Nonlinear conversion of a cw beam into a train of intense, short pulses in a fiber laser

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A method is proposed for the nonlinear conversion of a cw pump beam into a periodic train of intense, short pulses in a stimulated-Brillouin-scattering fiber laser. The pulses that are produced acquire the pump energy stored over a period of the resonator and have a length an order of magnitude shorter than the relaxation time of a hypersonic wave.

Optical fibers are finding progressively more applications in nonlinear optics and quantum electronics, for use in solving such problems as producing femtosecond-range emission pulses of optical solitons and developing stimulated-Raman-scattering and stimulated-Brillouin-scattering fiber lasers.[1–4]

In this letter we analyze the possibility of using optical fibers to convert a cw laser beam into a periodic train of intense, short pulses in a stimulated-Brillouin fiber laser. The idea underlying this conversion is the excitation of stimulated Brillouin scattering (or "stimulated Mandel'shtam-Brillouin scattering") in an optical fiber in an optical resonator. As the emission develops in a laser of this sort, intense, short backscattering pulses are formed. In each successive transit through the fiber these pulses "absorb" all the energy of the pump light stored over the period of the resonator. We have used numerical methods to analyze the dynamics of the operation of a stimulated-Brillouin fiber laser in the plane-wave model. Saturation and the finite relaxation time of the hypersonic wave are taken into account.

Calculations have been carried out both for the model in which the emission develops from spontaneous fluctuations of the light at the Stokes frequency and for a model of "hard" excitation of the emission, which occurs during the injection of a short trigger pulse into the resonator of the stimulated-Brillouin fiber laser. Figure 1 shows the typical evolution of the lasing in a laser of this type. In the initial stage, the Stokes pulse is amplified and compressed, but after each transit of the laser resonator this pulse leaves in its path an intense hypersonic wave near the leading edge of the fiber; this wave reflects part of the pump light backward and creates an extended trailing edge on the Stokes pulse. This residual hypersonic wave has the consequence that a progressively lower intensity of the pump pulse will penetrate into the fiber during each successive pass. Ultimately, an intense acoustic wave is created at the front of the fiber, and it reflects essentially all the pump light. The results are a smoothing of the temporal structure of the Stokes emission and a stabilization of this emission at the level $I_S = I_p$ (Fig. 1).

In our scheme, the steady-state pulse train in the stimulated-Brillouin fiber laser is to be produced by virtue of the nonlinear brightening of a resonantly absorbing medium in the laser resonator.[5] The use of a brightening filter makes it possible to

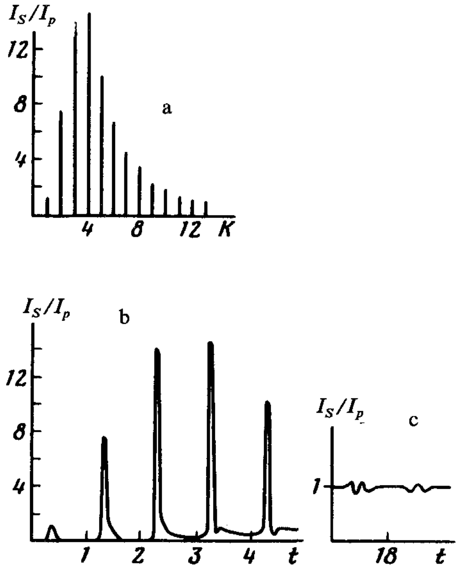

FIG. 1. Dynamics of the operation of a stimulated-Brillouin-scattering optical-fiber laser with cw pumping. a—Maximum intensity of the Stokes pulses, I_S/I_p, versus the number (k) of transits of the resonator (the form of the pulse train on an oscilloscope screen); b—shape of the emission pulses during the first few transits of the resonator; c—intensity of the Stokes light at the output from the stimulated-Brillouin fiber laser.

limit the pedestal of the Stokes pulses and to achieve the emission of a train of stimulated-Brillouin pulses with a length an order of magnitude shorter than the relaxation time of the hypersonic wave and with an intensity two orders of magnitude greater than the pump intensity. Figure 2 shows the typical output from this stimulated-Brillouin fiber laser.

Let us summarize the parameters of the laser system at which it is possible to observe these effects. The operating threshold of a stimulated-Brillouin fiber laser with a nonlinearly brightening filter is described by

$$I_{p/th} = (\kappa_0 - \ln R)/gl$$

and has the value of 0.97×10^6 W/cm^2 at the wavelength $l = 1.06$ μm ($g = 4.5\times 10^{-9}$

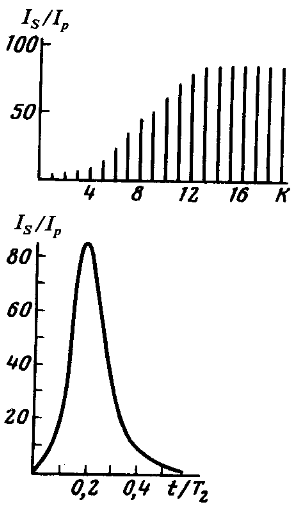

FIG. 2. Conversion of a cw pump beam into a train of intense, short pulses in a stimulated-Brillouin fiber laser with a nonlinearly brightening filter. a—Relaxation to steady-state emission of short pulses; b—steady-state shape of an emission pulse.

cm/W, $T_2 = 10$ ns, $l = 20$ m, and $R = 0.5$, where R is the effective reflectance of the mirrors, and $\kappa_0 = 8$ is the initial absorption of the filter).

Typical values of the pump intensity at which intense single pulses are produced in these numerical simulations are $gI_p l = 10$. We can thus estimate the pump intensity to be $I_p = 1.13 \times 10$ W/cm^2; with an effective cross-sectional area for the waveguide mode of $S = 20 \times 10^{-8}$ cm^2, we then find the output power of the cw pump laser to be $P = I_p S = (1.13 \times 10^6 \text{ W/cm}^2) \times (2 \times 10^{-7} \text{ cm}^2) = 220$ mW. In the numerical simulations, the intensity at which the filter brightened was on the order of 10^6 W/cm^2, so that the filters which are presently used widely for mode locking in lasers[5] could be used.

We wish to emphasize that an experimental implementation of this method might also use a cascade conversion of the light in the stimulated-Brillouin pulse in comoving stimulated Raman scattering. If the resonator mirrors also reflect light at the stimulated Raman frequency, then as the stimulated-Brillouin pulses grow, they may undergo a subsequent cascade stimulated-Raman conversion and a compression during excitation of Stokes components of higher orders.[6]

This method for nonlinear conversion of a cw beam into a periodic train of intense, short pulses requires rather high growth rates for the Stokes emission per transit of the laser resonator. An attempt at an experimental implementation of this conversion method in a bulk system may run into serious difficulties because of a competition between stimulated scattering and self-focusing. The amplification that occurs in oppositely directed stimulated scattering in a bulk medium is presently being used for phase conjugation and for controlling the parameters of intense nanosecond pulses for laser fusion.[7,8] To the best of our knowledge, there has been no previous study of the control of the parameters of cw emission during oppositely directed scattering in a bulk system.

We should point out in conclusion that the observation of stimulated Brillouin scattering in an optical fiber in the mid-IR range[9] raises the hope that the method discussed here may be used for in-resonator conversion of the cw light from a CO_2 laser.

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