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All-Fiber Raman Supercontinuum Generator

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Abstract—The results on an all-fiber supercontinuum generator that exhibits a continuous wide spectrum in the range 1060–1640 nm predominantly owing to the cascade stimulated Raman scattering in a single-mode quartz fiber at a relatively high power of the combined femtosecond–picosecond pumping with a central wavelength of 1080 nm are presented for the first time. The mean power of the supercontinuum is 2.1 W.

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INTRODUCTION

A microstructured or tapered fiber serves as the conventional medium for the supercontinuum generation [1, 2]. Passive and active nonlinear fibers are also used for this purpose [3, 4]. Normally, the ultrabroadband radiation is generated in such fibers owing to several simultaneous nonlinear effects. The contributions of the nonlinear effects can be different in different supercontinuum experiments but when a significant spectral broadening (hundreds of nanometers) of the pump pulses occurs, the supercontinuum is generated due to the simultaneous action of several strong nonlinear effects [5]. Note the self-phase modulation and the cross-phase modulation of radiation, the formation of the shock front of the radiation pulse envelope, the stimulated Raman scattering (SRS), the parametric four-wave mixing, and the dispersion and soliton effects.

Under certain conditions, the supercontinuum can be generated predominantly due to the cascade SRS. This effect was observed in the high-energy *Q*-switched nanosecond Yb laser [6].

In this work, we report for the first time on the generation of the Raman-dominated supercontinuum in the single-mode quartz fiber in the presence of the combined femtosecond–picosecond pumping.

EXPERIMENT

Figure 1 demonstrates the experimental scheme. An all-fiber all-positive-dispersion mode-locked linear Yb laser serves as the master oscillator. The mode-locking results from the nonlinear polarization evolution [7, 8]. A distinctive feature of the laser lies in the application of original fiber reflectors based on circulators with relatively wide working spectral ranges. The application of the fiber loop reflectors provides a reflectance of 90% in a spectral band with a width of 75 nm and a central wavelength of 1100 nm. Another feature of the laser is a specific time structure of the generated pulses: isolated picosecond pulses with stochastic sequence of femtosecond sub-pulses. The width of the autocorrelation function (ACF) of the short time structure is no greater than 190 fs, and the width of the ACF of the pedestal is 10 ps. The laser radiation is outcoupled from the laser cavity via a fiber polarization beam splitter that provides the linearly polarized output radiation. A fiber optical isolator is used at the laser exit. The power of the output laser radiation (150 mW) is limited by the maximum allowed power for the fiber polarization splitter.

The laser radiation is amplified in a side-coupled cladding-pumped ytterbium-doped fiber amplifier [9] that does not maintain the polarization. The amplifier is pumped by a multimode diode laser with a power of up to 6 W at a wavelength of 975 nm via a coreless quartz fiber with a diameter of 125 μm. The diameter of the core of the ytterbium amplifier is 15 μm. The mean output power of the amplifier is greater than 2 W.

Figure 2 shows the spectra of the laser radiation and the amplified radiation. The spectral width of the laser radiation is 4.4 nm, and the amplification results in the spectral broadening to 8.6 nm.

The amplified radiation is fed to a 1060-XP Nufern single-mode fiber with a length of 80 m. Figure 3 shows the spectrum of radiation transmitted by the 1060-XP fiber at a mean power of 2.1 W.

The analysis of the spectral data shows that the broadband radiation is formed owing to the spectral peaks that correspond to the SRS processes of various orders in the quartz fiber. The Stokes components of the SRS are spectrally broadened and overlapped due to a relatively broad SRS gain spectrum [10]. This circumstance leads to a continuous wide spectrum. The preliminary spectral broadening of the pumping radiation in the fiber amplifier provides the additional smoothing of the spectrum of the Raman-dominated supercontinuum.

A significant spectral dip at a wavelength of about 1.45 μm is related to the water absorption peak of the fiber. Note that, at the moderate length (80 m) of the single-mode fiber, the radiation is incompletely

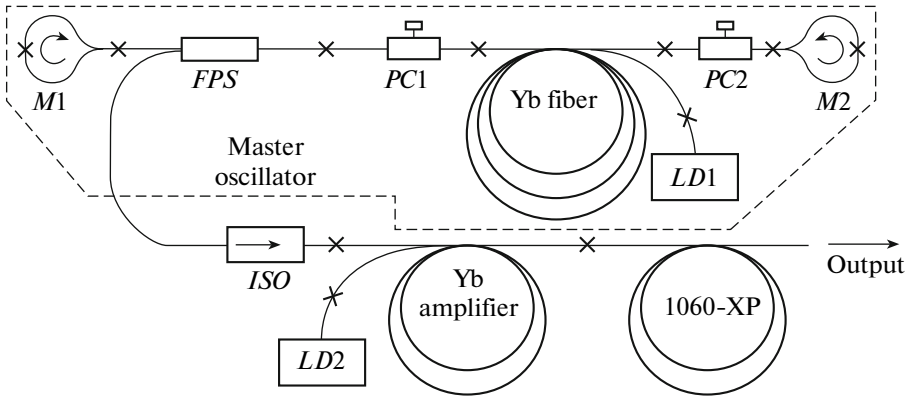

Fig. 1. Scheme of the all-fiber supercontinuum generator: *LD*1 and *LD*2 pumping laser diodes with a wavelength of 975 nm, *PC*1 and *PC*2 polarization controllers, *M*1 and *M*2 broadband fiber reflectors, *FPS* fiber polarization splitter, and *ISO* optical isolator.

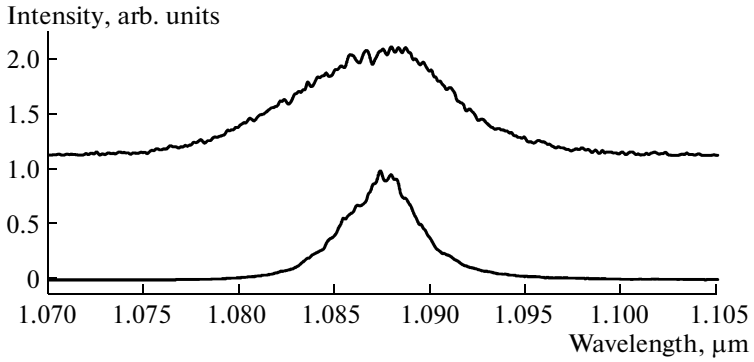

Fig. 2. Spectra of (lower curve) the laser radiation and (upper curve) the amplified radiation.

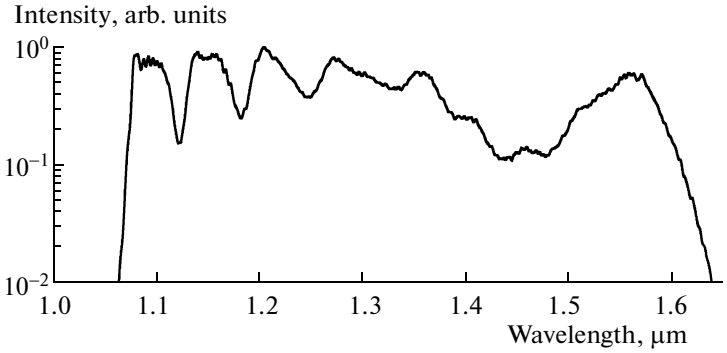

Fig. 3. The spectrum of the Raman-dominated supercontinuum at the exit of the 1060-XP fiber.

absorbed in the vicinity of 1.45 μm and a spectral peak is observed at a wavelength of about 1.55 μm. In Fig. 3, the greater the wavelength, the stronger the smoothing of the spectral peaks. This result corresponds to the increasing spectral width of the pumping radiation for the higher Stokes components of the SRS.

CONCLUSIONS

In this work, we present the first experimental results on an all-fiber supercontinuum generator that provides a continuous wide spectrum in the range 1060–1640 nm predominantly owing to the cascade SRS in an external single-mode quartz fiber at a relatively high power of the combined femtosecond–picosecond pumping radiation with a central wavelength of 1088 nm. A typical feature of the supercontinuum lies in the red shift of the continuous spectrum relative to the wavelength of the pump pulses. Note an important role of the preliminary spectral broadening of the pump pulses in the nonlinear fiber amplifier that allows the smoothing of the cascade-SRS spectrum. In spite of the fact that the spectral width of the femtosecond–picosecond pumping radiation (8.6 nm) in the experiment is significantly less than the SRS frequency shift in quartz (more than 50 nm at a wavelength of about 1100 nm), the simultaneous manifestation of the spectral broadening of the pumping radiation and the broad SRS gain spectrum leads to the smoothing of the cascade-SRS spectrum and provides a wide continuous radiation spectrum in a band with a width of about 600 nm.

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