Wave-front inversion of weak optical signals with a large reflection coefficient

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The possibilities of a large (up to $\sim 10^5$) increase of the reflection coefficient of weak signals as a result of their wave-front inversion in nonlinear media are determined. Saturation effects, in which the intensity of the inverted wave depends weakly on the intensity of the incident signal and is determined primarily by the pumping intensity, were observed.

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I. Investigation of the possibilities of wave-front inversion (WFI) of very weak signals with a large reflection coefficient R is important both for the identification of the physical features of nonlinear processes that serve as the basis of the WFI effect and also for using this effect in scientific and applied studies, such as the diagnostics of an object in terms of its light scattering capabilities or thermal radiation. Development of reversing mirrors with high R values will also make it possible to greatly simplify the systems that produce high-power optical radiation.

However, the self-excitation due to the development of instabilities as a result of parametric mixing of light waves hinders the attainment of a high sensitivity and large reflection coefficients with WFI. This is apparently the primary reason for the fact that in almost all processes based on the parametric mixing of light waves the maximum achievable R values have not exceeded a few units[1,2] [$R<1$ for WFI in a mirror based on Mandel'shtam-Brillouin stimulated scattering (MBSS)].[3,4] The experiments,[5] where the value of $R \approx 10^2$ was obtained by means of a tunable laser that tuned the radiation frequency to resonance with the natural frequency of sodium

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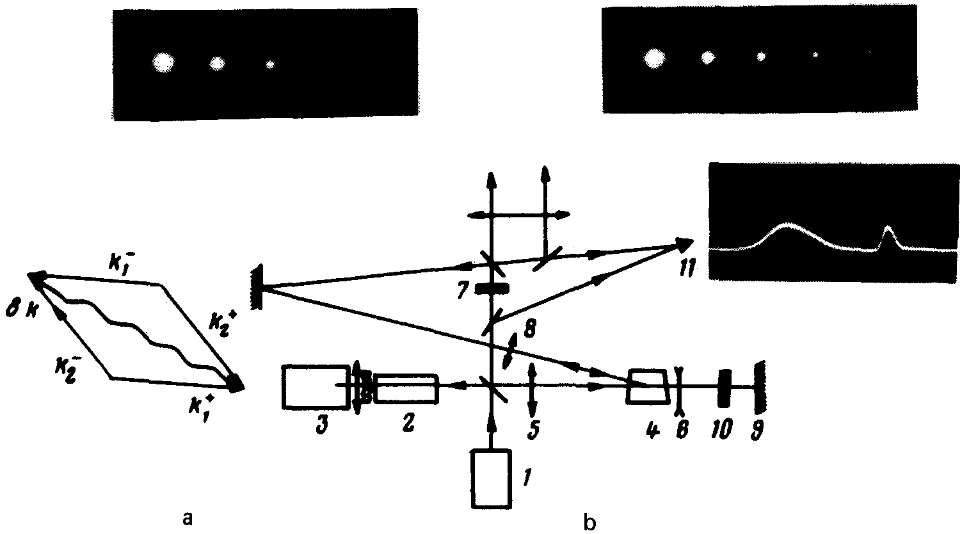

FIG. 1. Experimental setup. The angular spectrum was recorded by using a mirror wedge.

vapor (D line, $\lambda = 0.59\ \mu m$), are the only exception.

This paper presents the results of experimental studies of the WFI process in which it was possible, by means of a significant decrease of the level of the start-up instabilities to a value that is determined only by the thermal noise in the interaction band, to reduce the energy of the signals that are inverted and to obtain the reflecttion coefficient $R \geqslant 10^5$, i.e., many times greater than the values achieved previously. These results were obtained by using a four-photon combination interaction, in which the WFI was accomplished by the scattering into Stokes satellites of the high-power pumping ξ_1^+ by a hypersonic wave, which was excited by a weaker counter pumping ξ_1^- and which was inverted by a signal wave ξ_2^+ with an anti-Stokes (with respect to pumping) frequency shift (Fig. 1a). The operating efficiency of the reversing mirror, which is based on this process, depends slightly on the average frequency of the optical radiation; therefore, it can be used within a broad wavelength range.

II. The experimental setup is shown in Fig. 1b. The single-mode beam of a phosphate-glass neodymium laser 1 (pulse length, 33 nsec) with a Faraday isolation was split into two beams (diameter $d_0 = 0.5$ cm), one of which, after amplification in the amplifier 2 and WFI in an acetone MBSS mirror 3, served as one of the pumps of the four-photon mirror 4, which is located inside the telescope comprised of lenses 5 and 6 (the diameter of the pumping beams in the cell 4 is $d_1 = 0.15$ cm). The other beam, after attenuation by the filter 7 and an optical delay, was focused by lens 8 ($F = 133$ cm) and entered the cell 4, which was filled with acetone (cell length $L = 3$ cm), simultaneously with the pumping beam at an angle of 1.5×10^{-2} radian. This beam served as the anti-Stokes (with respect to pumping) signal wave ξ_2^+, which, together with the counter-pumping beam ξ_1^- that was reflected from the glass plate 9 and

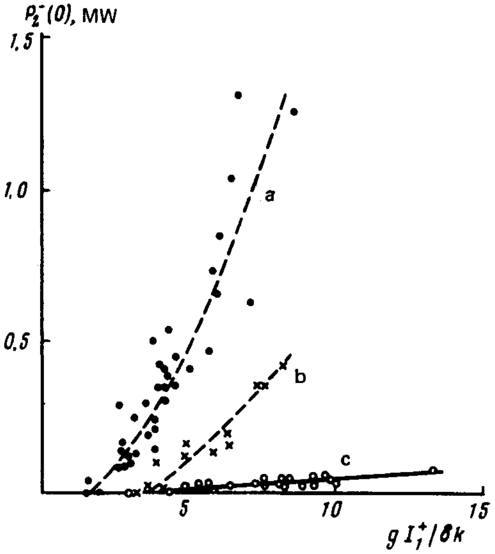

FIG. 2. Dependence of inverted-wave power $P_{2(0)}^-$ on pumping intensity I_1^+ for a constant signal-wave power $P_{2(0)}^+$ (a $-P_{2(0)}^+ = 130 \pm 50$ W, b $-P_{2(0)}^+ = 1.5 \pm 0.3$ W, and c – noise-radiation power for $P_{2(0)}^+ = 0$); g is the MBSS increment in acetone, normalized to unit length and unit intensity, $\delta k = 4\pi\Delta\nu$ is the wave detuning, and $\Delta\nu = 0.09$ cm^{-1} is the MBSS shift in acetone.

attenuated by a factor of about 400 during the two passes through the filter 10, produced a hypersonic wave. Scattering of the high-power pumping beam ξ_1^+ by this wave excited the inverted wave ξ_2^+. Polarization isolation (not shown in Fig. 1) was used to prevent MBSS of the counter pumping ξ_1^- in the cell 3.

The duration of the scattered pulse, which was shorter than the signal-wave pulse, was ~12 nsec (Fig. 1b). The peak power $P_{2(0)}^-$ of the wave that was reflected from the four-photon mirror and the reflection coefficient $R = P_{2(0)}^-/P_{2(0)}^+$ had a clearly defined threshold dependence on the pumping intensity I_1^+ for a constant power $P_{2(0)}^+$ of the weak output signal (Figs. 2 and 3).

It can be seen in Fig. 2 that at a sufficiently high pumping intensity the power of the inverted signal $P_{2(0)}^-$ decreases by a factor of only 4–5 as the incident signal power $P_{2(0)}^+$ decreases from 130 W to 1.5 W. The maximum conversion coefficient of high-power pumping into the inverted wave was ∿10%, which is severalfold greater than the ratio of the cross sections of the signal wave ξ_2^+ and the pumping ξ_1^+ beams. This indicates that the four-photon interaction process is saturated because of depletion of the ξ_1^+ wave in the region of its overlapping with the incident ξ_2^+ wave and the inverted ξ_2^- wave.

In the conducted experiments the divergence of the wave striking the four-photon mirror, which was close to the diffraction limit, was equal to 1.5×10^{-4} rad (Fig. 1). The angular spectrum of the inverted wave consisted of a diffraction lobe with a divergence of 2×10^{-4} (Fig. 1).

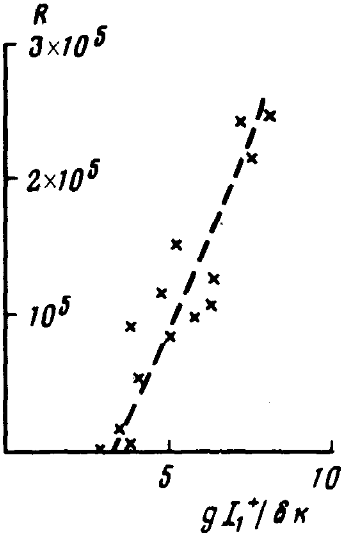

FIG. 3. Dependence of the reflection coefficient R of a four-photon mirror on the pumping intensity I_1^+ for a constant signal-wave power $P_{2(0)}^+ = 1.5 \pm 0.3$ W

III. In the absence of the signal wave ξ_2^+ the noise radiation of the four-photon mirror, whose power depended in a threshold manner on the pumping intensity (see solid curve in Fig. 2a), was observed at the useful signal-recording angle ($\sim 10^{-2}$). This radiation originates from the MBSS in the field of the two bucking pumping waves ξ_1^+ and ξ_1^-. It is interesting to note that when the pumping ξ_1^- was shut off under the normal SS conditions, the noise-radiation power increased markedly. This indicates that a weak counter pumping reduces the MBSS intensity of the high-power pumping ξ_1^+.

Because of the noise radiation, the reflection of the useful signal from the four-photon mirror was detected with certainty only when the power P_2^+ of the incident ξ_2^+ wave was greater than a minimum value P_{2m}^+. The power P_{2m}^+ increased with increasing intensity of the pumping ξ_1^+ and reached a value of $P_{2m}^+ \approx 0.1$ W for the parameters $gI_1^+/\delta k \approx 10$–$12$. The largest value, $R \approx 7 \times 10^5$, was obtained in our experiment when the incident-signal power $P_2^+ = 0.4$ W exceeded the P_{2m}^+ value by only several factors.

The increase of P_{2m}^+ with an increase in $gI_1^+/\delta k$ is due to the difference in the radii of the inverted beam ξ_2^- and the noise-radiation beam. This difference does not play an important role in the unsaturated regime. Under saturation conditions, however, the relatively wide noise-radiation beam can have a larger integrated power than the narrower, high-intensity beam of the inverted wave. Therefore, to obtain the smallest possible values of P_{2m}^+, we must use relatively wide signal-wave beams or realize the conditions under which the saturation effects are unimportant. It must be kept in mind, however, that the pumping-intensity level in the range of parameters, where the saturation effects are missing with respect to the input signal, must be maintained constant with a high accuracy for stable recording of the energy characteristics of the inverted wave in different experiments.

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