output power versus launched pump power and (b) multi-wavelength laser spectrum with 0.8 nm channel spacing.

The laser output power was measured at different launched pump powers and the corresponding laser slope efficiencies from output-1 and output-2 are plotted in Fig. 3(a). The pump threshold of the proposed fiber laser was ~32.3dBm and the maximum achievable output power from output-1 was 7.8dBm at 34.2dBm pump power with a slope efficiency of ~0.5%. Note that most of the laser output is emitted from *output-2* with a slope efficiency of ~18.4%. If needed the extracted power from output-1 could be improved by increasing the reflectivity on the right hand side of the cavity (e.g. by incorporating a high reflectivity mirror). Importantly, the lasing wavelengths of the multi-wavelength fiber laser are determined by the choice of the output ports of the AWG module and any combination of wavelengths can be generated on a 100 GHz grid. For example, 7 lasing wavelengths with a 0.8 nm channel spacing (shown in Fig. 3(b)) can be readily achieved by changing the output port of the AWG. Also, note that the cores of the 7-core EYDF are truly independent of each other (i.e. the gain dynamics amongst the cores is almost negligible), therefore it is possible to power up a subset of cores without any degradation in laser performance on any given lasing core.



(a) (b)

Fig. 4. (a) Multiple collimated free-space beams from multicore fiber and (b) laser output spectrum of one of the cores.

At the free space output port (*output-2*), a collimating lens can be placed to generate multiple collimated free-space beams from the multicore fiber. Multiple laser beams emitting from the individual cores of the MCF have different lasing wavelengths and propagate in different angular directions as shown in Fig. 4(a). A portion of the individual core beam was tapped-off by a multimode fiber to measure the optical spectrum of the individual core beams. As shown in Fig. 4(b), single wavelength lasing was clearly observed in each core of the multicore fiber with a side mode suppression ratio (SMSR) of >45 dB. Note that the distinct 6 small side peaks observed originate from the inter-core crosstalk of the MCF laser cavity. We attribute the crosstalk to a combination of the FIFO device and two splice points between the passive and active MCFs. The SMSR of the laser although already very good could be further improved by optimizing the passive MCF components and MCF splicing. Importantly, the multiple laser beams emitting at different wavelengths could be used to enhance the sensitivity and to simply the system architecture of fibre LIDAR systems.

4. Conclusion

Using a multicore erbium doped fiber, a multi-wavelength fiber laser has been successfully realized in a linear cavity configuration. Each core of the multicore EDF can be used as an independent gain medium and an exemplary multi-wavelength fiber laser was constructed using a 7-core EDF without any significant longitudinal mode competition. Such multi-wavelength fiber lasers may find applications in wavelength division multiplexed (WDM) communications, fiber optic sensors, LIDAR, microwave generation and high resolution spectroscopy.

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