PHASE CONJUGATION BY STIMULATED BRILLOUIN SCATTERING IN HEXANE

[1]Zaitsev G.I., [2]Kolesnikov G.I.

[1]Kuzbass state technical university of T.F. Gorbachev, Kemerovo, e-mail: geniz@kemcity.ru;
[2]Kemerovo state agricultural institute, Kemerovo, e-mail: ksai@ksai.ru

In the work there is described laser facility, which consists of master oscillator with neodymium glass, quantum amplifier and radiation frequency doubler. High-quality single-frequency radiation at 530 nm wave length with regulated power was used for examination of frequency and energy characteristics of stimulated Brillouin scattering (SBS). With the help of Michelson interferometer and high-speed recording equipment with the method of light heterodyning there was examined the quality of phase conjugacy by SBS in hexane. It was showed that backward scattered wave consists of inverse and non-inverse components, relation between them can be changed either with wave pump power or its phase strong distortion. It turned out that temperature changes in the frequency component of the MB in stimulated scattering are less than in spontaneous thermal scattering.

Keywords: stimulated scattering, phase conjugacy, heterodyning

Introduction. Stimulated light scattering is a process of non-linear interaction of light waves with modes of intrinsic motion environment, at the result of which the intensity of powerful exciting wave decreases and the intensity of weak scattered wave increases. Stimulated light scattering is accompanied with the wave front inverse. In this work there were examined energy and frequency characteristics of stimulated Brillouin scattering (SBS) and there was found out their connection with wave font reversal (WFR).

Experimental facility for SBS study. Experimental facility consisted of single-frequency laser and Michelson interferometer, which served for carrying out and registration of beatings of light waves that are scattered in reference and signal channels.

Laser represented the master oscillator, which was producing light at $\lambda = 1060$ wave length, quantum doubler and frequency doubler. Master oscillator consisted of neodymium glass rod (Fig. 1), concave mirror M_1, exit flat mirror M_2, which was combined with longitudinal-mode selector, diaphragm D, eliminating undesirable transverse mode. The crystal of lithium fluoride with F^{2+} color centers was put inside for the modulation of laser resonator's quality. Light impulse in the generator with the help of prisms P_1 and P_2 was directed to three-pass amplifier, which was made like master oscillator (only elements for modulation of quality and mode selection were absent). So that generator's work wasn't be influenced by superluminescence of amplifier, there was set one more modulator of lithium fluoride between these prisms. After the amplification, light impulse got onto *KDP* crystal, where the radiation transformed into second harmonic with $\lambda_2 = 530$ nm. So that fundamental radiation didn't get into register part of facility, on the way of laser impulse there was put the blue-green light filter. Frequency doubler had one more important role, because of it the laser got undone from the radiation of stimulated scattering, what didn't allow wave of SBS strengthen manyfold in generator.

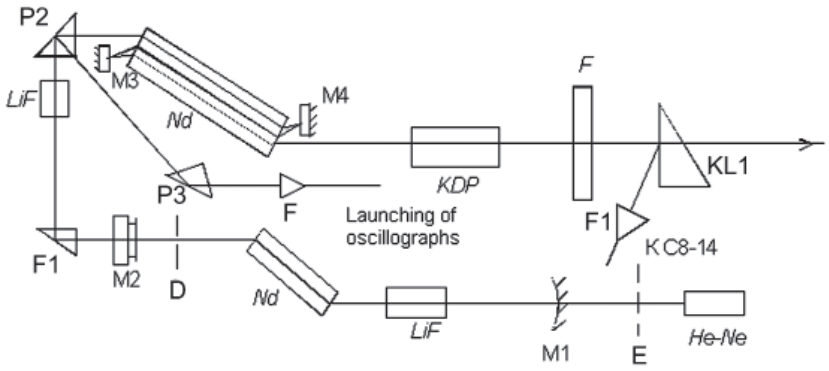


Fig. 1. Optical scheme of single-frequency of neodymium laser with frequency doubler:
Nd – active element; M1–M4 – mirrors; P1–P3 – riqht-anqle prisms; LiF – crystal of lithium fluoride; KDP – radiation frequency doubler; F – light filter; He–Ne – laser alignment; F and F1 – photocells; KL1 – wedge-shaped glass plate; D – diaphragm; E – sceen

Initial radiation at λ = 1060 nm wave length had regulated energy from 10 to 240 megajoule, duration of impulse at half-height – about 30 ns and divergence not more that 0,5 millirad. The coefficient of primary emission's transformation into second harmonic was about 15%. With the help of photoelement F1 and storage oscillograph C8-14 there were controlled the time dynamics and the energy of exciting radiation.

For analysis of energy and phase-frequency characteristics of scattered radiation there was used the method of heterodyning at the base of Michelson interferometer (Fig. 2).

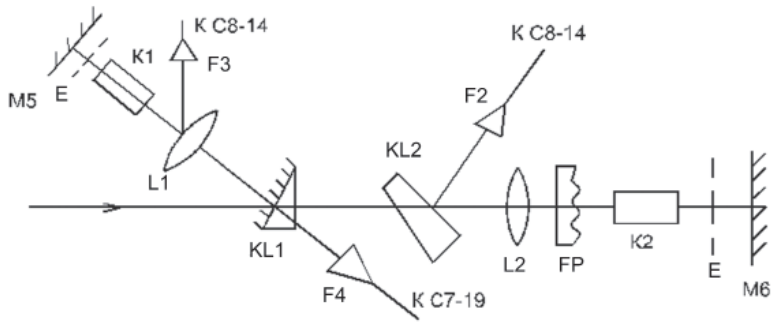


Fig. 2. Optical scheme of examination of spectral, energy and phase-frequency characteristic of SBS experiment: K1, K2 – cells with hexane; L1, L2 – lens (F = 50 cm); FP – phase plate; K1, K2 – wedge-shaped glass plates; F2–F4 – coaxial photocells; E – screens for tuning;M5, M6 – mirrors

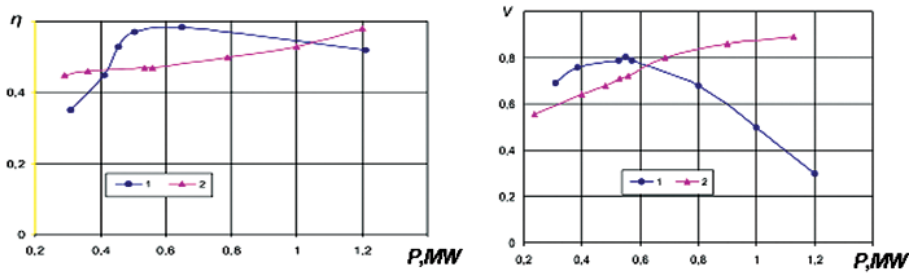
Radiation of second harmonic was divided with semitransparent wedge KL1 into two beams of approximately equal intensity, then each of them was focused with corresponding lens on the cell with hexane, where SBS arose and propagated backward at the angle of 180°. After second KL1 reflection it was mixed at the F4 detector with pass band of 5 GHz and registered with high-speed storage oscillograph C7-19. As the reference beam while heterodyning there was used SBS, excited with collimated pump beam in the cell of hexane K1 at 20°C temperature. Pump beam was focused on the cell with Л1 lens and controlled with photoelement F3 and oscillograph C8-14. Signal beam while heterodyning represented SBS radiation, which appeared in the K2 cell of hexane as well, but at 35°C temperature. Radiation was focused with L2 lens here. Signal impulse was controlled with photoelement F2 and oscillograph C8-14. Scans of all oscillographs were released with single signal from photodetector F (see Fig. 1): one light impulse of master generator allowed to register four signals simultaneously: pump wave signal (F1), SBS at reference (F3) and signal (F2) channels and signal on their residual frequency with photodetector (F4). Initial phases of signals were equalized with cable delay lines of corresponding length.

Experiment was carried out in the following way. Hexane in both arms of interferometer was initially room-temperature. In these conditions photodetector registered smooth impulse of SBS radiation. When heating the hexane in K2 cell the frequency of SBS decreased, and there arose the signal as beatings at residual frequency of SBS in the photodetector F4, these beatings were coming from reference and signal channels. From oscillograms there were evaluated the frequency of beatings Δυ, as value reciprocal to time interval, which separate two contiguous minimums, and the visibility $V = (I_{max} - I_{min})/(I_{max} + I_{min})$. Here I_{min} is an average value of minimums' intensity, these minimums are situated to the right and to the left of corresponding maximum. Error of beatings' frequency measurement didn't exceed 5%, error of visibility measurement didn't exceed 10%. The coefficient of transformation of peak power of laser radiation P into peak power of SBS in both channels P_i ($i = 1, 2$) was evaluated with formula $\eta = P_i k_i / P$. Here k_i is the value, which takes into consideration the inequality of wave pump intensity at reference and signal channels. The value η was evaluated up to 6% accuracy.

Results of research and their discussion

According to a theoretical work [1] the coefficient of transformation is bound to tent to one when pump power increasing. The dependence of transformation coefficient η on laser radiation power, gotten during our experiment, is shown on Fig. 3.

It's obvious that in the whole examined interval of pump power value $\eta < 1$. In K2 cell there appeared SBS radiation directed towards pump wave. It contained both inverse (coherent) and non-inverse components of SBS. Inverse component propagated only backward into solid pump beam corner of 0,5 millirad, non-inverse propagated into the whole aperture of recording system.



a b

Fig. 3. Dependence of laser radiation transformation into SBS wave coefficient (a) and visibility of beating (b) on the pump power: 1 – ideal pump; 2 – speckle-structure

The same was observed in the reference channel. If radiation of SBS in it is diaphragmed in the way that photodetector has only inverse radiation passing and then mix it with signal wave, it will become possible to judje the quality of wave reversal by the visibility of beatings. How visibility of beatings changes with pump power increasing is shown at Fig. 3b. Comparing to Fig. 3a it can be observed that gain saturation of SBS is accompanied with quality of phase conjugacy deterioration, fraction of inverse component decreases, causing decrease of beatings' visibility. An analogous regularity was registered in work [2].

But the quality of phase conjugation by SBS at the signal channel can be considerably increased, if the pump wave passes through phase (matt) plate before the input to cell. In that case pumping case become heterogeneous and stokes wave of SBS acquire the structure, which is more accurately reversed to pump wave speckle-structure. This wave has primary amplification, other waves discriminate by means of lesser amplification. At Fig. 3a there is shown the dependence of transformation coefficient η on pump power in these conditions. It's obvious that with the same power the deep SBS saturation isn't reached, and the visibility of beatings at Fig. 3b, in contrast to previous case, increases. Thereby if pump wave has speckle-structure, the quality of phase conjugation by SBS increases, but the saturation of transformation coefficient apparently happens with higher power. It should be noted that visibility of beatings had equal value within the limits of whole impulse duration, it concerns all examined values of pump power with phase plate.

The difference of frequencies ν_{20} and ν_{35} relatively to pumping frequency $\Delta\nu = \nu_{20} - \nu_{35}$ was determined from the oscillograms of beatings, which appear while heterodyning of SBS radiation from the cells of hexane with temperatures of 20 and 35°C. It was gotten as $\Delta\nu = 1/\Delta t$, where Δt is time between two contiguous minimums at oscillogram. Measurements showed that $\Delta\nu$ depends neither on pump power, nor on presence of phase plate on radiation way. Within the limits of whole impulse duration $\Delta\nu$ was constant and equal 261 ± 10 MHz. This value can be calculated on the basis of the fact that movement of SBS components relatively to pump frequency [5] is formed with the sound spreading speed υ, with the index of medium refraction n, with the scattering angle θ and with the length of exciting light wave λ: $\nu = 2\lambda^{-1}n\upsilon sin(\theta/2)$. As both values υ and n do not depend on medium temperature, then ν_{20} and ν_{35} will be different. Taking into consideration, that during our experiment SBS was excited with the light of wave length of λ_2 = 530 nm and was examined at an angle of θ = 180°, the shift of SBS frequencies within 20 and 35°C can be written: $\Delta\nu = 2\lambda_2^{-1}(n_{20}\upsilon_{20} - n_{35}\upsilon_{35})$.

Using literature information for hexane [4,6]: n_{20} = 1,3742 and n_{35} = 1,3661 (at the wave length of 546 nm); υ_{20} = 1098 m/s, υ_{35} = 1032 m/s, we get the value $\Delta\nu$ = 374 MHz, what is 113 MHz higher than experimental. Such discrepancy of experimental and calculating results in this case cannot be explained only by linear light absorption, as it is suggested in work [2]. Apparently, other non-linear optical effects have influence on the scattering process [3].

References

1. Bogachev V.A., Kochemasov G.G., Starykov F.A. Phase conjugation by SBS of focused laser speckle-beam.// Quantum electronics. – 2008. – Vol. 38. – № 9. – P. 849–854.

2. Grygoryev S.F., Zaskalko O.P., Kuzmin V.V. Features of SBS at light absorbing mediums // JETP. – 1987. – Vol. 92. – № 3. – P. 1246–1251.

3. Dmytriev V.G. Non-linear optics and phase conjugation. – M.: Science, 2003. –165 p.

4. Zotov V.V., Neruchev U.A., Otpushennikov N.F. Experimental research of temperature dependence of sound speed at some organic liquids// Ultra-sound and physical-chemical properties of substances. – Kursk: KSTI, 1969. – Vol. 54. – P. 25–35.

5. Fabellinskyi I.L. Selected works in 2v. – M.: Physmathlit, 2005. – Vol. 2. – 503 P.

6. Physical values: Reference book / Babychev A.P. [and others] – M.: Energoatomizdat, 1991. – 1232 p.