Influence of saturation on the amplification of light in stimulated Brillouin scattering

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An investigation was made of an amplifier utilizing the stimulated Brillouin scattering under quasistatic conditions. The operation was considered as a function of the instantaneous power of the exciting radiation. The experimental results obtained for different input signals were in good agreement with the theory.

The most precise information on the stimulated Brillouin scattering can be obtained by investigating the development of this scattering in amplifiers.[1,2] The experimental results reported in [1,2] are in good agreement with the theoretical predictions. However, the investigations have so far been restricted to small signals and weak amplification when only a small proportion of the exciting light is scattered and, consequently, saturation is not reached. The present paper is concerned with the influence of the saturation on the amplification in the stimulated Brillouin scattering.

The apparatus is shown schematically in Fig. 1. The radiation of a ruby laser is split by a mirror M_1 into two beams. One is focused several times in a cell C_1 filled with gaseous methane. This gives rise to the stimulated Brillouin scattering and a very large proportion of the exciting light (up to 95%) is reflected in this process. The reflected light is formed, with the aid of a telescope T and an aperture A_1, into a signal with an almost plane wave front (the radiation which passes through the aperture has the diffraction divergence).

The second beam is used to pump an amplifier. Two pumping radiation beams reach an optical waveguide placed inside a methane cell C_2.[1)] The use of a waveguide ensures the constancy of the gain across the amplifier. A lens L at the waveguide input produces an image of a second aperture A_2, so that a measuring system S_2 records only that part of the pumping radiation which reaches the waveguide. The optical paths are selected to ensure that the signal and pumping radiation reach the amplifier simultaneously.

The ruby laser emits a single axial mode and the radiation power reaching the input of the cell C_2 may be up to 1 MW in the form of pulses of ~120 nsec duration (at mid-amplitude). The divergence of each pumping pulse is ~5 mrad; the angular separation between them is 23 mrad. The widths of the pumping and signal spectra are <30 MHz. The laser and cell C_1 are decoupled by an optical isolator in the form of the Faraday cell.

Photocells P_1 and P_2 record the pumping radiation at the input and output of the cell C_2. The signals produced by these cells are applied simultaneously to the horizontal and vertical deflection plates of a cathode-ray oscillograph O, producing an oscillogram of the dependence of the instantaneous radiation power P_0 transmitted by the cell C_2 on the power P_L at the entry to the cell. A similar recording system has been described in [4,3].

The input signal P_{in} can be determined as a function of the pumping power (Fig. 2) by placing the photocell P_2 in the position S_1 (Fig. 1). The lower part of the curve in Fig. 2 represents the leading edge of the pumping pulse and the upper curve the trailing edge. We can see that in a wide range of values of P_L the ratio $A = P_{in}/P_L$ is practically constant. In this way we can study the operation of an amplifier for a practically constant signal/pump ratio during a pulse. The ratio A can be varied by altering the transmission of two filters F_1 and F_2 (Fig. 1).

If $A = 0$, nonlinear processes do not develop in the amplifier and the dependence of P_0 on P_L is linear (Fig. 3). If $A > 0$, we find that—beginning from a certain pumping power—this dependence becomes nonlinear, which indicates the attainment of saturation. The branches of the oscillograms corresponding to the rising and falling pumping power lie close to one another. This shows that the amplification process is almost stationary. Figure 3 shows averages of the two branches. The deviations from these averages at the leading and trailing edges of a pulse are regarded as the experimental errors.

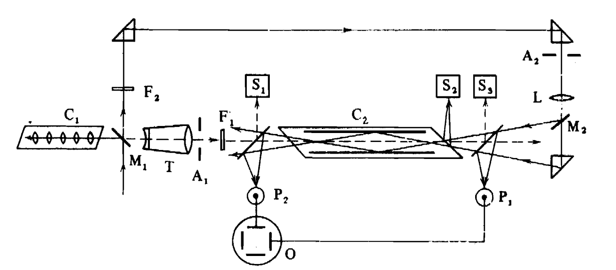
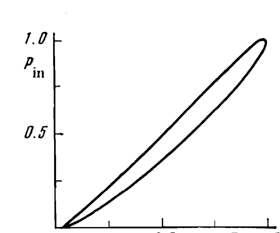


FIG. 1. Schematic diagram of the apparatus: M_1 and M_2 are dielectric-coated mirrors with transmissions of 65 and 50% at $\lambda = 0.694\ \mu$; C_1 is a cell with five lenses (Multiple focusing is used to reduce the stimulated Brillouin scattering threshold), the focal length of the first lens is 54 mm, the focal lengths of the other lenses is 27 mm, and the separation between the lenses is 108 mm; T is a telescope with fourfold magnification; A_1 is an aperture of 5 × 5 mm in size; A_2 is an aperture of 3 × 3 mm in size; F_1 and F_2 are filters; C_2 is a cell with a hollow glass waveguide, the cell windows are inclined at 45°, the cell is 96 cm long, the waveguide is 94 cm long and its cross section is 6 × 6 mm (the pumping radiation losses in the waveguide walls are ~ 10%); L is a lens of 37 cm focal length; P_1 and P_2 are photocells of the FÉK-0.9 type; O is an I2-7 oscillograph; S_1, S_2, and S_3 are, respectively, the systems used to measure the parameters of the input signal, pump wave, and amplified signal.

FIG. 2. Dependence of the power of the input signal on the pumping power. The maximum values of P_{in} and P_L are taken to be unity.



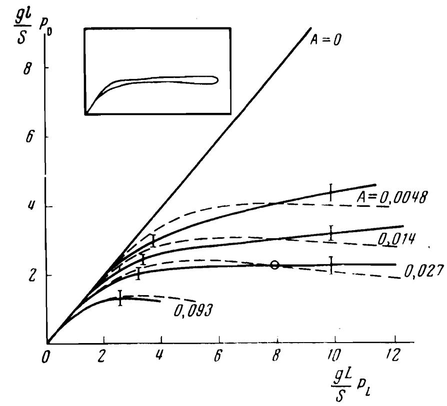


FIG. 3. Dependence of the instantaneous power transmitted by the cell C_2 on the instantaneous pump power. The continuous curves represent the experimental results and the dashed curves the calculations. An experimentally obtained oscillogram is shown in the top left-hand corner: the axes are the same as in the main part of the figure.

The steady-state problem of the interaction between the signal and pump waves in an amplifier is considered in [5]. The solution of this problem can be represented in the parametric form

$$P_L = \frac{\ln[\gamma + (\gamma - \gamma^2)/A]}{\gamma - A}, \quad P_0 = \gamma P_L. \qquad (1)$$

Here, the parameter γ varies within the limits $0 < \gamma \leq 1$ and the power is measured in units of S/gL, where S is the area of the signal and pump beams and L is the amplifier length.[2)] The dashed curves in Fig. 3 are plotted on the basis of Eq. (1).

In our experiments the absolute power was not measured very accurately (~30%). Moreover, errors could have been made in the determination of g. Therefore, the scales of the experimental dependences (Fig. 3) were selected so that one of them coincided with the theoretical dependence (at the point indicated by a circle). A satisfactory agreement between the theoretical and experimental results was obtained in this way. Some discrepancy could be explained by the fact that the theoretical analysis was carried out for plane signal and pump waves.[3)] Therefore, we concluded that Tang's theory[5] describes correctly the saturation conditions in the stimulated Brillouin scattering.

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[1)]The methane in both cells is kept at room temperature at a pressure of 115 atm. Under these conditions the gain because of the stimulated Brillouin scattering is $g \approx 0.08$ cm/MW and the width of the gain line is ≈ 20 MHz [3].

[2)]It should be noted that the signal gain in the absence of saturation is equal to $\exp(P_L)$, where P_L is measured in the units just defined.

[3)]In our experiments only the signal wave was plane (over the whole length of the amplifier).

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