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MULTIDIMENSIONAL THEORETICAL/COMPUTATIONAL MODELING OF NON-COAXIAL SBS

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Final report

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Abstract

In this report computational model of transient transverse stimulated Brillouin scattering in anisotropic crystals and computational code based on this model are described. Some calculational results for angular distribution of gain coefficients and temporal growth of parasitic transverse Stokes radiation are also described.

Introduction

The main way of improving efficiency of high-power laser facilities for ICF is increasing of flux density of laser radiation in the end part of amplifier chain. As it became clear last years transverse stimulated Brillouin and Raman scatterings (TSBS and TSRS) may cause serious difficulties on this way / 1,2,3,4 /. Besides energy losses transverse SS can lead also to optical elements damage / 5 /.

One of the most dangerous points in the amplifier chain is in this respect crystal-converter into the third harmonic of fundamental frequency. First of all it is one of the points with highest radiation intensity and second is that this crystal is exposed to the third harmonic radiation for which gain coefficient of stimulated scattering (SS) is maximal. This is why investigation of transverse SS in this crystal is of special interest.

In this report computational model of transient transverse stimulated Brillouin scattering in anisotropic crystals and computational code based on this model are described. Some calculational results for angular distribution of gain coefficients and temporal growth of parasitic transverse Stokes radiation with and without phase modulation of pump radiation are also described.

1. Physical model

1.1 General scheme

Direct numerical modeling of the stimulated Stokes radiation field for transverse scattering seems to be impossible due to absence of angle selection and necessity to take into account whole range of propagation directions angular spectrum. Characteristic spatial scale of field variations is in this case on the order of wavelength. This was the reason why as a base of modeling was taken one-dimensional calculation of Stokes wave propagation along the given direction. Pump saturation is not taken into account because it would require knowledge of Stokes amplitudes in the whole bulk of optical element and for all propagation directions. Nevertheless simultaneous evolution calculation of several dozens Stokes rays seems to be desirable. If these rays converge to one common point onto the side surface of optical element this would allow to take into account diffuse interscattering between them which can play an important part in the determining of SBS threshold. To do this one must include in the model rays propagating from the common vertex as well as those propagating to it.

Field amplitude in one-dimensional equations is considered usually as amplitude of the wave propagating in some solid angle $\Delta\Omega$ which is defined by experimental conditions. In our case it is the angle for which angular components of Stokes wave are amplified coherently and therefore their amplitudes rather than intensities are summed up. One can estimate this angle from the condition that Stokes shifts for rays inside $\Delta\Omega$ must lie in the limits of spontaneous Brillouin scattering line. Here we neglect the possibility of stimulated coherentization at high pump intensities. This estimate gives:

$$\Delta\Omega \approx \left(\gamma \big/ k_p v_{s\,ph} \right)^2 \qquad (1)$$

where $\gamma = 1 \big/ \tau_{ph}$ - hypersound damping coefficient, k_p - wave number of pump wave, $v_{s\,ph}$ - sound phase velocity. Characteristic value of $\Delta\Omega$ for $\gamma \approx 3 \cdot 10^8 \text{ns}^{-1}$, $k_p = 3.6 \cdot 10^5 \text{cm}^{-1}$, $v_{s\,ph} \approx 5 \cdot 10^5 \text{cm / sec}$ is $\Delta\Omega \approx 3 \cdot 10^{-6}$ ster. Corresponding linear angle is $\Delta\varphi \approx 2 \cdot 10^{-3}$, this value corresponding to geometrical site angle for Stokes ray of length 40 cm and diameter 0.04 cm. Diffraction length for such a ray will be $L_d \approx 80$ cm and this exceeds the aperture dimension of pump beam. Thus, the scheme of one dimensional Stokes rays is self-consistent: firstly for rays of half millimeter diameter one may neglect diffraction, and secondly Stokes angular components propagating in the limits of geometrical angle of this ray are amplified coherently. Noise source amplitude in the equation for hypersound amplitude is determined from the requirement that calculated spontaneous scattering is equal to experimentally observed in the limits of angle considered.

General model scheme is as follows. Transient transverse SBS in the uniaxial crystal is considered in the given pump field. Optical element is supposed to have rectangular shape. Stokes rays are defined as a cone originating from some point at the side surface. For each ray Stokes waves are considered propagating both to the common vertex and in the opposite direction. Rays are arranged in hexagonal rings homogeneously filling the cone of given angle. Possibility is taken into account of Stokes rays reflecting from face surfaces of crystal and scattering at its side surface. At the cone vertex given scattering diagram is taken into account in some simple model. Boundary conditions at the opposite rays ends are those of reflecting with given reflection coefficient and phase modulation caused by Stokes shifts difference for wave propagating to the cone vertex and wave of opposite direction. Phase modulation caused by relative Stokes shifts difference is taken into account also for reflection from face surfaces and scattering at side surface.

When formulating initial conditions for the task, Stokes wave polarization (ordinary or extraordinary) and hypersound mode (quasilongitudinal, fast quasitransverse or slow quasitransverse) must be indicated. Without this specification six Stokes waves instead of one must be considered for each propagation direction. Meanwhile, for one of Stokes waves which corresponds usually to quasilongitudinal sound mode and Stokes polarization correlating with pump polarization, SBS gain coefficient is substantially (two - three times) grater than for others. It is this wave which amplitude will grow most quickly and which is therefore most dangerous. For comparison, calculation can be fulfilled for other polarization's and sound modes.

To model evolution of Stokes radiation, one dimensional non-stationary equations for slow envelops of Stokes wave and hypersound wave are used. Hypersound wave equation is considered to be local (space derivative is not taken into account). and includes noise source. Pump amplitude definition includes space intensity profile and temporal pulse profile. Pump amplitude can be modulated in phase. Besides this temporal shifts of different aperture sections can be defined which model artificial transverse decoherentization of the pump beam.

1.2 SBS equations in anisotropic medium

Wave equation for light field is

$$\frac{1}{c^2}\frac{\partial^2\vec{D}}{\partial t^2}+rot\,rot\vec{E}=-\frac{4\pi}{c^2}\frac{\partial^2\vec{P}_{NL}}{\partial t^2} \tag{2}$$

where $D_i = \varepsilon_{ij} E_j$,

$P_{iNL} = \dfrac{\Delta\varepsilon_{ij}}{4\pi} E_j$ - nonlinear polarization,

$\Delta\varepsilon_{ij}$ - strictional refractive index modulation,

$$\Delta\varepsilon_{ij} = -\varepsilon_{il}\Delta\beta_{lm}\varepsilon_{mj} \quad (\beta_{ij}\cdot\varepsilon_{jk} = \delta_{ij}) \tag{3}$$

Inverse refraction index modulation is connected with medium deformations by relationship

$$\Delta\beta_{ij} = p_{ijlm}\frac{\partial u_l}{\partial x_m} \tag{4}$$

where u_i - is displacement vector, and elasto-optical coefficients tensor p_{ijlm} must include besides usual symmetric also antisymmetric part which arises from medium element rotations / 6,7 /:

$$p_{ijlm} = p_{ij(lm)} + p_{ij[lm]}$$
$$p_{ij[lm]} = \frac{1}{2}(\beta_{im}\cdot\delta_{jl} + \beta_{jm}\cdot\delta_{il} - \beta_{il}\cdot\delta_{jm} - \beta_{jl}\cdot\delta_{im}) \tag{5}$$

Medium displacements obey sound wave equation:

$$\rho\frac{\partial^2 u_j}{\partial t^2}+\eta_{ij}\frac{\partial u_j}{\partial t}-c_{ijkl}\frac{\partial^2 u_l}{\partial x_j \partial x_k}=f_i \qquad (6)$$

Here u_i - displacement vector,

ρ - density,

c_{ijkl} - elasticity tensor,

η_{ij} - effective viscosity tensor,

f_i - driving force

In case of SBS f_i is strictional pressure which volume density is / 8 /

$$f_i=\frac{\partial\sigma_{ij}}{\partial x_j};\quad \sigma_{ij}=\frac{1}{8\pi}p_{klij}D_k D_l \qquad (7)$$

Modes structure of sound waves can be found from eigenvalue problem / 9 /

$$\Gamma_{ij}p_j=\rho v_s^2 p_i \qquad (8)$$

where p_i polarization vector of sound wave,

$\Gamma_{ij}=c_{iklj}m_k m_l$ - first Christoffel tensor,

$m_i=q_i/|\vec{q}|$ - vector of unity length in the propagation direction,

$v_{s\,ph}=\Omega/|\vec{q}|$ - phase velocity which is found from (8) together with polarization vector for given mode.

Introducing as usual in equations (2) and (6) slow complex envelops for pump, Stokes and sound waves

$$E_i^{\,p}=\frac{1}{2}\left(E^p e_i^{\,p}\exp\left(i\left(\omega_p t-\vec{k}_p\vec{r}\right)\right)+\kappa.c.\right)$$

$$E_i^{\,s}=\frac{1}{2}\left(E^s e_i^{\,s}\exp\left(i\left(\omega_s t-\vec{k}_s\vec{r}\right)\right)+\kappa.c.\right) \qquad (9)$$

$$u_i=\frac{1}{2}\left(Up_i\exp\left(i\left(\Omega t-\vec{q}\vec{r}\right)\right)+\kappa.c.\right)$$

we get equations

$$\frac{\partial E_p}{\partial t}+\frac{\left[\vec{e}_p\left[\vec{k}_p\vec{e}_p\right]\right]}{\frac{\omega_p}{c^2}\left(\vec{e}_p\hat{\varepsilon}\vec{e}_p\right)}\vec{\nabla}E_p=\frac{\omega_p q}{4\left(\vec{e}_p\hat{\varepsilon}\vec{e}_p\right)}RE_sU$$

$$\frac{\partial E_s}{\partial t}+\frac{\left[\vec{e}_s\left[\vec{k}_s\vec{e}_s\right]\right]}{\frac{\omega_s}{c^2}\left(\vec{e}_s\hat{\varepsilon}\vec{e}_s\right)}\vec{\nabla}E_s=\frac{\omega_s q}{4\left(\vec{e}_s\hat{\varepsilon}\vec{e}_s\right)}RE_pU^* \qquad (10)$$

$$\frac{\partial U}{\partial t}+\frac{\langle\eta\rangle}{2\rho}U+\frac{1}{v_{s\,ph}}\frac{P_{kj}m_j}{\rho}\frac{\partial U}{\partial x_k}=-\frac{q}{16\pi\Omega\rho}RE_pE_s^*$$

where $P_{ij}=c_{ikjl}p_l p_l$ second Christoffel tensor,

$R=p_{lmnk}\varepsilon_{il}\varepsilon_{mj}p_n m_k e_j^{\,s}e_i^{\,p}$ - factor including elasto-optical characteristics of the medium and main part of anisotropy properties,

$\langle\eta\rangle=p_i\eta_{ij}p_j,\quad \left(\vec{e}\varepsilon\vec{e}\right)=e_i\varepsilon_{ij}e_j$

As it was already mentioned pump field is considered to be unsaturated so first equation of (10) is not used. In the sound equation we neglect spatial derivative. Normalizing besides this amplitudes E_s and U so that $|E_s|^2 = I_s$, where I_s - Stokes wave intensity, and in the right-hand-side of equation for Stokes amplitude figured stationary SBS gain coefficient, and adding in the right-hand-side of sound equation stochastic force, we come finally to equations which are integrated in the model of transverse SBS

$$\begin{aligned} &\frac{\partial E_s}{\partial s} + \frac{1}{w_s}\frac{\partial E_s}{\partial t} = \frac{g}{2}E_p U^* \\ &\frac{\partial U}{\partial t} + \gamma U = \gamma E_p E_s^* + \xi \end{aligned} \tag{11}$$

here $\gamma = \langle \eta \rangle / 2\rho$ sound damping coefficient,

$$w_s = \left| \frac{\left[\vec{e}_s\left[\vec{k}_s\vec{e}_s\right]\right]}{\frac{\omega_s}{c^2}\left(\vec{e}_s\hat{\varepsilon}\vec{e}_s\right)} \right|$$ - ray velocity of Stokes wave,

$$g = \frac{q\omega_s R^2}{4\gamma\rho v_{sph} c^2 n_s n_p \cos\gamma_s \cos\gamma_p}$$ - stationary SBS gain coefficient,

$\cos\gamma = \left\|\left[\vec{e}\left[\vec{n}\vec{e}\right]\right]\right\|$ - cosine of anisotropy angle, $\vec{n}$ - direction of wave normal, $\vec{e}$ - polarization vector of electric field.

Spatial derivative in the first equation (11) is calculated along the ray velocity direction.

1.3 Reflection calculation from crystal face surfaces

1.3.1 Calculation of secondary waves directions

Rays of cone considered may in general intersect face surfaces of crystal. In this case calculation of secondary waves directions and reflection coefficients must be provided. First directions of secondary waves are calculated: wave in the isotropic medium and two waves in the anisotropic medium, ordinary and extraordinary. If incident wave has refraction vector $\vec{m}_0$ ($\vec{m}_0 = n \cdot \vec{n}$, where n - refraction index for incident wave and $\vec{n}$ - wave normal vector) then directions of secondary waves are defined by requirement that their refraction vectors had the same tangential components as $\vec{m}_0$. For wave in the isotropic medium and ordinary wave in the crystal from this requirement we obtain

$$m_\perp = \sqrt{n^2 - m_{0t}{}^2} \tag{12}$$

where $m_\perp, m_{0t}$ - normal and tangential components of $\vec{m}$. If $|m_{0t}| > n$ then refraction vector becomes complex and corresponding wave is inhomogeneous. For extraordinary wave equation of normals can be written in the form [9]

$$\vec{m}_e \hat{\varepsilon} \vec{m}_e = \varepsilon_o \varepsilon_e \tag{13}$$

Substituting refraction vector in the form $\vec{m}_e = \vec{m}_{0t} + x \cdot \vec{q}$ where $\vec{q}$ - normal to the surface into the eq. (15) we get second order equation for x:

$$\begin{aligned} &Ax^2 + 2Bx + C = 0 \\ &A = \varepsilon_o + (\varepsilon_e - \varepsilon_o)(\vec{q}\vec{c})^2,\ B = (\varepsilon_e - \varepsilon_o)(\vec{m}_{ot}\vec{c})(\vec{q}\vec{c}), \\ &C = \varepsilon_o m_{ot}{}^2 + (\varepsilon_e - \varepsilon_o)(\vec{m}_{ot}\vec{c})^2 - \varepsilon_o\varepsilon_e \end{aligned} \tag{14}$$

If $\vec{q}$ is directed inside the crystal then solution with positive sign must be chosen:

$$x = \frac{1}{A}\left(-B + \sqrt{B^2 - AC}\right)$$

If some of secondary waves are inhomogeneous their refraction vectors are also calculated. The sign before square root is defined in this case by the requirement that corresponding wave decreased with increasing distance from the surface.

1.3.2 Calculation of secondary waves amplitudes

Secondary waves amplitudes are found from boundary conditions

$$\left[\vec{q}\vec{E}_I\right] = \left[\vec{q}\vec{E}_{II}\right], \qquad \left[\vec{q}\vec{H}_I\right] = \left[\vec{q}\vec{H}_{II}\right] \tag{15}$$

where $\vec{E}_I, \vec{E}_{II}$ and $\vec{H}_I, \vec{H}_{II}$ - electric and magnetic fields on both sides of boundary ($\vec{H} = \left[\vec{m}\vec{E}\right]$ for plane wave).

Expanding fields over suitable orts system and projecting (15) onto the orts system lying in the boundary plane we obtain four linear complex equations for secondary waves amplitudes. Solving them we obtain complex amplitudes of secondary waves.

1.4 Model for scattering from side surface

Scattering indicatrix at the side surface is defined as a sum of broadened mirror and lambertian components:

$$F(\vartheta, \varphi) = \left(\alpha \cdot F_m + (1-\alpha) \cdot F_L\right) \cdot R \tag{16}$$

where $0 < \alpha < 1$ is the mirror component fraction,

$$F_m = C \cdot \cos\vartheta \cdot \exp\left[-4\left(\frac{\sin^2\frac{(\vartheta - \vartheta_m)}{2}}{\delta\vartheta^2} + \frac{\sin^2\frac{(\varphi - \varphi_m)}{2}}{\delta\varphi^2}\right)\right] \tag{17}$$

Normalizing coefficient C is determined from the equation

$$\int_{-\pi}^{\pi}\int_{0}^{\pi/2} F_m(\vartheta, \varphi) \cdot \sin\vartheta \cdot d\varphi \cdot d\vartheta = 1 \tag{18}$$

ϑ_m, φ_m - direction of mirror reflection.

Lambertian indicatrix

$$F_L = \frac{1}{\pi} \cdot \cos\vartheta \tag{19}$$

R - integral reflection coefficient

For each Stokes ray coming to the common vertex scattering coefficient is calculated according to (16) into each of rays leaving this vertex. Besides this phase modulation caused by relative Stokes shifts between rays is taken into account when calculating interscattering.

Scattering coefficients matrix and matrix of phase shifts factors for one time step are calculated at the stage of initiating the program and therefore calculation of boundary conditions during integration of the equations (11) require only multiplying by corresponding factors.

1.5 Defining the pump field

Pump field in the given spatial point and at the given moment of time is found as a product of distribution functions defining transverse, longitudinal and temporal profiles of pump beam. Transverse profile is defined at the entrance surface of optical element. Corresponding value of distribution function is carried to the point, where pump amplitude is calculated, along the pump wave propagation direction. Longitudinal profile models increasing in depth of third harmonic radiation intensity which serves as pump radiation for TSBS. Temporal profile is normalized to the total output energy of pump pulse calculated taking into account transverse and longitudinal pump beam distributions. When defining the time moment for which temporal profile value is calculated, retardation for given spatial point and additional retardation introduced by the artificial decoherentization model are taken into account.

Transverse intensity profile is considered to be supergaussian:

$$F_t = \exp\left\{-\left[\left(\frac{x}{L_x/2}\right)^{\alpha} + \left(\frac{y}{L_y/2}\right)^{\alpha}\right]\right\} \qquad (20)$$

Longitudinal profile can be defined of two forms:

$$F_z = 1 \quad \text{or} \quad F_z = \tanh\left(z/z_0\right) \qquad (21)$$

L_x, L_y and z_0 are spatial scales defined in the input data file.

Temporal intensity profile is defined in table form. Values of intensity profile between nods is defined by linear interpolation.

Temporal profile is normalized so that integrating over exit aperture with transverse and longitudinal distributions taken into account gives exit pump energy

Phase modulation $\exp(i \cdot \varphi(t))$ can be defined in tree forms:

a) gaussian: $\varphi(t) = \varphi_m \cdot \exp\left(-t^2/\tau_{\varphi}^{\,2}\right)$ (22)

b) harmonic: $\varphi(t) = \varphi_m \cdot \cos(\nu \cdot t)$ and (23)

c) quadratic (linear frequency modulation):

$\varphi(t) = a \cdot t^2$ (24)

Defining the pump amplitude provides the possibility to model artificial pump radiation decoherentization which is defined in the ISI (Induced Spatial Incoherence) model: pump beam aperture is covered by rectangular mesh and for each cell of this mesh some temporal delay is defined. Delay values for each cell are generated randomly with homogeneous distribution in the interval from zero to some maximal value. These additional retardations are taken into account when calculating pump amplitudes in the grid points of Stokes rays.

2. Computational algorithms

2.1 Coordinate systems used in the program

In the numerical TSBS modeling and defining initial data several coordinate systems are used.

Main coordinate system to which all physical characteristics are reduced and in which computations are fulfilled is defined as follows. Coordinate system origin is placed in the center of rectangular entrance face of optical element. z axis is normal to the entrance surface and is directed along the pump propagation direction. x and y axes are parallel to side surfaces, x axis is considered to be directed upwards, y axis supplement coordinate axes to right system. Abbreviated name of this system is 'oecs' - (optical element coordinate system).

Crystal coordinate system - 'crcs'. In this system crystal tensor characteristics are defined. Relative orientation of 'crcs' axes and 'oecs' axes is defined by Euler angles. These angles can be defined either in 'crcs' or in 'oecs'.

Coordinate system in which Stokes rays orientation is defined. Rays cone originating from some point on the side surface is defined in the coordinate system which origin is in the cone vertex. z axis of this system is directed inside the crystal, normally to side surface. x and y axes are parallel to sides of side surface and constitute together with z axis right coordinate system. x axis is directed in the pump propagation direction.

2.2 Finite difference scheme of integrating TSBS equations

For numerical integration of equations (11) we use the following finite difference scheme. Along each of rays considered homogeneous grid is defined with interval lengths $\Delta s_t = w_{st} * \Delta t$ where w_{st} is ray velocity along i-th ray and Δt - time step common for all rays. Let $k = 0,1,2..,n_{\max}$ numerates points along the ray from common vertex and $n = 0,1,...$ - time layers, then field amplitudes are defined in the nods of this grid and sound amplitudes in points (k+1/2, n+1/2), $U_{k+1/2}^{n+1/2}$.

Equations (11) for a ray going to the common vertex are approximated by finite difference equations

$$\frac{E_{sk}^{n+1} - E_{sk+1}^{n}}{\Delta s} = \frac{g\left(U_{k+1/2}^{n+1/2}\right)^*}{2} E_{p_{k+1/2}}^{n+1/2}$$

$$\frac{U_{k+1/2}^{n+3/2} - U_{k+1/2}^{n+1/2}}{\Delta t} = -\frac{\gamma}{2}\left(U_{k+1/2}^{n+3/2} + U_{k+1/2}^{n+1/2}\right) + \frac{1}{2} E_{p_{k+1/2}}^{n+1} \cdot \left(E_{sk}^{n+1} + E_{sk+1}^{n+1}\right)^* + \xi_n \qquad (25a)$$

Equations for a ray going in the reverse direction only slightly differ by numeration:

$$\frac{E_{sk+1}^{n+1} - E_{sk}^{n}}{\Delta s} = \frac{g\left(U_{k+1/2}^{n+1/2}\right)^*}{2} E_{p_{k+1/2}}^{n+1/2}$$

$$\frac{U_{k+1/2}^{n+3/2} - U_{k+1/2}^{n+1/2}}{\Delta t} = -\frac{\gamma}{2}\left(U_{k+1/2}^{n+3/2} + U_{k+1/2}^{n+1/2}\right) + \frac{1}{2} E_{p_{k+1/2}}^{n+1} \cdot \left(E_{sk}^{n+1} + E_{sk+1}^{n+1}\right)^* + \xi_n \qquad (25б)$$

We begin with calculation of Stokes amplitude at the next time layer using first equation (25) and then from the second equation we find sound amplitude at the second intermediate layer. Pump amplitude is considered to be unsaturated therefore it is found by recalculation from entrance face taking into account known retardations and pump direction.

Initial values of Stokes amplitudes are zero, initial values of complex hypersound amplitudes are randomly generated with homogeneous phase distribution and amplitude dispersion

$$\left\langle |U|^2 \right\rangle = \frac{\Delta t}{2\gamma} \left\langle |\xi|^2 \right\rangle \qquad (26)$$

Defining the amplitude of stochastic source is discussed in the next section

Finite difference equations (11) refer to the case of regular cell which does not contain reflection point from face surface. If cell contains reflection point then difference in physical characteristics (phase velocity, SBS gain coefficient, Stokes shift) for Stokes waves before and after reflection must be taken into account. To preserve second order of finite difference scheme propagation from one node to another in such a cell is calculated in two steps, from one node to the reflection point and from reflection point to another node, keeping the same principles of centering for each partial step as for regular cells.

2.3 Stochastic source amplitude estimation

Numerical integration of equations (11) with zero pump amplitude using finite difference scheme (25) gives sound amplitude which rms value $\left\langle |U|^2 \right\rangle$ is related to dispersion of stochastic source ξ by relationship (26)

In its turn $\left\langle |U|^2 \right\rangle$ (taking into account adopted normalization) can be connected with experimentally measured spontaneous scattering coefficient into the unit solid angle. Numerical integration of stationary SBS equation gives growth of Stokes amplitude at one spatial step by the value

$$\Delta E_s = \frac{g}{2} E_p \cdot U^* \cdot \Delta s \qquad (27)$$

For δ - correlated sound amplitude spontaneously scattered radiation amplitude grows over n steps by the value

$$\Delta I_s = \frac{g^2}{4} \left|E_p\right|^2 \cdot \left\langle |U|^2 \right\rangle \cdot \Delta s^2 \cdot n = \frac{g^2}{4} I_s \cdot \left\langle |U|^2 \right\rangle \cdot \Delta s \cdot \Delta l \qquad (28)$$

Experimentally measured power of spontaneous scattering into unit solid angle is

$$\Delta P_s = \rho_s \cdot I_p \cdot \Delta V = \rho_s \cdot I_p \cdot \Delta A \cdot \Delta l \qquad (29)$$

where ρ_s - spontaneous scattering coefficient, ΔV - scattering volume, ΔA - cross-section area of Stokes ray considered. Multiplying (29) by $\Delta\Omega$ and dividing by ΔA we get

$$I_s = \rho_s \cdot I_p \cdot \Delta l \cdot \Delta\Omega \qquad (30)$$

Comparing (14) and (17) we get

$$\left\langle |U|^2 \right\rangle = \frac{4\rho_s \Delta\Omega}{g^2 \Delta s} \qquad (31)$$

Finally we have

$$\left\langle |\xi|^2 \right\rangle = \frac{8\gamma \cdot \rho_s \Delta\Omega}{g^2 \Delta s \cdot \Delta t} \qquad (32)$$

2.4 Estimation of Stokes radiation absolute power

To estimate Stokes radiation absolute power from the total side surface of optical element one must divide average calculated Stokes intensity by $\Delta\Omega$ and multiply by total solid angle (for which one can take total geometrical angle of optical element) and by total side surface area. For characteristic values $S_{side} = 100\text{cm}^2$, $\Omega \approx 2\pi \cdot L_z / (L_\perp/2) \approx 2\pi \cdot 1\text{cm}/20\text{cm} = \pi/10$, $\Delta\Omega \approx 3 \cdot 10^{-6}$ we'll have $P_{s\,\text{out}} = 10^7 \cdot I_{s\,\text{out}}$. Characteristic pump power is $P_p = 10^4 J / 3\text{ns} = 3 \cdot 10^3 \text{GW}$. As a threshold the situation can be considered when scattered power comprises considerable part of pump power. Take this part to be 1%. Then we get estimate of Stokes intensity which corresponds to threshold of strong scattering:

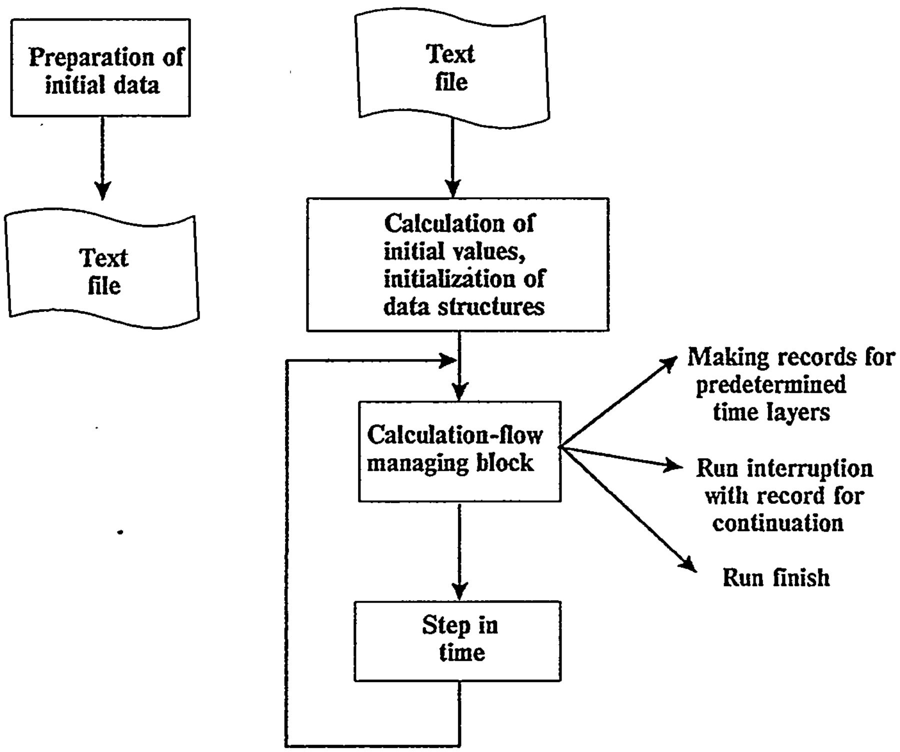
$$P_{s\,\text{thr}} \approx 0.01 \cdot P_p \approx 10^7 \cdot I_{s\,\text{thr}} \text{ or } I_{s\,\text{thr}} \approx 3 \cdot 10^{-6} \text{GW} / \text{cm}^2 \qquad (33)$$

This value must be kept in mind when considering results of parasitic TSBS computational modeling

3. Code for TSBS computer modeling

3.1 General code description

Above described physical-mathematical model of TSBS in the anisotropic medium was realized as a computer code 'TSBS'. Following general flow-chart of code organization was adopted



Subroutines employed in realizing computational model itself were written using Microsoft Fortran language. Dialogue program for preparing initial data file was written using C++.

Program for preparing initial data permits to make text file of definite format which will be described below. This program includes appropriate checks which guarantee completeness and correctness of input information. Text file generated by this program can be easily edited by any DOS text editor

Main computational program begin its work by reading text file containing initial data and parsing it, or by reading the file containing information for continuation of previous interrupted run.

Before launching the main cycle of temporal steps rather big amount of preparatory works is fulfilled. They include:

-Recalculation of crystal physical characteristics into 'oecs' system;

-Calculation of pump pulse wave characteristics;

-Calculation of Stokes rays directions;

-Calculation for each Stokes ray of Stokes radiation wave characteristics, of sound mode structure corresponding to given Stokes waves directions, of TSBS gain coefficients and Stokes shifts;

-Calculation of Fresnel reflection conditions (reflection direction, reflection coefficient, conditions of total internal reflection) for rays intersecting front and rare face surfaces of optical element;

-Calculation of spatial grids along the Stokes rays which must satisfy conditions of integrating along characteristics ($\Delta s = \Delta t \cdot v_r$, where Δs – spatial step, Δt -time step common for all rays, v_r -ray velocity for given ray);

-Calculation of interscattering matrix and relative phase shifts factors matrix between rays in the common vertex;

-Generation of temporal delays matrix for the model of transverse decoherentization;

-Filling by initial values of Stokes and sound amplitudes arrays.

Step in time is fulfilled in turn for all rays of cone considered. Cycle over rays is finished by taking into account of interscattering between rays. Integration itself of Stokes wave transport and time equation for hypersound amplitude is fulfilled by explicit finite difference scheme of second order.

In the process of modeling run information is monitored on the screen about current model time and step number, maximal Stokes intensity and intensity distribution over rays. It is possible to suspend run at any moment and give command to write section or to stop run and write file for continuation or without writing such file. Output information is written as section files which contain Stokes intensities distribution along rays and arrays of temporal evolution of Stokes intensities at the end points of Stokes rays from the beginning of the run up to current moment. Sections can be written at the moments indicated in the input data file and at any moment by interrupting the run and giving corresponding command.

3.2 Code's data structure

Initial information read from initial data text file, data generated during initializing stage and current data structures modeling the TSBS process are grouped in 9 COMMON-blocks. Texts of these COMMON-blocks with commentaries describing variables and arrays are given in the Appendix 1. Here we give general description of these blocks.

1) COMMON /GEOM/ -contains geometrical dimensions of optical element along x, y and z dimensions in the 'oecs'.

2) COMMON /CSAXES/ -contains information about relative orientation of 'oecs' and 'crcs' systems.

3) COMMON /PHYSPM/ -contains physical characteristics of the crystal read from input data file and recalculated into 'oecs'.

4) COMMON /PUMP/ - contains all parameters used for pump amplitude calculation.

5) COMMON /BUNCH/ - contains information about Stokes rays cone: location of the vertex, angle of the cone, number of hexagonal rings in which rays are grouped.

6) COMMON /RAYS/ - this common-block contains main calculational information: Stokes and sound amplitudes and coordinates of rays grids nods. Besides this it contains directions and polarizations of Stokes and sound waves.

7) COMMON /RPRMS/ - contains calculated parameters for each Stokes ray: SBS gain coefficients, anisotropy factors R, refractivities, wave and ray velocities, Stokes shifts etc.

8) COMMON /BNDSCAT/ - contains scattering indicatrix parameters, interscattering matrices and reflection coefficients at rare ends of rays.

9) COMMON /RUNPRMS/ - contains general run information: integrating step, time when run must be finished, moments when sections must be written, names of files used etc.

3.3 Preparation of initial data

Initial data text file structure is given in the Appendix 2. Initial data are grouped into five sections. Names of these sections are present at the screen as menu choices when preparing initial data text file. Submenus of the main menu contain the names of data subsections, selection of subsection causes appearance on the screen of input windows through which initial parameters are defined. When all parameters are defined prepared text file is recorded. Till data are not fully defined file recording is blocked.

After entering main computational program it asks if this is new task or continuation of previously interrupted. Depending on the answer program requests the initial data file name or the name of continuation data file. In the first case then data initializing occurs and launching of the main cycle, in the second - file is read containing full set of information pertaining to the moment of interruption, and run is continued.

3.4 Output information

Calculational results are output in a set of files which name include the task identificator. These files contain: 1) Physical characteristics of each ray (velocities, SBS gain coefficients, anisotropy factors, Stokes shifts et al.) calculated at the initialization stage; 2) longitudinal distributions of Stokes intensities along each of rays at given moments (sections), moments of sections output can be indicated in the input data file or defined manually suspending the run and giving corresponding command; 3) Arrays representing temporal evolution of Stokes intensities in the end points of rays..

These files are organized as a text tables which can be imported into some electronic table and processed there.

4. Some calculational results

Some calculations of gain coefficients and computational modeling of TSBS generation were fulfilled for the wide-aperture crystal-converter and for conditions of experiments carried out by Yu.V.Dolgopolov (contract B239661) /11/. Optical, elastical and elasto-optical crystal characteristics were taken from literature / 12,13,14 /.

Most uncertain is the value of hypersound damping. We used for this quantity the value close to that obtained in the Dolgopolov's experiments, $\tau_{ph} \approx 2.5\,\text{ns}$.

4.1 SBS gain dependence on the angle between the pump direction and crystal axis in the conditions of experiments on SBS excitation in the transverse resonator.

Model described in the section 1 was used for calculation of stationary TSBS gain dependence on the angle between the pump direction and crystal axis for two counterpropagating Stokes waves. Gain coefficients for two waves propagating in the opposite directions somewhat differ because each of them is generated as a result of pump wave scattering on different sound waves which directions in the crystal are not equivalent.

Task's geometry was that used in experiments under the contract B239661 /11/. Pump wave and Stokes waves polarizations were ordinary, $\vec{k}_p$, $\vec{k}_s$ and crystal axis $\vec{c}$ were lying in one plane, $\vec{k}_p \perp \vec{k}_s$. Elastic and elaso-optic characteristics of KD*P were taken from reference literature. Phonon lifetime was taken to be $\tau_{ph} = 3\,\text{ns}$. Calculation results are shown at the fig.1. In the experiments the crystal was used cut at the angle $\vartheta = 38°$. Mean calculated value of g for this angle over the resonator roundpass is $g = 4.5\,\text{cm / GW}$ which is in a good agreement with experimentally found $g_{\exp} = 4.4 \pm 0.4\,\text{cm / GW}$.

4.2 TSBS calculation in the wide-aperture crystal-converter

Several model runs were conducted for the case of pump with wavelength $\lambda = 0.353\,\mu\text{m}$ propagating in the synchronism direction for third harmonic generation in the KDP crystal. Crystal dimensions were 30 x 30 x 1 cm. Pump intensity was considered to be constant along the propagation direction. Transverse distribution of pump intensity was supergaussian with fill ratio of 0.825. Output energy was 10 kJ. Temporal pulse form was rectangular of 3 ns duration with front and rare slopes of 0.2 ns and with pedestal of linear form 2 ns duration and amplitude 0.01 of main pulse amplitude. Hypersound damping time was taken to be 2.5 ns. Pump polarization was extraordinary.

Firs of all dependencies of stationary TSBS gains for ordinary and extraordinary polarizations of Stokes waves on azimuthal angle of propagation direction were calculated. Results are shown on the fig.2. Angle is measured from x axis direction which coincides with pump polarization direction. Gain angular distribution just in accordance with expectation has a maximum in the direction orthogonal to pump polarization direction. Maximal gain coefficient for ordinary wave is ~3 times greater than for extraordinary one. So TSBS calculations were conducted for ordinary Stokes wave polarization. Stokes rays cone was orientated along the direction of maximal TSBS gain.

Then several calculations were fulfilled which modeled growth of parasitic Stokes radiation without phase modulation of pump beam and with harmonic phase modulation of varying amplitude. In the first run phase pump modulation was absent. Fig.3 shows increasing in time of Stokes intensities in the common vertex for rays propagating to this vertex Intensities scatter over rays is connected possibly with initial statistical scatter of intensities levels from which stimulated growth stage begins. One can see that Stokes intensities grow nearly exponentially and very quickly reach threshold level. In the next three runs phase modulation was switched on. Phase was modulated sinusoidally with frequency 30 Ghz and amplitudes 1, 2, and 3 radians. These runs results are shown on the fig.4 together with the case of no modulation. On the fig.5 longitudinal distributions of Stokes intensities are shown for these runs for the moment 5 ns when Stokes intensity is maximal. Pump field spectrums are shown on the fig.6.

Some comments can be given on results presented. First of all we see that TSBS threshold is exceeded greatly in the very beginning of main pulse in conditions of high radiation loading (~10 J/cm^2) and without phase modulation. Inclusion of phase modulation damps TSBS but it requires rather broadband modulation. Stokes intensity lowers down to acceptable level only for modulation bandwidth ~ 150 Ghz.

Conclusion

Computer code is developed capable of modeling non-stationary transverse SBS in uniaxial crystals. Model calculations show the importance of suppressing of TSBS, possibility of such suppression by phase modulation of pump wave and give an estimate of required modulation bandwidth. Calculated TSBS gain for conditions of Dolgopolov's experiments /11/ is in a good agreement with experimentally measured one when experimental value of phonon lifetime is used.

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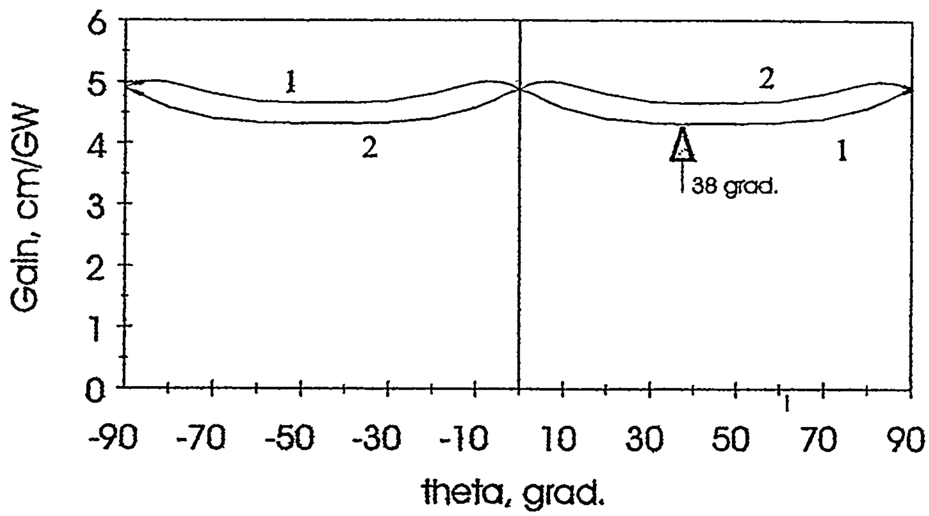

Fig.1 Dependence of TSBS gain coefficient of KD*P crystal on the angle between pump direction and crystal axis. 1 and 2 - curves for waves propagating in opposite directions

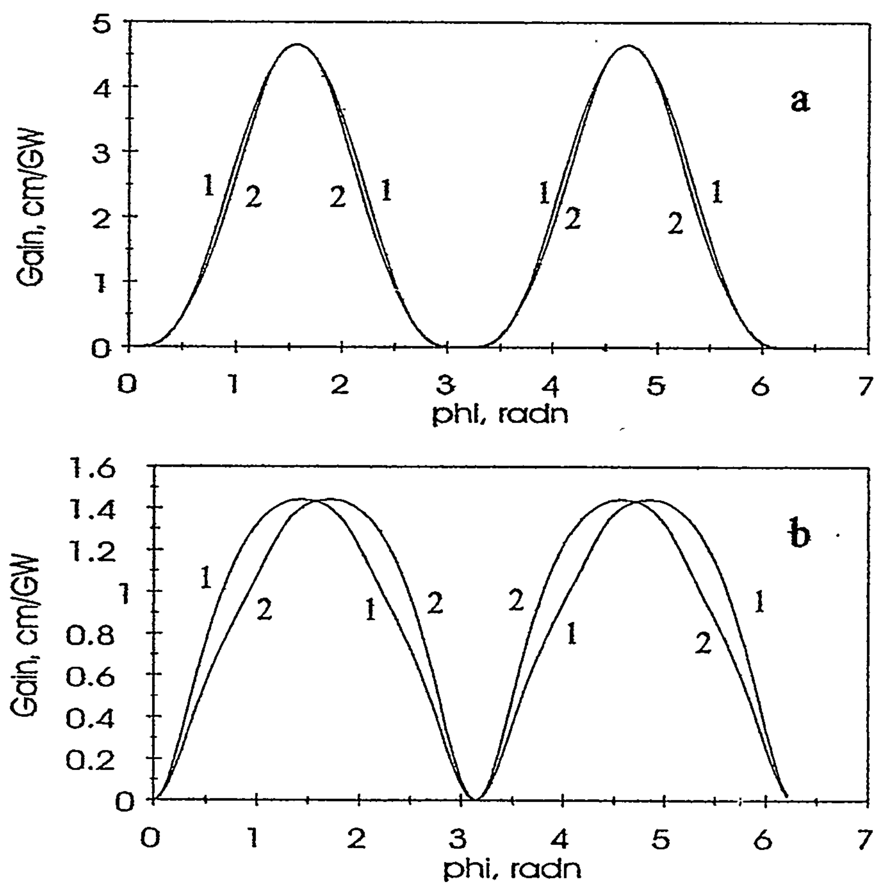

Fig. 2 Azimuthal TSBS gain dependence.
a - ordinary Stokes wave, b - extraordinary Stokes wave.
1 and 2 - curves for waves propagating in opposite directions

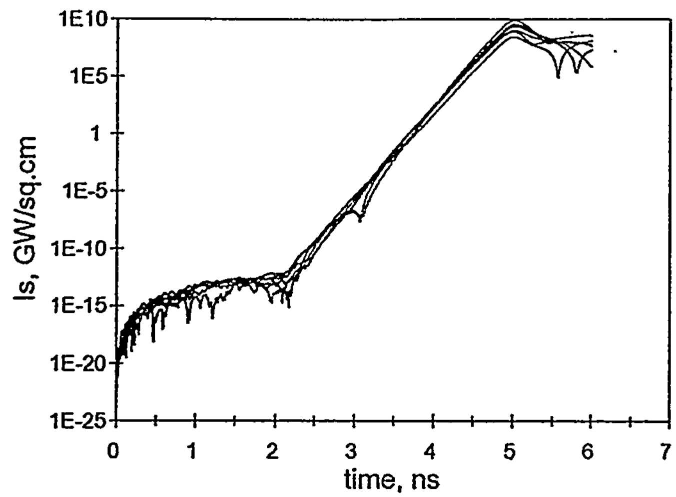

Fig.3 Output Stokes intensities without phase modulation.

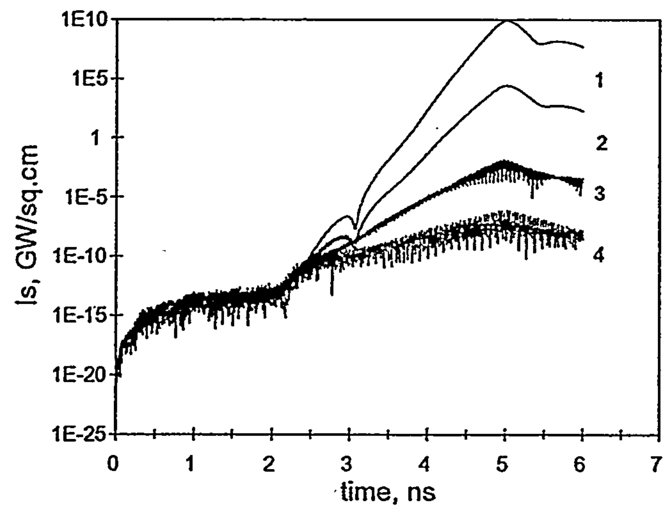

Fig. 4 Output Stokes intensities. 1 - no phase modulation; 2,3,4 - sinusoidal phase modulation, f_{mod} = 30 Ghz, φ_{max} = 2 - 1, 3 - 2, 4 - 3 radn.

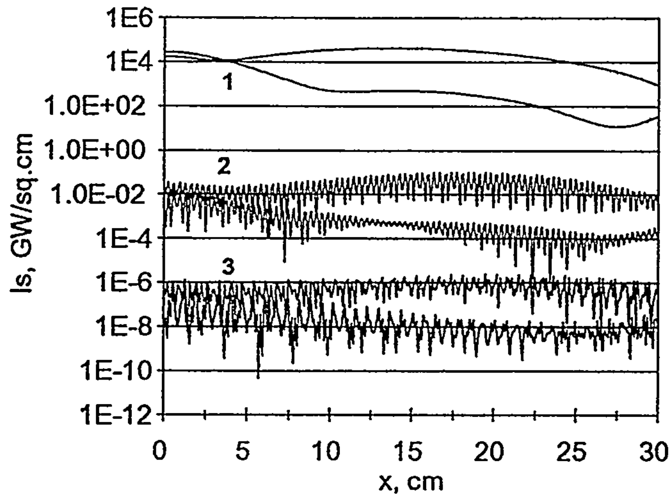

Fig. 5 Spatial distributions of Stokes intensities. $f_{mod} = 30$ Ghz, φ_m = 1 - 1, 2 - 2, 3 - 3 radn

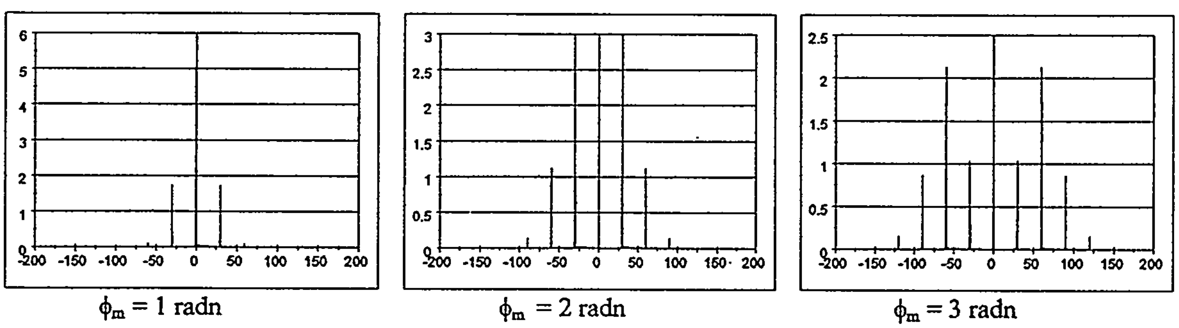

Fig. 6 Phase modulated pump spectra. $f_{mod} = 30$ Ghz, frequency in GHz.

Appendix 1

Common blocks containing all computational parameters

```
c***********************************************************
    parameter (nmx=300, nrngsmx=5,
    -        nrm=3*nrngsmx*(nrngsmx+1)+1,
    -        ntp=100, ntpm=ntp+2, nxpm=50,nypm=50,nstm=5000,
    -        nstrgm=10, refiso=1.d0)
c
c   nmx - max number of points along the ray
c   nrngsmx - max number of ray rings
c   nrm - max number of rays
c   ntp - max number of temporal points in table defining pump profile
c   nxpm,nypm - max numbers of x and y divisions of echelon plate
c           determining local retardations
c   nstm - maximal length of arrays where output Stokes intensities are accumulated
c   nstrgm - max number of moments for which system state
c          can be written down
c   nmtbf - buffer length for pump temporal profile
c   refiso - refractivity of isotropic medium surrounding optical element
c
c****************************************************/geom/
    real*8  hx,hy,hz
    common /geom/  hx, hy, hz
c
c   hx,hy,hz (cm) - dimensions of optical element which is supposed to
c   be of parallelepiped form
c
c************************************************** /csaxes/
    character*8 pcs1
    real*8      theta,phi,psi,tr(3,3)
    common /csaxes/    pcs1,theta,phi,psi,tr
c
c   pcs1 - char parameter determining how mutual orientation
c        of crystal coordinate system(CS) and optical element CS
c        is defined:
c        pcs1='oecs' - axes of CRCS are defined in OECS
c             'crcs' - axes of OECS are defined in CRCS
c   theta,phi,psi - Euler's angles of one CS axes in another
c   tr(3,3) - transformation matrix which being applied to tensor
c          in CRCS transforms it into OECS
c
c*******************************************************/physpm/
    real*8  c11,c33,c44,c66,c12,c13,elst(3,3,3,3),
    -      p11,p33,p44,p66,p12,p13,elopt(3,3,3,3),
    -      epso,epse,refo,refe,eps(3,3),bet(3,3),
    -      rho,tauph,cax(3),srcns
    common /physpm/    c11,c33,c44,c66,c12,c13,elst,
    -             p11,p33,p44,p66,p12,p13,elopt,
    -             epso,epse,refo,refe,eps,bet,
    -             rho,tauph,cax,srcns
c
c   cij (10^10 u.CGSE) - elastic coefficients in two-index notation
c   elst(3,3,3,3) - four-index elastic tensor;
```

```
c    pij,elopt(3,3,3,3) - analogous quantities for electrooptic constants
c    epso,epse - ordinary and extraordinary permettivities, eps(3,3) -
c              permettivity tensor
c    rho(g/cm^3) - optical element material density;
c    tauph (ns) - damping time of hypersound wave
c    cax(3) -unit vector defining the direction of crystal axis
c    srcns - root mean square value of stochastic source in hypersound
c          amplitude equation
c
c**********************************************************/pump/
     character*8  pcs2,pldis,pplrz,phsmod
     real*8  ptheta, pphi, pdv(3),prw,pref,epp(3),pgam,pk(3),
     -       phx, phy, palpha,pz0,
     -       pt(ntp),ppwr(ntp),pqout,pwl,hnu,totrtd, trtd(nxpm,nypm),
     -       phmax, fmod
     integer*4   nxp, nyp, nppnts
     common /pump/  pcs2, ptheta, pphi, pdv,
     -            prw,pref,epp,pgam,pk,
     -            phx, phy, palpha,
     -            pldis, pz0,
     -            pplrz,
     -            pt,ppwr,pqout,pwl,hnu,
     -            totrtd, trtd,
     -            phsmod, phmax, fmod,
     -            nxp, nyp, nppnts
c
c    pcs2 - parameter determining in what CS pump direction is defined:
c         pcs2='oecs' - OECS is used
c             'crcs' - CRCS is used
c    ptheta,pphi - angles defining direction of pump wave,
c    pdv(3) - unit direction vector of pump wave
c    prw - ray velocity of pump wave
c    pref - refractivity for pump wave
c    ppe - unit polarization vector of el. field for pump wave
c    pgam - anisotropy angle for pump wave
c    pk - pump wave vector in inverse micrometers
c    phx, phy, palpha - parameters of supergaussian transverse distribution
c                of pump intensity in the entrance plane of the optical
c                element:
c                F(x,y)=exp{-[(x/(phx/2))^alpha+(y/(phy/2))^alpha]}
c    pldis - defines the type of longitudinal pump distribution:
c          pldis='const' - pump intensity is constant
c              'tanh' - longitudinal pump profile is tanh(z/z0)
c    pz0 - parameter in tanh distribution tanh(z/z0)
c    pplrz - defines pump polarization: pplrz={'ord'|'extrord}
c    (pt(ntp),ppwr(ntp)) - pump temporal profile,
c    nppnts - number of points defining pump temporal profile,
c    pqout - output pump energy
c    pwl - pump wavelength in micrometers
c    hnu - energy of the pump radiation quantum
c    nxp,nyp - numbers of x and y divisions of echelon plate determining local
.c           retardations
c    totrtd - total retardations interval,
c    trtd(nxpm,nypm) - local retardations for each division of echelone
c    phsmod - defines method of pump phase modulation:
c          phsmod={'gaussian|rf|linear}
```

```
c    phmax, fmod - parameters in formulas determining modulation dependencies:
c       phi=phmax*exp(-(t/tauphi)**2),tauphi=(1/pi)*sqrt(2/e)*(phmax/fmod)
c       phi=phmax*cos(2*pi*fmod*t),
c       phi=(fmod**2/4*phmax)*t**2.
c    for gaussian, rf and linear modes of phase modulation correspondingly
c
c*****************************************************************/bunch/
      character*8 vpos
      real*8  vpx, vpy, vpz, bxthet, bxphi,
     -      bhthet,bthet(nrm),bphi(nrm), trb(3,3),trbinv(3,3)
      integer*4   nrings,nr
      common /bunch/ vpos, vpx, vpy, vpz, bxthet, bxphi,
     -            bhthet,nrings,nr,bthet,bphi,trb ,trbinv
c
c    vpos -  defines optical element side plane where the top of rays bunch
c          rests, vpos={left|right|upper|lower}
c    vpx,vpy,vpz - coordinates of rays bunch top,
c    bxthet, bxphi - angles determining direction of bunch axis relative to
c         following CS: z - axis inside optical element, along normal to side
c         face where the bunch top rests, x,y lie in the side plane and are
c         paralel to the sides of side face rectangle, x - axis along pump
c         direction
c    splrz - see above
c    bhthet - half-angle of rays cone
c    nr - number of rays
c    bthet(nrm), bphi(nrm) - angles of each ray relative to the same CS.
c    trb(3,3) transformation matrix from side plane CS to OECS
c    trbinv(3,3) inverse matrix to trb(3,3)
c
c*****************************************************************/rays/
      complex*16  vto(0:nmx,nrm) ,vfrm(0:nmx,nrm),
     -          pto(1:nmx,nrm ) ,pfrm(1:nmx,nrm )
      real*8      xr(0:nmx,nrm),yr(0:nmx,nrm),zr(0:nmx,nrm),
     -          rvto(3,2,nrm),rvfrm(3,2,nrm),
     -          wnto(3,2,nrm),wnfrm(3,2,nrm),
     -          esto(3,2,nrm),esfrm(3,2,nrm),
     -          vsdto(3,2,nrm), vsdfrm(3,2,nrm),
     -          psdto(3,2,nrm),psdfrm(3,2,nrm)
      integer*4   krv(0:nmx,nrm),kptmx(nrm)
      common /rays/   vto, vfrm,pto,pfrm,
     -            xr,yr,zr,
     -            rvto,rvfrm,wnto,wnfrm,esto,esfrm,
     -            vsdto,vsdfrm,psdto,psdfrm,krv,kptmx
c
c    vto, vfrm - complex amplitudes in the space grid nodes of Stokes waves
c            travelling to and from the bunch top correspondingly,
c    pto, pfrm - complex amplitudes of corresponding hypersound waves
c            in the cell centers of space grid
c    xr,yr,zr -  cartesian coordinates of space grid nodes for given ray
c    rvto,rvfrm -    unit ray vectors of Stokes waves
c    wnto,wnfrm - unit wave normal vectors of Stokes waves
c    esto, esfrm - unit polarization vectors for Stokes waves to and from
c            (they are equal but are introduced as two vectors for
c            notations unification).
c    vsdto, vsdfrm - unit direction vectors of hypersound waves
c    psdto,psdfrm - unit polarization vectors for hypersound waves to and from
```

```
c
c   For rvto,rvfrm,wnto,wnfrm,esto,esfrm,vsdto,vsdfrm,psdto,psdfrm
c   first index is cartesian index of vector; second is effective if ray
c   intersects entrance or exit face of optical element and undergo
c   reflection, then this index refers to the part of the broken ray
c   1 corresponds to the part of the ray adjacent to the vertex and
c     all parts with the same direction, 2 corresponds to alternative
c     parts of the ray; third index numerates rays.
c   krv -  binary parameter determining for each node of space grid to which
c          part of broken ray it belongs
c   kptmx - number of space grid points for each ray
c
c**************************************************************/rprpms/
      character*8 splrz,sndmod
      real*8    wrto(2,nrm),wrfrm(2,nrm),
     -          refto(2,nrm),reffrm(2,nrm),dsr(2,nrm),
     -          gamto(2,nrm),gamfrm(2,nrm),
     -          omgto(2,nrm), omgfrm(2,nrm),
     -          uphto(2,nrm),uphfrm(2,nrm),
     -          Rto(2,nrm), Rfrm(2,nrm), gto(2,nrm), gfrm(2,nrm),
     -          areflto(2,nrm),areflfrm(2,nrm)
      complex*16
     -          domtodt(2,nrm),domfrmdt(2,nrm),
     -          domtot(2,nrm),domfrmt(2,nrm)

      common /rprms/  splrz,sndmod,
     -            wrto,wrfrm,refto,reffrm,dsr,
     -            areflto,areflfrm,
     -            gamto,gamfrm,omgto, omgfrm,
     -            domtodt,domfrmdt,domtot,domfrmt,
     -            uphto,uphfrm,
     -            Rto, Rfrm, gto, gfrm
c
c   splrz - defines Stokes wave polarization. Char constants are the same
c          as for pplrz
c   sndmod - defines sound mode, sndmod={QL,QSS,QFS}
c   dsr - space steps along rays
c   wrto, wrfrm -   ray velocities of Stokes waves
c   refto, reffrm - refractivities for Stokes waves
c   dsr - space steps for each ray
c   gamto ,gamfrm - anisitripy angles for Stokes waves
c   omgto, omgfrm - Stokes shifts for Stokes waves
c   domtodt, domfrmdt - complex exponents corresponding to phase modulation
c                  per one time step caused by relative frequency shifts
c                  between incident and reflected Stokes beams
c   domtot, domfrmt - the same by current time
c   uphto,uphfrm - phase velocities of hypersound waves
c   Rto, Rfrm -    anisotropy factors for Stokes wave transport equations
c   gto, gfrm -    SBS gains for Stokes wave transport equations
c   areflto, areflfrm - Fresnel reflectivities for rays to and from.
c
c************************************************************/bndscat/
      real*8 bndr,rendr,mirrat,dtheta,dphi ,
     -     brefl(nrm,nrm)
      complex*16 bdomdt(nrm,nrm),bdomt(nrm,nrm)
      common /bndscat/ bdomdt,bdomt,
```

Appendix 2

Input data text file structure

1) **[Optical_element]**

geometry (optical element dimensions)
hx=
hy=
hz=

crystal_axes (relative orientation of 'oecs' and 'crcs')
cs =\{oecs|crcs\}
theta=
phi=
psi=

elastisity_coefficients
c11=
c33=
c44=
c66=
c12=
c13=

density
rho=

elastooptic_coefficients
p11=
p33=
p44=
p66=
p12=
p13=

permittivity
epso=
epse=

sound_damping
tauph=
stochastic_src_rms
srcns=

---

2) **[Pump]**

pump_direction
cs =\{oecs|crcs\}
theta=

```
     -              bndr,rendr,mirrat,dtheta,dphi,brefl
c
c    bndr - total reflectivity of the boundary where rays converge
c    rendr - reflectivity at the rare end of rays
c    mirrat - mirror reflection ratio
c    dtheta, dphi - angular widths of diffuse reflection distributions
c    brefl(i,j)- amplitude scattering coefficient for scattering
c              from i-th ray into j-th
c    bdomdt(i,j) = cexp(i*(ws(i)-ws(j))*dt) - phase multipliers per one
c              time step for scattering from i-th ray into j-th
c              taking into account difference in Stokes shifts for
c              different rays
c    bdomt(i,j) = cexp(i*(ws(i)-ws(j))*t) - phase multipliers for
c               current time
c
c*********************************************************/runprms/
     real*8 dt,tc, tstrg(nstrgm),tcur,
     -    qtto(nstm,nrm), qtfrm(nstm,nrm)
     integer*4 kst,nstrg,kstrg,iseed,ksec
     character*64 prbfil,contfil,indatfil,wrkdir,
     -          tmfilto,tmfilfrm
     character*5 idprb
     common / runprms/ wrkdir, contfil,indatfil,
     -          dt,tc,tstrg ,tcur,qtto, qtfrm,
     -              idprb,kst,nstrg,kstrg,iseed,ksec
c
c    wrkfil - name of the current working directory
c    contfil - filename where to write current state record
c           before interruption
c    indatfil - text file name with initial data
c    dt - integrating step in time
c    tc - final time
c    tstrg(*) - times, for which system states (sections) must be saved
c    tcur - current time
c    qtto - time array of output "TO"-rays intensities
c    qtfrm - time array of output "FROM"-rays intensities
c    idprb - five-character problem identifier
c    kst - number of time steps passed
c    nstrg - number of time sections which must be saved
c    kstrg - number of predefined sections already written
c    iseed - integer number defining quasirandom sequence
c    ksec - number of sections already written
c*******************************************************************
```

phi =

transverse_distribution
hx =
hy =
alpha=

longitudinal_distribution
ld={const|tanh}
z0= (In case of tanh)

polarization
pp={ord|extraord}
output_power_profile (double-column table: t_i - P_i)
. .
. .
. .

exit_energy
qout=

wavelength
wl=

transverse_coherence
nx =
ny =
totretrd=

phase_modulation
pm={gaussian| rf |linear}
phmax=
nu=

---

3) **[Rays_bunch]**

vertex_position
vp={left|right|upper|lower} (considering x to be directed upward)
x= for "left" y=-hx/2 (hx and hy from
y= for "right" y=hx/2 geometry item)
z= for "upper" x=hy/2
for "lower" x=-hy/2

axis_direction
theta=
phi =

polarization
sp={ord|extraord}

sound_mode
ssm={QL|QSS|QFS}

rays_definition
htheta=
nrings=

---

4) **[Boundary_scattering**

bndrefl=
rendrefl=
mirrat=
dtheta=
dphi =

---

5) **[Computational_parameters]**

dt=
tc=
iseed=
idprb=
strgtimes (one-column table : t_i)
.
.
.
endtable