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Development of Femtosecond Laser Based on an Erbium-Doped Fiber

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Abstract

A high-power femtosecond Er-doped fiber ring laser is developed and investigated. Self-starting passive mode locking is obtained with nonlinear polarization evolution in optical fibers. The spectral width of the output pulses is about 53 nm at a mean wavelength of 1545 nm; the minimum pulse width is about 97 fs at a pulse repetition rate of 76.65 MHz. We use a 976 nm pump diode laser with ex-fiber power of 935 mW to obtain an average output power of 261 mW with a 27.9 % pump-to-signal conversion efficiency.

Keywords: femtosecond laser; Er-doped fiber; frequency combs; ring cavity; nonlinear polarization evolution; dispersion

Nomenclature

SA	saturable absorption
NPE	nonlinear polarization evolution

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MTBF	mean time between failures
RIN	relative intensity noise
WDM	wavelength division multiplexer
GVD	group velocity dispersion

1. Introduction

At present, femtosecond fiber frequency combs are widely used not only in time and frequency metrology but in other scientific fields as well [1]. Low-noise frequency combs are required to transfer metrological characteristics of developed optical frequency standards [2, 3, 4] to RF range. Research and development to produce advanced combs, improve their metrological properties, and reduce their size and weight is being actively pursued. The main part of a fiber comb is a master oscillator, a mode-locked femtosecond laser. One of the most important tasks in fiber comb development is improving a master oscillator's characteristics, particularly enhancing the output power. Creation of a femtosecond fiber laser having output power and pulse energy sufficient to generate an octave-spanning supercontinuum without using a fiber amplifier will lead to a substantially simpler comb design with a smaller size and weight. Moreover, the use of an amplifier results in phase coherence deterioration of the generated supercontinuum due to the amplified spontaneous emission [5, 6]. Recently, it has been reported that a highly coherent supercontinuum has been generated without an Er-doped fiber amplifier using an Er-doped oscillator that produces 146 fs pulses with a 130 mW average power and a 2.6 nJ pulse energy [6]. In this work, a hybrid scheme that combines SA with NPE has been employed to obtain self-starting passive mode locking. It should be noted that, while it makes the femtosecond laser output parameters better, SA itself has a limited MTBF and reliability. In this paper, we report an Er-doped femtosecond fiber laser with an output power of 261 mW and a pulse energy of 3.4 nJ at a 97.1 fs pulse width, which is used for development of frequency comb. Self-starting passive mode locking is obtained with NPE in optical fibers without using SA. Note that recently it was reported an Yb-fiber laser frequency comb with an amplifier-free supercontinuum generation [7]. In this work, however, to develop a femtosecond fiber laser bulk optic components were used, which require careful alignment and reduce the stability and reliability of a laser system. Our femtosecond fiber laser was developed with commercial fiber optic components without bulk optics.

2. Experimental setup

Unidirectional ring cavity was chosen for design of fiber laser, see Fig.1. It was noted, that femtosecond fiber lasers with ring cavities have lower RIN and phase noise than ones with linear cavities [5]. An Er-doped fiber with an absorption coefficient of about 47 dB/m at 1.53 μm was used. The radiation of Fiber Bragg Grating stabilized 976 nm pump laser diode was coupled into the laser cavity with 980/1550 WDM. The second 980/1590 WDM was used for the additional protection of the pump laser diode from pulsed laser radiation. We used a counter-propagating pump scheme to minimize Er-doped fiber length and to increase pump power conversion efficiency. The femtosecond pulses are extracted from the resonator with 80% port of 80/20 fiber coupler. A polarization-dependent isolator provided a unidirectional laser operation, which also was used as a polarizer. Proper adjustment of two polarization controllers allows us to achieve stable self-starting single-pulse mode locking with the help of NPE [8].

3. Results and discussion

The total dispersion of the cavity was estimated to be of about +0.022 ps^2. At the exit of the cavity pulses had some time broadening – a positive chirp. A piece of SMF-28 fiber with a negative GVD was used to partially compensate for the chirp. Minimum pulse width was obtained with the help of silicon prism dispersion delay line. Laser pulse width was measured by collinear interferometric autocorrelator with two-photon absorption photodiode. Intensity autocorrelation was extracted from interferometric autocorrelation data with a Fourier filtering algorithm. We obtain intensity autocorrelation width of 137.37 fs, which corresponds to the pulse width of about 97 fs,