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SECOND WORKSHOP ON
OPTICAL FIBRE COMMUNICATION
(14 - 25 March 1988)

STIMULATED MANDEL'SHTAM-BRILOUIN SCATTERING IN A MULTIMODE GLASS FIBER LIGHTGUIDE

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Stimulated Mandel'shtam-Brillouin scattering in a multimode glass fiber lightguide

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(Submitted 1 July 1982)
Pis'ma Zh. Eksp. Teor. Fiz. 36, No. 3, 85–87 (5 August 1982)

Stimulated Mandel'shtam-Brillouin scattering (SMBS) is observed for the first time in a multimode glass fiber lightguide (GFL). The low divergence of the SMBS radiation and the uniformity of its field are related to the inversion of the wave front of the laser pumping field.

PACS numbers: 42.80.Lt, 42.80.Mv, 78.35. + c, 42.65.Cq

GFL with small optical losses and a diameter of the light-guiding core d_c of the order of several tens of microns have allowed reducing sharply the pumping power in observing such nonlinear processes as stimulated Raman scattering, the Kerr effect, phase modulation (see Ref. 1), four-photon processes.[2] Until now, SMBS has been investigated only in single-mode GFL with $d_c = 2.5$–$4\ \mu$m pumped by single-frequency gas lasers.[3,4] This is related to the narrow SMBS amplification line, consisting of several tens of MHz, and to the fact that the efficiency of the process decreases with broad-band pumping.

In this work, we used an optically pumped, Nd:YAG solid state laser operating in the passive Q-switching mode, which was realized with the help of an LiF crystal with color centers placed in the resonator as the pumping source.[5] The self-Q-switching regime was realized by bleaching F_2^- color centers in LiF; in addition, depending on the initial transmission of the shutter (75–90%), generation was achieved in the pulsed periodic regime with τ_i varying from 100 to 300 ns and f_i varying from 1 to 5 kHz. Generation was achieved at $\lambda = 1.064\ \mu$m in the regime with a single transverse TEM_{00} mode for two longitudinal types of oscillations separated by a distance $c/2L \approx 280$ MHz. In this case, the pulse power reached 1.5 kW and the radiation was linearly polarized. The investigations were performed on a multimode GFL with a quartz core with $d_c \approx 30\ \mu$m and a stepped profile of the index of refraction with length 80 m. The measured numerical aperture of the GFL was equal to 0.15. The losses at $\lambda = 1.064\ \mu$m constituted 7 dB/km.

A diagram of the experimental arrangement is shown in Fig. 1. The laser radiation is introduced into the GFL (exciting radiation aperture ≈ 0.07) with the help of the lens L_1 ($F = 1$ cm). In order to avoid parasitic reflections, the ends of the lightguide were placed in cells (C_1, C_2) containing glycerin. We used a light-dividing plate (LP) and a mirror (M) to record the backscattering and the pumping. The optical signals investigated entered the optical analyzer (OA), which will be described in detail in a subsequent paper or a Fabry-Perot interferometer. In order to measure the energy characteristics, we used a pyroelectric joule meter.

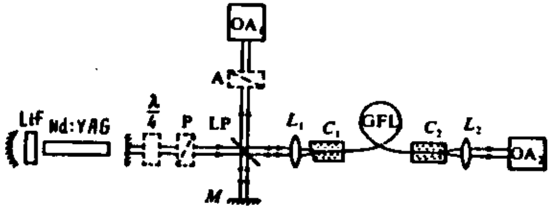
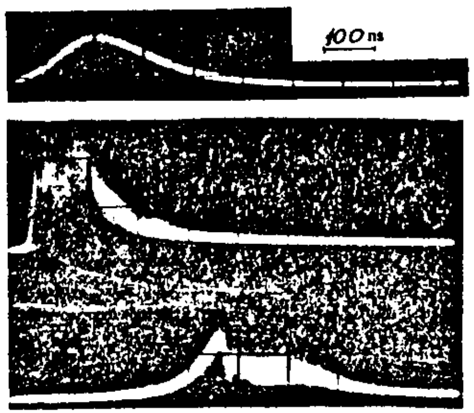


FIG. 1. Experimental setup.

When pumping power above a threshold value (34 W) was introduced into the GFL, the first Stokes component of the SMBS was observed in the backscattered spectrum, shifted relative to the laser spectrum by 16 GHz, which agrees well with the experimental data for fused quartz.[3] Figure 2 shows oscillograms of the pumping pulses (a), SMBS (b), and the radiation passing through the GFL (c). It is evident that the pumping pulse is strongly deformed in passing through the GFL, which is related to the efficient transformation of pumping power in SMBS. The presence of a steep drop at the beginning of the pulse passing through the GFL is related to the leading edge of the SMBS pulse and marks the moment at which it is formed. Since the distance between these pulse fronts (≈ 390 ns) corresponds to the time for light to pass through the GFL, it may be assumed that the maximum SMBS efficiency occurs at the very beginning of the light guide. Aside from the pumping radiation, the radiation passing through the GFL includes the SMBS radiation reflected from the laser output mirror and secondarily entering into the GFL. This complicates the measurement of the efficiency of nonlinear transformation of pumping power into SMBS, which is equal to at least 65%.

Figure 3a shows photographs of the SMBS field, which was formed by the lens L_1 and was incident on a photodetector (OA_1), positioned at the location where the image

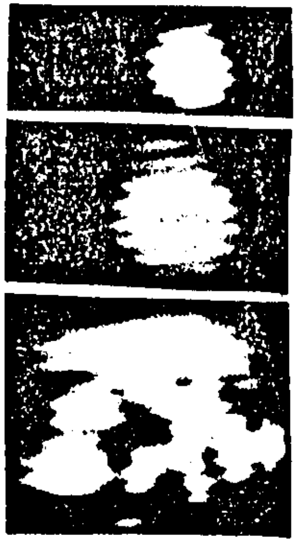


a

b

c

FIG. 2. Temporal characteristics of pumping (a), of SMBS (b), and of radiation passing through the lightguide (c).



a

b

c

FIG. 3. Photographs of SMBS (a) and laser (b) radiation and radiation passing through the lightguide with $P_i < P_{th}$ (c).

of the endface of the GFL forms, through the light-dividing plate (LP) (Fig. 1). Figure 3b shows the radiation field of the laser, obtained on the same stationary photodetector by rotating the LP by 90°. Figure 3c shows an image of the entrance endface of the GFL under conditions when ≈30-W laser radiation, was introduced through the lens L_2 into the GFL. In this case, the spotty structure of the field, which is related to interference of different groups of modes with different phase velocities, characteristic of a multimode GFL, is visible. In contrast to this case, the SMBS radiation has smaller divergence and its field is uniform over the cross section (the bands in all spots in Fig. 3 are caused by interference on the light-dividing elements). These facts show that the SMBS front, just as the pumping radiation front, is not phase distorted.

A similar phenomenon in this situation is possible only in two cases: 1) the SMBS is concentrated in the fundamental light-guide mode or 2) the phase of the backscattered wave is the conjugate of the phase of the pumping wave.[6] The optical analyzer (OA) allowed us to record the profile of the radiation fields investigated. It was established that the width of the profile of the SMBS field (Fig. 3a) is less than one-half of the corresponding computed quantity for the fundamental GFL mode. Thus, we relate the uniform backscattered field with inversion of the pumping wave front. The smaller size of the SMBS spot compared to the pumping spot is apparently related to the fact that the nonlinear transformation of the laser pumping radiation into SMBS radiation proceeds with a lower efficiency on the wings of a Gaussian beam.

The second proposition is supported by the following fact. When the direction of polarization of laser pumping radiation was rotated (a quarter-wave plate and polarizer P in Fig. 1) by nearly 180°, the SMBS field was also nearly linearly polarized and coincided with the azimuth of the pump polarization. Popovichev *et al.*[7] related the possibility of phase-front inversion with SMBS to a case in which the coherence length

of the pumping radiation is greater than the interaction length of the waves. A similar situation can be realized in our case, since, as we established, the SMBS process proceeds more efficiently at the beginning of the GFL.

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Translated by M. E. Alferieff
Edited by S. J. Amoretty

Muon-number nonconservation in models with Majorana neutrinos

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(Submitted 29 May 1982)
Pis'ma Zh. Eksp. Teor. Fiz. 36, 87–89 (5 August 1982)

The processes $\mu \to e\gamma$ and $e^+e^- \to \mu^+e^-$ in models with Majorana neutrinos of nonzero mass are examined, and their probabilities are calculated.

PACS numbers: 13.10. + q, 13.35. + s, 11.30.Er, 14.60.Ef

The possible existence of a Majorana neutrino of nonzero mass has recently been discussed widely in the literature. Renormalizability requires that the Majorana neutrino acquire a mass spontaneously, as a result of a spontaneous breaking of B-L symmetry.[1,2] The experimental consequences of this hypothesis, in particular, the existence and properties of a massless pseudoscalar particle—the Majorana—were discussed in Refs. 1, 2, and (in more detail) 3.

In this letter we are reporting some calculations of the probabilities for the processes $\mu \to e\gamma$ and $e^+e^- \to \mu^+e^-$ based on the models of Refs. 1 and 2. As will be seen

