Paramagnetic excitation of SRS in a fiber light conductor

Z. V. Nesterova, I. V. Aleksandrov, I. V. Mel'nik, B. S. Neporent, and D. K. Sattarov

(Submitted 11 February 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 6, 363–366 (20 March 1980)

A number of anti-Stokes SRS bands in a fiber light conductor and an anomalous distribution of the intensity of the Stokes SRS bands in the vibrations of the Si—O bonds of a fiber were observed experimentally. The spectral, amplitude, and time characteristics of SRS are attributable to the parametric interactions of the light waves in the investigated fiber.

PACS numbers: 42.55.Rz, 42.65.Cq, 42.80.Mv

Investigation of the processes of stimulated scattering in fiber light conductors is of considerable interest in understanding the mechanism of multiphoton interactions in the field of a powerful light emission and in estimating the quality of fiber light conductors for optical-fiber communication lines. The spectra of SRS in a fiber, produced as a result of pulsed and continuous excitation in the visible and near IR regions of the spectra, including those with multistage excitation of the Stokes SRS lines, which are interpreted in terms of the well-known scheme of the cascade SRS, have recently been obtained.[1,2] In this paper we describe for the first time a Raman laser based on a fiber light conductor with a parametric generation of a series of Stokes components ($n_s = 1$–9) and anti-Stokes components ($n_{as} = 1$–3) of the SRS in the visible region of the spectrum.

The schematic of the experimental setup is shown in Fig. 1. A pulsed radiation from a LTIPCh-6 laser ($\lambda_0 = 532$ nm, $P_p \sim 400$ kW, $\tau_p \sim 15$ nsec), after passing through a filter F that cut off the radiation at the fundamental frequency, was focused

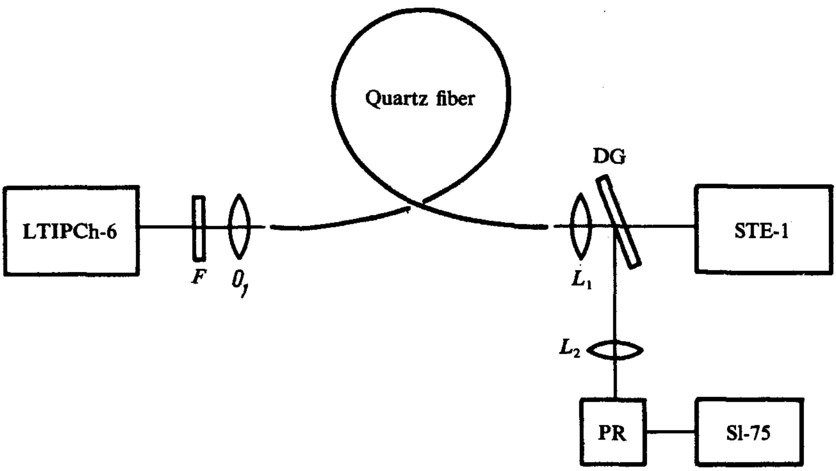

FIG. 1. Schematic of the experimental setup.

 © 1980 American Institute of Physics

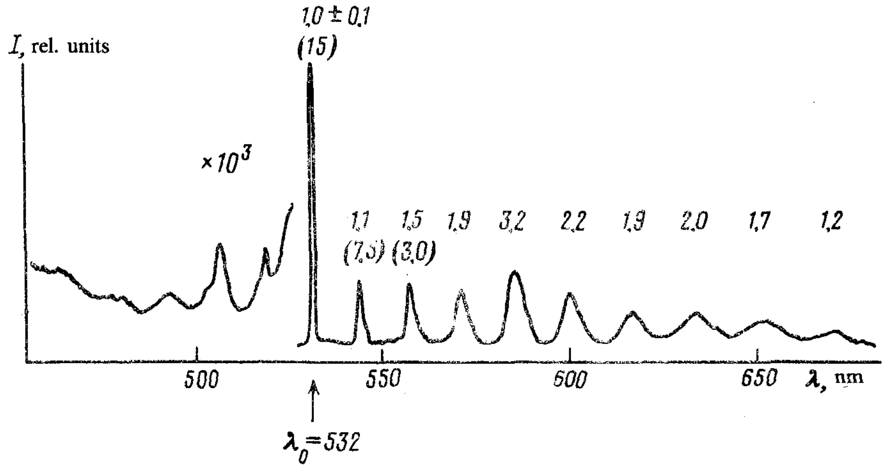

FIG. 2. Microphotogram of SRS bands in a fiber light conductor.

by a coated micro objective O_1 (10^x) on the end of a low-dispersion quartz fiber made at GOI by the method of chemical deposition of components from the gas-phase. The length of the fiber was ~ 150 m, and the diameters of the core and the envelope were 50 and 130 mk, respectively, for an aperture of 0.17. The losses in the fiber at a wavelength of 532 nm did not exceed 30 db/km. The radiation at the output of the fiber, which was collected by the lenses L_1 and L_2, was directed to the input of a STE-1 spectrograph or, after being diffracted by a DG 1500 lines/mm diffraction grating, was directed to the input photoreceiver PR with a time resolution of ~ 0.2 nsec, that was connected to a SI-75 oscillograph.

Figure 2 shows a typical microphotogram of the lines of SRS generation in the described laser. The two-digit numbers above the bands represent the relative integral intensity of the components and the numbers in parentheses denote the pulse duration of the exciting laser and of the Stokes SRS components in the range of the time resolution of the oscillograph. We note that the SRS bands, which are located at a distance of 410–440 cm^{-1}, correspond to the excitation of the molecular vibration of the Si—O bond of the tetrahedral groups of fused quartz. The anti-Stokes region of the spectrum has three bands, of which the second has the largest intensity. A number of SRS bands (Stokes and anti-Stokes) reveal a structure with an additional maximum which may be attributable to different types of vibrations.

As is known, the generation of anti-Stokes radiation is a unique feature of the parametric interactions. The activation of anti-Stokes bands in our case is attributable to the high efficiency of the parametric processes in a limited volume of the fiber light conductor with long active medium in which the phase-locking mode is realized. It is conceivable that with the loss of phase locking at a certain length of the fiber the SRS process can be explained in terms of the mechanism of cascade SRS.

Using the first Stokes component as an example, we can see that the SRS bands in a fiber light conductor have a large width ($\delta\nu_1 \sim 1.2$ nm) corresponding to that of the structureless bands of analogous vibrations in the spectra of spontaneous SRS of fused quartz.[1] The relative integral intensity of the first band ($\lambda_1 = 545$ nm) amount to ~ 1.15 that of the pump radiation at the output of a fiber and is much smaller than the intensity of the second Stokes band (~ 1.50), which is also a consequence of parametric interactions in the field of the biharmonic pumping ($\lambda_0 = 532$ nm, $\lambda_1 = 545$ nm), whereas the ordinary cascade SRS in a fiber is characterized by a monotonic decrease of the intensity of the Stokes bands with their increasing number n.[2]

It can be seen from the data in Fig. 2 that the pulse duration τ_p of the Stokes bands of a fiber, parametric laser decreases with increasing number n and, beginning with $n_s = 4$, goes over to the subnanosecond band. An important characteristic of the generation of the higher Stokes SRS components in our case is the sharp spectral broadening of the corresponding bands (for example, $\delta \nu_8 \sim 10$ nm). For a selected length of the fiber ($l \sim 150$ m), which greatly exceeds the optimum length ($l \sim 110$ m) for intensification of the first Stokes component, which was determined by us on the basis of a computer calculation, the fourth Stokes SRS component had the largest intensity.

We can assume that activation of a fiber by phosphorous and germanium oxides produces an additional light continuum in the near IR region due to excitation of the SRS bands of the phosphate and germanate groups with a large Stokes shift, and by selecting a fiber of a certain length, the intensity of higher Stokes components increases substantially.

According to the current ideas about the role of parametric and Raman processes in the generation of higher Stokes components,[3,4] the parametric interactions produce in the medium a nonlinear polarization at the frequencies of the interacting fields, which determines the effective correction for the linear dielectric constant of the medium. In this case the threshold density of the radiation energy, which is essential for excitation of the Stokes bands with $n_s > 1$, may decrease by several orders of magnitude. The generation of bands with $n_s = 3$–9 in this case occurred at the same time the pump power above the generation threshold of the second Stokes band increased neglibibly. We note that Khronopulo[5] predicted theoretically the possibility of building a parametric Raman fiber laser that could operate at generation modes for which the dependence of the intensity of the Stokes component on the axial coordinate increases monotonically.

Thus, the described Raman laser, which is the first experimental example of parametric interaction in fiber light conductors, has a number of unique characteristics. Such laser can be an efficient source of powerful, quasi-continuous radiation in the visible and near IR regions, and also a generator of light pulses of subnanosecond duration. The fiber light conductors currently seem to be the only devices that can simultaneously generate at a low pump power a number of anti-Stokes SRS components, which makes it possible to investigate in greater detail the characteristics of the four-photon, parametric interactions in condensed active media.

[1]C. Lin, R. K. Jain, and R. H. Stolen, J. Opt. Soc. Amer. 67, 250A (1977).

[2]V. V. Grigoryants, B. L. Davydov, M. E. Zhabotinskiĭ, V. F. Zolin, G. A. Ivanov, V. I. Smirnov, and Yu. K. Chamorovskiĭ, Pis'ma Zh. Tek. Fiz. 3, 54 (1977) [Sov. Tech. Phys. Lett. 3, 22 (1977)].

[3]G. V. Venkin, G. M. Krochik, L. L. Kulyuk, D. I. Maleev, and Yu. G. Khronopulo, Pis'ma Zh. Eksp. Teor. Fiz. **21**, 235 (1975) [JETP Lett. **21**, 105 (1975)].
[4]V. S. Butylkin, G. V. Venkin, L. L. Kulyuk, D. I. Maleev, Yu. G. Khronopulo, and M. F. Shalyaev, Kvantovaya Elektronika **4**, 1537 (1977) [Sov. J. Quantum Electron. **7**, 867 (1977)].
[5]Yu. G. Khronopulo, sbornik "Rezonansnye vzaimodeĭstviya sveta sveshchestrom" (A collection of papers entitled "Resonance Interaction of Light with Matter,") publ. by Nauka, M., 1977, p. 247.