Compact 100 mW fiber laser with 2 kHz linewidth

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Abstract: A novel single frequency fiber laser with more than 100 mW output is presented. Low noise and a coherence length of >75 km make this laser extremely useful in sensing, LIDAR, and coherent communication applications.

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1. Introduction

Short single-frequency fiber lasers around 1550 nm using fiber Bragg reflectors have been demonstrated first by Ball *et al.* in Er-doped silicate fibers about 10 years ago [1]. Their potential for mode-hop free, single frequency operation, high wavelength stability and accuracy, low noise, and narrow linewidth, all in a compact all-fiber design, has attracted much interest since then [2-8]. Both distributed feedback (DFB) as well as distributed Bragg reflector (DBR) lasers have been demonstrated. Very narrow spectral linewidth of 2 to 15 kHz and low noise have been reported for both cavity configurations [2,3,5]. Low pump absorption typically limits the output power for single frequency Erbium doped fiber lasers with a length of only a few centimeters to about 250 μW [2,3,5]. This power can then be boosted using the residual pump in a MOPA structure [5,6]. An output power of 60 mW was observed with a 19 m long Er doped fiber amplifier [5]. However, ASE from the amplifier deteriorates the signal-to-noise ratio and broadband rms noise considerably [5,6]. This fundamental problem can be overcome by co-doping the Er doped fiber with Yb. The absorption at the pump wavelength is increased and this enables highly efficient operation of cm-long fiber lasers with output powers of tens of mW. Using Er:Yb co-doped phosphosilicate fiber with relatively high doping concentrations, DBR lasers have shown output powers of up to 60 mW [4], and 160 mW in a MOPA configuration [7]. Unfortunately, these lasers have shown a much broader linewidth of 200 to 500 kHz [7,4]. DFB lasers made from the same material have shown much better performance with 18 kHz linewidth [4] but the high lasing intensities typically found at the center of the phase shifted DFB limit the output power to less than 5 mW [4].

Here we present a high performance DBR fiber laser based on heavily Er:Yb co-doped phosphate glass, that combines high single frequency output power with very narrow linewidth and low noise. Single mode fiber made of Er/Yb co-doped phosphate glass exhibits extremely high optical gain per unit length of up to 5 dB/cm [9] with negligible ion clustering and is uniquely suited for short linear single frequency fiber lasers. We demonstrate what to the best of our knowledge is the first linear diode pumped DBR fiber laser with more than 100 mW of output power and a very narrow linewidth of less than 2 kHz. Measurements of the frequency and intensity noise demonstrate the high performance of this laser. A coherence length of more than 75 km has been experimentally verified. In addition to thermal wavelength tuning, the laser frequency can be modulated at a bandwidth of up to 10 kHz via a piezoelectric actuator. The laser has good mode stability of less than ± 30 MHz over hours, polarized output, and low sensitivity to external vibrations and acoustic noise.

At a wavelength where Erbium doped fiber amplifiers and low cost fiber optic components are readily available, this laser will be extremely useful for a variety of applications, including sensing, coherent communication, frequency locking and as a seed laser for LIDAR.

2. The laser

A laser cavity is established by two spectrally narrow passive fiber Bragg gratings (FBG) that are fusion spliced to a 2 cm long piece of active material. Both grating temperatures are controlled and stabilized to ± 0.01 K. One FBG has been written into polarization maintaining (PM) fiber. The fiber birefringence splits the reflection peak and since only one of the two peaks spectrally overlaps with the reflection of the other FBG, optical feedback is realized for one polarization only. The resulting polarization extinction ratio (PER) is limited by the background ASE. The PM FBG acts as the output coupler and the polarization state of the laser can be selected and keyed to a standard PM fiber connector. The laser is excited by a 976 nm single mode pump laser with a maximum output power of 550 mW through one of the FBG's. Fiber laser, pump diode, drive electronics, a photo diode monitor as well as a PM isolator and WDM pump dump are integrated in a compact, acoustically damped package.

3. Output power and intensity noise

Figure 1. shows the optical output power at 1535 nm versus the pump power. The lasing threshold is around 100 mW and output powers of more than 120 mW are demonstrated for the maximum pump power. The slope efficiency is 27.5 % and a side mode suppression ratio of > 65 dB has been measured. The output power is stable to ≈± 0.17 % over several hours (see insert). Single frequency operation was verified using a scanning Fabry Perot interferometer with 3 MHz resolution and a free spectral range of 1 GHz.

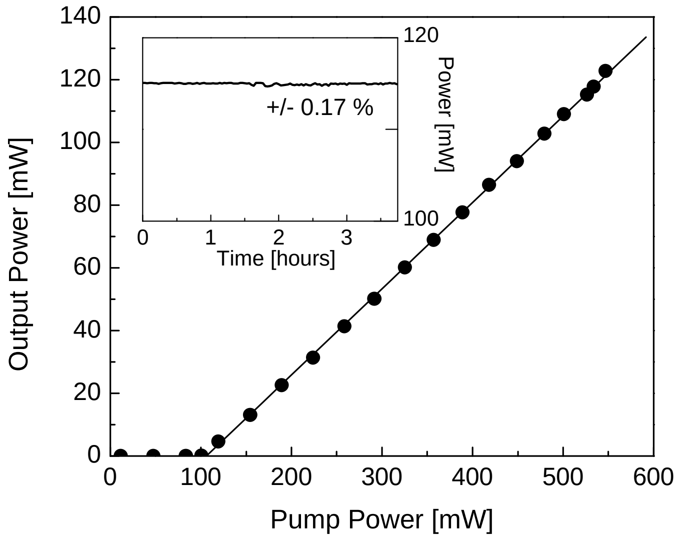

Fig. 1. Laser power as a function of pump power. Insert shows long-term power stability

The relative intensity noise (RIN) is plotted in Figure 2. The noise spectrum is dominated by a peak at the relaxation oscillation frequency of the laser around 1 MHz and is shot-noise limited otherwise. The RIN peak can be suppressed by more than 20 dB using negative feedback to the pump diode. The laser does not suffer from pulsing and is robust against external vibration and acoustic noise.

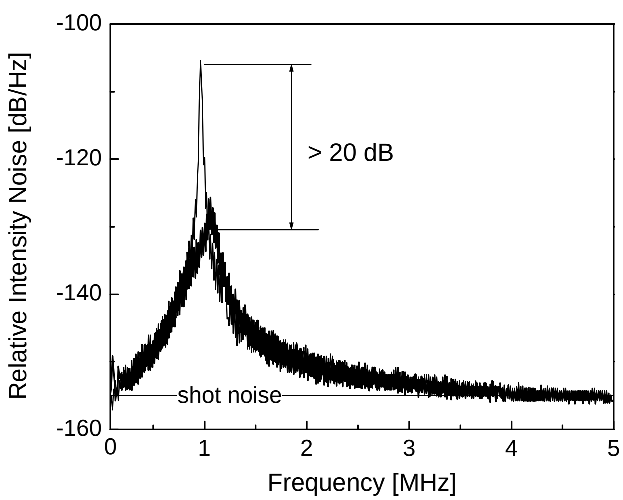

Fig. 2. Relative intensity noise as a function of the frequency

4. Linewidth, frequency noise and coherence length

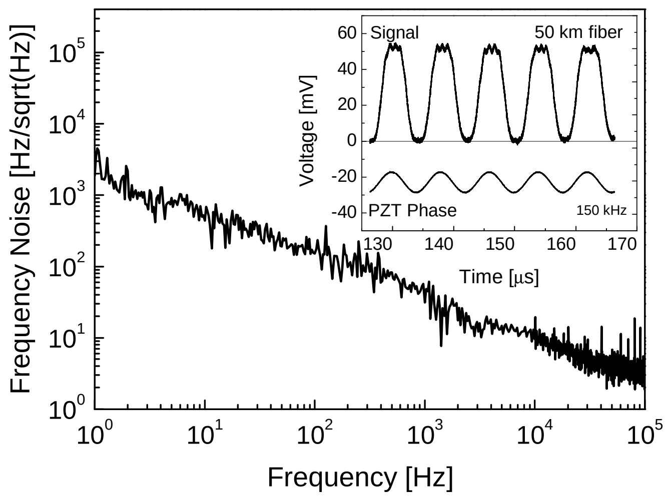

Fig. 3. Frequency noise spectrum, the insert shows interference fringes after part of the light has passed through 50 km of optical fiber

The heterodyne linewidth of this laser has been measured using 25 km of delay. We observe a full width of 35 kHz when measured 20 dB down from the peak of the signal, corresponding to a Lorentzian FWHM of 1.75 kHz. The data suggest a linewidth of less than 2 kHz, even though the delay line was too short to avoid coherent effects and the lineshape was not Lorentzian. In order to further investigate the spectral characteristics of the laser we measured the frequency noise of the laser. The laser signal was fed into a Michelson interferometer with 100 m total path mismatch and Faraday rotating mirrors to avoid polarization effects. A piezoelectric phase shifter in one arm of the interferometer was used to bring the interferometer into quadrature. The interference signal was then analyzed with an electrical audio analyzer and the result of this measurement is presented in Figure 3. The square root of the frequency noise spectral density follows a $1/f^{0.5}$ dependence, characteristic for flicker noise.

A coherence length measurement was made using the same fiber optic interferometer and a delay of 25 km in one arm, corresponding to a full delay of 50 km. Strong interference fringes were observed when the phase in one path was modulated at a frequency of 150 kHz (see inset of Fig. 3.). No fringes were present when either arm of the interferometer was disconnected or a tunable external cavity diode laser was used. This measurement indicates a coherence length of more than 50 km in the fiber or 75 km in air. This is consistent with the narrow linewidth observed in the heterodyne experiment.

4. References

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