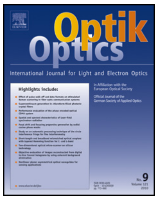
Optik 126 (2015) 1462–1466

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



Diffusion effect of stimulated Raman scattering and synchronous conversion of optical signal

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ARTICLE INFO

Article history:
Received 27 February 2014
Accepted 9 April 2015

Keywords:
Synchronous conversion
Diffusion effect
Stimulated Raman scattering
Lyapunov exponent

ABSTRACT

Diffusion effect of stimulated Raman scattering and synchronous conversion of optical signal are investigated. Taking into account the spatial diffusion effects of light fields, the coupled-wave equation of stimulated Raman scattering is modified firstly. Optical signal synchronous conversion has been completed using modified coupled-wave equations of stimulated Raman scattering. The threshold value of the coupling strength in which the optical signal realizes the synchronous conversion is determined through calculating the maximum Lyapunov exponent of the coupled system.

1. Introduction

Stimulated Raman scattering (SRS) is an important nonlinear optical effect, and it becomes an effective means to construct the laser with new wavelength because the wavelength of stimulated Raman scattering takes on a certain frequency shift relative to the original wavelength.

The phenomenon of stimulated Raman scattering was first discovered and researched by Woodbury and Ng [1]. In recent years, the SRS has shown a unique role in many fields because of its narrow line width and pulse, better directivity and high conversion efficiency advantages, such as remote sensing technology, spectrum exploration technique, optical communication, laser technology, and so on [2–9]. Especially, the high efficiency conversion conditions obtaining anti-Stokes light was reported by Bespalov and Makarov through numerical simulations about stimulated Raman scattering at steady state and transient state [10]. The influence of the phase coherence decay process on the characteristics of both the single solitary pulses in stimulated Raman scattering and their train has been theoretically studied by Shvedko and Orlovich [11]; Mašek and Rohlena discussed the behavior of electron gas in a laser plasma corona in the presence of stimulated Raman scattering [12]; photodynamic damage (PDD) study using stimulated Raman scattering is made by AlSalhi et al. [13]. Ackerhalt analyzed the theory mechanisms of stimulated Raman scattering and gave the steady state coupled-wave equations of the electric field amplitude of anti-Stokes light, pump light and Stokes light when the phase match exactly [14]. But the space change of light filed in the media plane perpendicular to the light's propagation direction is ignored in the Ref. [14], and in practice, the diffusion effect tends to be underestimated. For these reasons, the coupled-wave equation of stimulated Raman scattering has been modified firstly in this paper in order to take into account the spatial diffusion effects of light fields. Therefore, the optical signal synchronous conversion is completed using modified coupled-wave equations of stimulated Raman scattering, and the technique of optical signal synchronous conversion is of potential applications in the fields of optical communications and laser technology.

2. Diffusion effect of stimulated Raman scattering

The device to generate anti-Stokes light using collimated pump and Stokes seed beams, slightly crossed within a Raman active medium is shown in Fig. 1.

In stimulated Raman scattering process, the light is assumed to spread along the z axis of the three dimensional space and the steady state coupled-wave equation of the electric field amplitude A_1, A_2 and A_3 of anti-Stokes, pump and Stokes is matched exactly in phase. So the steady state coupled-wave equation can be expressed

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http://dx.doi.org/10.1016/j.ijleo.2015.04.014
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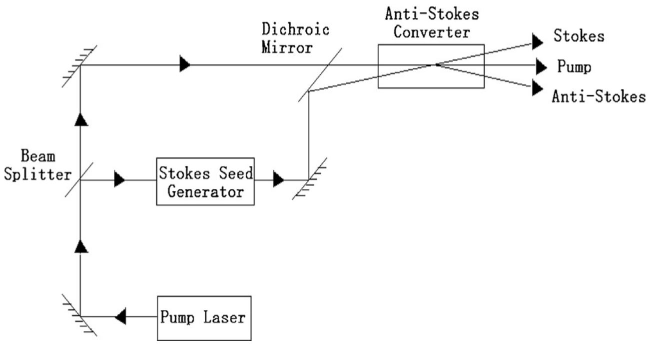

Fig. 1. The device for generation of anti-Stokes light.

as the following differential equation under taking into account the loss or gain in circumstances [14].

$$\begin{cases} \dfrac{dA_1}{dz} = -\gamma_1 A_1 - \beta_1(|A_2|^2 A_1 + A_2^2 A_3^*) \\ \dfrac{dA_2}{dz} = -\gamma_2 A_2 + \beta_2(|A_1|^2 - |A_3|^2)A_2 \\ \dfrac{dA_3}{dz} = -\gamma_3 A_3 + \beta_3(|A_2|^2 A_3 + A_1^* A_2^2) \end{cases} \tag{1}$$

where $\gamma_i (i = 1, 2, 3)$ are loss or gain coefficient, $\beta_i (i = 1, 2, 3)$ are coupling coefficient of light modes.

For calculation purposes, the scale transformation is taken as

$$A_i = a_i e^{j\theta_i} \quad (i = 1, 2, 3) \tag{2}$$

where j is the imaginary unit, and assuming that the following relation is exacted in the incidence media plane of light [15].

$$2\theta_2 - \theta_3 - \theta_1 = 0 \tag{3}$$

Thus, the coupled-wave Eq. (1) can be translated to the following real-variable equations

$$\begin{cases} \dfrac{da_1}{dz} = -\gamma_1 a_1 - \beta_1(a_1 + a_3)a_2^2 \\ \dfrac{da_2}{dz} = -\gamma_2 a_2 + \beta_2(a_1^2 - a_3^2)a_2 \\ \dfrac{da_3}{dz} = -\gamma_3 a_3 + \beta_3(a_1 + a_3)a_2^2 \end{cases} \tag{4}$$

Adopting parameters $\beta_1 = 9$, $\beta_2 = 5$, $\beta_3 = 1$, anti-Stokes light gain $\gamma_1 = -1$, pump light loss $\gamma_2 = 1$, and Stokes light loss γ_3 is taken as adjustable parameter.

Modeling the method taking average of time to calculate Lyapunov exponent of the system, the evolution of maximum Lyapunov exponent $\lambda_{\max}$ in system (4) with the parameter γ_3 is shown in Fig. 2. It is can be known that the maximum Lyapunov exponent exists the range in which it is greater than zero, meaning that the light signal of the system is at chaotic state. The maximum Lyapunov exponent is positive when the parameter is taken as $\gamma_3 = 1$, and the phase map of the state variables a_2 and a_3 is shown in Fig. 3. The spatial evolutions of the electric field amplitude of anti-Stokes light, pump light and Stokes light are shown in Fig. 4.

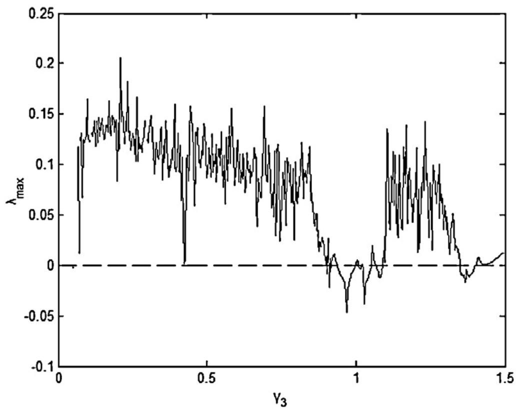

Fig. 2. The evolution of maximum Lyapunov exponent with the parameter γ_3.

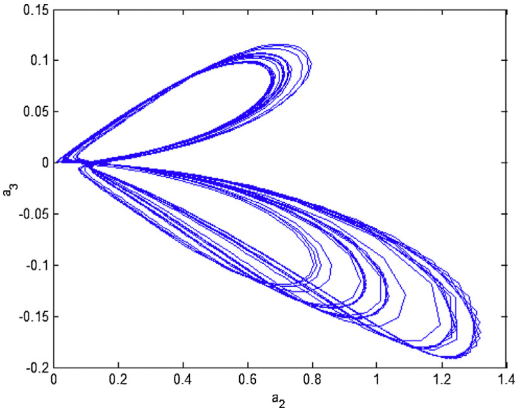

Fig. 3. The chaotic attractor in the (a_2, a_3) phase space.

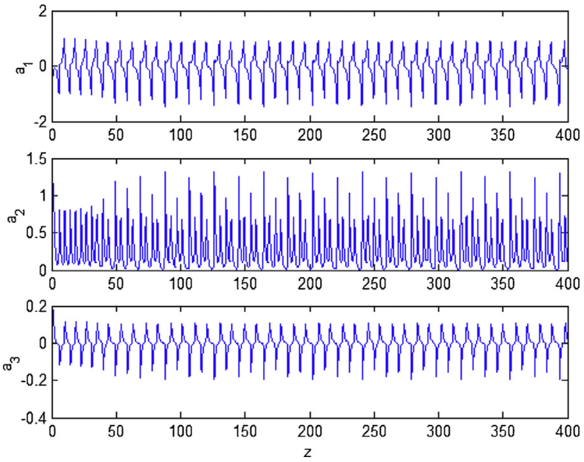

Fig. 4. The spatial evolution of the electric field amplitude.

Only the evolution of light filed along the light's propagation direction is investigated using by the coupled-wave Eq. (4) of stimulated Raman scattering, however, the space change of light filed in the media plane perpendicular to the light's propagation direction is ignored, and such diffusion effect of light field with the space is real. Therefore, it needs to add a term of the spatial diffusion $D\nabla^2 a_i$ of light filed in the Eq. (4). The modified coupled-wave equations are as follows

$$\begin{cases} \dfrac{da_1}{dz} = -\gamma_1 a_1 - \beta_1(a_1 + a_3)a_2^2 + D\nabla^2 a_1 \\ \dfrac{da_2}{dz} = -\gamma_2 a_2 + \beta_2(a_1^2 - a_3^2)a_2 + D\nabla^2 a_2 \\ \dfrac{da_3}{dz} = -\gamma_3 a_3 + \beta_3(a_1 + a_3)a_2^2 + D\nabla^2 a_3 \end{cases} \tag{5}$$

where D is the diffusion coefficient, $\nabla^2 = \partial^2/\partial x^2$.