ISSN 1054-660X, Laser Physics, 2008, Vol. 18, No. 11, pp. 1257–1259.

Fiber Supercontinuum Generator with Wavelength-Tunable Pumping

S. M. Kobtsev*, S. V. Kukarin, and S. V. Smirnov
Novosibirsk State University, ul. Pirogova 2, Novosibirsk, 630090 Russia
*e-mail: kobtsev@lab.nsu.ru
Received June 20, 2008

Abstract—The initial results of the experimental and numerical study of a fiber supercontinuum generator based on a wavelength-tunable femtosecond Yb:KYW laser are presented. It is demonstrated that a variation in the pumping wavelength in the vicinity of the zero-dispersion wavelength of a microstructured fiber at about 1040 nm allows for a wide-range variation in the supercontinuum spectral width at a constant mean pumping power. The experimentally measured strong dependence of the supercontinuum spectral width (from 70 to 390 nm) on the pumping wavelength (1040–1049 nm) at a pulse energy of about 1 nJ and a pulse duration of 250 fs is qualitatively reproduced in the simulation.

PACS numbers: 42.65.-k, 42.65.Wi

DOI: 10.1134/S1054660X0811008X

INTRODUCTION

Fiber-optic supercontinuum (SC) generators (FOSCGs) represent new broadband laser sources that are widely used in fundamental and applied research [1]. A key element of the FOSCG is a conventional or specific optical fiber in which several nonlinear effects lead to a significant spectral broadening of the input radiation. The SC generation is implemented using microstructured [2], pulled [3], or highly nonlinear [4] optical fibers. The SC generation is strongly affected by the dispersion characteristics of the fibers, in particular, the position of the zero-dispersion wavelength of the fiber relative to the pumping wavelength [5]. The commercially available microstructured and nanostructured fibers [6], which exhibit relatively long lifetimes, are widely used at present for the SC generation. Femtosecond [7], picosecond [8], nanosecond [9], or CW lasers whose radiation intensity is modulated at a relatively high frequency (50–300 GHz) serve as pumping sources. Normally, the pumping power is a single variable parameter of the commercially available and laboratory FOSCGs. Variations in the remaining parameters (SC spectral width, power spectral density, etc.) results from a variation in the pumping power.

The possibility of controlling the SC spectral width using a variation in the radiation wavelength of the femtosecond Ti:sapphire pumping laser was recently demonstrated in [10]. The Kerr-lens mode-locked Ti:sapphire laser enables one to vary the wavelength of the femtosecond-pulse radiation in a relatively wide spectral range. The mode-locked lasers based on saturable absorbers exhibit a narrower wavelength tuning range of short pulses owing to the spectral dependence of the saturable-absorber parameters. However, saturable absorbers are widely used in various lasers due to the simplicity of the mode-locking procedure in comparison with the procedure that is needed for the Kerr-lens mode locking and that involves a thorough preliminary tuning of the multimirror laser cavity. In this regard, it is expedient to study the possibilities offered by relatively simple femtosecond lasers based on saturable absorbers in the control of the SC parameters. From the practical point of view, it is important to characterize the range of variations in the SC parameters at a relatively weak variation in the pumping wavelength in the immediate vicinity of the zero-dispersion wavelength of a conventional commercially available microstructured fiber. The femtosecond Yb:KYW laser with a maximum power in the range 1040–1050 nm appears appropriate for such a study using a Crystal Fiber SC-1040 microstructured fiber. The interest in the femtosecond Yb:KYW laser as a master oscillator of an FOSCG is also due to the significant advantages of this modern laser in comparison with the femtosecond Ti:sapphire lasers: the Yb:KYW laser employs direct-diode pumping (IR laser diodes for the pumping of the Yb:KYW lasers are substantially simpler and cheaper than the green laser diodes needed for the pumping of the Ti:sapphire lasers).

In this work, we present the initial experimental results on the FOSCG based on a wavelength-tunable femtosecond Yb:KYW laser and the microstructured fiber whose zero-dispersion wavelength falls into the working spectral range of the Yb:KYW laser.

EXPERIMENT

In the experiments, we employ a Yb:KYW laser [11] with the following parameters at a pumping power of up to 4 W and a pumping wavelength of 976 nm: pulse duration, 250 fs; pulse repetition rate, 80 MHz; mean output power, up to 400 mW; and pulse energy,

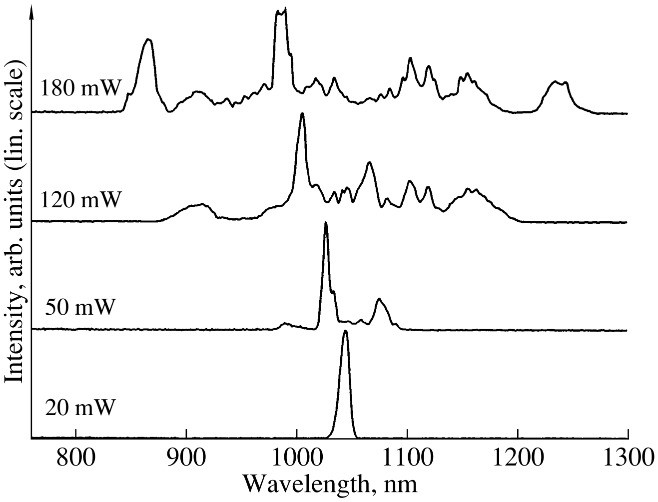

Fig. 1. SC spectra at various mean radiation powers (figures on the curves) at the exit of the microstructured fiber pumped by femtosecond pulses with a central wavelength of 1049 nm.

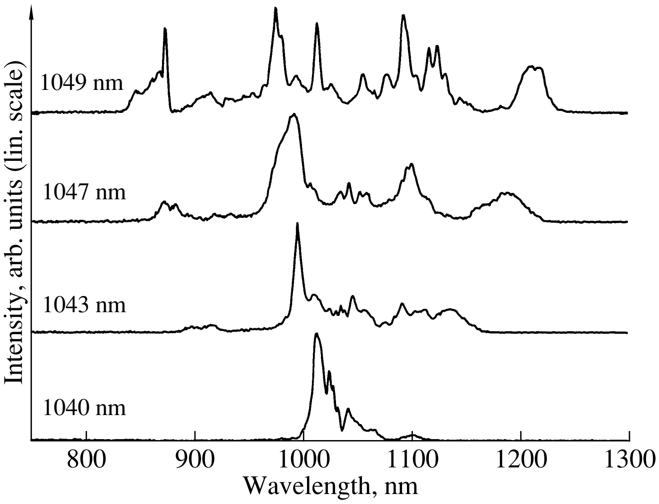

Fig. 2. SC spectra at a fixed mean pumping power of 300 mW and various pumping wavelengths (figures on the curves).

about 5 nJ. In the mode-locked laser, the wavelength can be tuned in the range 1038–1053 nm. For the SC generation, we use a Crystal Fiber SC-5.0-1040 microstructured fiber with a length of about 3 m. In accordance with the specification, the zero-dispersion wavelength of this fiber (1040 ± 10 nm) falls into the wavelength-tuning range of the Yb:KYW laser. The laser radiation is delivered to the fiber using a Faraday isolator and a 10 × 0.3 microobjective. This objective delivers up to 50% of the laser radiation to the fiber.

The experiment consists of two stages. At the first stage, we fix the central wavelength of the pumping-pulse spectrum (1049 nm) and vary the mean power of the input radiation. Figure 1 demonstrates the dependence of the SC spectral width on the mean power of the output radiation for the microstructured fiber pumped by the femtosecond pulses. The width of the upper spectrum (at a level of 1%), which corresponds to a mean power of 180 mW, is 390 nm at a mean power spectral density of about 0.5 mW/nm.

Note the typical soliton peaks that emerge in the long-wavelength part of the spectrum and the red shift of these peaks with an increasing pumping power. Note also the short-wavelength components that emerge at a certain power level and exhibit a blue shift with an increasing power. Such features in the SC spectrum are characteristic of the transformation of the pumping pulse into a high-order soliton, its decay to fundamental solitons, the self-shift of the central wavelengths of the fundamental solitons towards long wavelengths, and the corresponding generation of the nonsoliton (dispersion) radiation in the short-wavelength range [12].

At the second stage, we fix the mean output power of the pumping laser and tune the central wavelength of the spectrum of pulses. Figure 2 shows the experimental spectra measured at the exit of the microstructured fiber at a fixed mean pumping power of 300 mW and the pumping wavelengths ranging from 1040 to 1049 nm. In this experiment, the SC integral power is 150 mW at any pumping wavelength.

It is seen that the SC spectral width sharply increases when the pumping wavelength is tuned in the range 1040–1049 nm in the vicinity of the zero-dispersion wavelength of the fiber. In particular, the spectral width at a relative level of –10 (–15) dB increases by a factor of 5.5 (3.1) from 70 (124) to 390 (390) nm. Such a strong dependence of the SC spectral width on the pumping wavelength must be due to the proximity of the zero-dispersion wavelength ($\lambda_0 \sim 1040$ nm).

For the numerical simulation of the experimental results, we employ the generalized nonlinear Schrödinger equation allowing for a fiber dispersion accurate to the fifth term in the polynomial approximation of the dispersion curve in the wavelength range 670–1690 nm. The numerically simulated dependence of the SC spectral width on the wavelength of the pumping pulses is presented in Fig. 3.

The comparison of the experimental data and simulated curves indicates that the experimentally measured strong dependence of the spectral width on the pumping wavelength is qualitatively simulated. The smaller slope of the calculated curve can be related to a possible difference between the experimental and simulation parameters.

The calculations make it possible to interpret the strong experimental dependence of the spectral broadening on the pumping wavelength λ_p. When this wavelength is rather far in the normal-dispersion region of the fiber, the insignificant spectral broadening is predominantly due to the self-phase modulation (SPM). When the pumping wavelength approaches the zero-

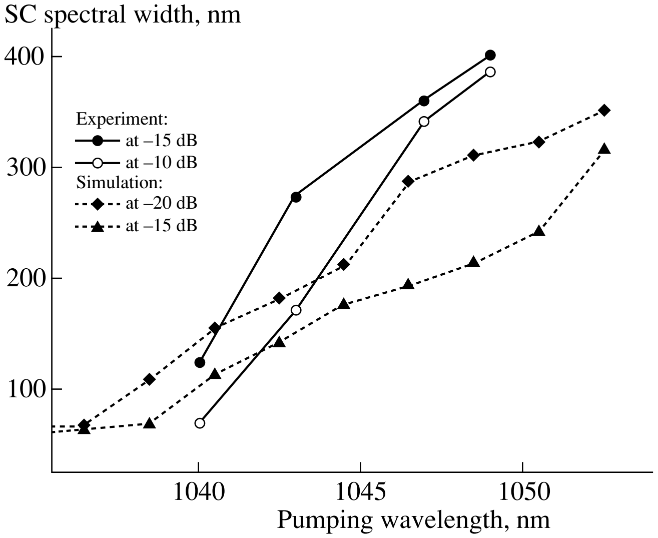

Fig. 3. Simulated curves of the SC spectral width vs. the pumping wavelength.

dispersion wavelength of the fiber, a part of the energy is transferred (owing to the SPM) to the anomalous-dispersion region, where the phase-matching conditions for the parametric processes are satisfied. This gives rise to the modulation instability, which leads to the decay of a pulse to a series of subpulses and the soliton formation. The self-shift of the soliton frequency owing to the stimulated Raman self-scattering and parametric processes cause a significantly more effective spectral broadening in comparison with the SPM effect in the normal-dispersion region. This accounts for the rapid increase in the SC spectral width with an increase in the pumping wavelength.

CONCLUSIONS

The possibility of controlling the SC spectral width and power spectral density due to variations in the wavelength of the femtosecond Yb:KYW laser at a fixed mean pumping power is demonstrated for the first time using the experimental results and numerically calculated data. When the radiation wavelength of the Yb:KYW laser is tuned in the range 1040–1049 nm at a pulse duration of 250 fs and a mean power of 300 mW at the fiber entrance, the spectral width of the SC generated in the SC-5.0-1040 microstructured fiber increases by a factor of 5.5 (3.1) (from 70 (124) to 390 (390) nm) at a relative level of –10 (–15) dB.

ACKNOWLEDGMENTS

This work was supported by the Federal Agency on Science and Innovations (contract no. 02.513.11.3360) and, in part, by the Ministry of Science and Education of the Russian Federation (grant of the Rautian–Shalagin Scientific School).

REFERENCES

1. A. M. Zheltikov, Phys. Usp. **49**, 605 (2006).
2. J. C. Knight, T. A. Birks, P. S. J. Russell, and D. M. Atkin, Opt. Lett. **21**, 1547 (1996).
3. T. A. Birks, W. J. Wadsworth, and P. S. J. Russell, Opt. Lett. **25**, 1415 (2000).
4. A. K. Abeeluck and C. Headley, Opt. Lett. **30**, 61 (2005).
5. G. P. Agrawal, *Nonlinear Fiber Optics* (Academic, San Diego, 2001; Mir, Moscow, 1996).
6. A. B. Fedotov, E. E. Serebriannikov, A. A. Ivanov, et al., Ross. Nanotekhnol. **1**, 252 (2006).
7. J. K. Ranka, R. S. Windler, and A. J. Stentz, Opt. Lett. **25**, 25 (2000).
8. S. Coen, A. H. L. Chau, R. Leonhardt, et al., J. Opt. Soc. Am. B **19**, 753 (2002).
9. J. M. Dudley, L. Provino, N. Grossard, et al., J. Opt. Soc. Am. B **19**, 765 (2002).
10. S. M. Kobtsev, S. V. Kukarin, and N. V. Fateev, Quantum Electron. **32**, 11 (2002).
11. S. M. Kobtsev and S. V. Kukarin, Quantum Electron. **37**, 993 (2007).
12. J. Herrmann, U. Griebner, N. Zhavoronkov, et al., Phys. Rev. Lett. **88**, 173901 (2002).