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Effect of gain medium's volume of amplifier on DF amplification system with MOPA configuration

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ABSTRACT

The interaction of amplified spontaneous emission (ASE) flux and coherent laser flux in cuboid DF amplifiers are studied, by using a finite difference method and an iterative arithmetic. The influence of gain medium's volume on amplification ratio and energy extraction efficiency is discussed in detail. The simulation results in the amplifier which gain zone is cuboid and the small gain coefficient is distributed as parabola indicated that the amplification ratio and energy extraction efficiency increase as the increase of gain medium length, but they decrease as the increase of gain medium's width; the amplification ratio and energy extraction efficiency are increased with the increase of gain medium length when the gain medium's volume is definite; although the amplification ratio and energy extraction efficiency will decrease with the increase of gain medium's height, but the energy extraction from the amplifier will increase when the gain medium's length is definite.

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1. Introduction

In high-power DF chemical laser amplification system which adopts master oscillator-power amplification (MOPA) configuration, the amplification ratio (AR), the energy extraction efficiency (E_{ff}) in the amplifier are the problems that the researchers care about [1–7]. The gain medium's volume not only affects the AR and E_{ff}, but also decides the magnitude of the ASE light intensity. In DF chemical laser system, the gain medium's length is restricted by the DF chemical laser system's volume, and the gain medium's height is restricted by the size of reflect mirrors. So how to choose the gain medium's length and gain medium's height is one of the problems that the DF chemical laser researchers care about. In this letter, the influence of gain medium's volume on the amplification ratio of amplifier, the energy extraction efficiency of amplifier, are studied by using a finite difference method and an iterative arithmetic by establishing the equation of ASE flux and the equation of coherent flux in the amplifier.

2. Calculation model of ASE and coherent flux

The schematic of the master oscillator-power amplifier configuration is illustrated in Fig. 1. In the MOPA configuration, the beam from master oscillator is shaped and propagated through the amplifier gain medium. The spontaneous emission is amplified when the coherent laser is amplified in the amplifier, and turned into an important factor which affects the coherent laser to extraction energy in amplifier, so the equation of ASE and the equation of coherent laser should be given. And by solving the equations of ASE and coherence laser, the ASE intensity and coherence laser intensity in any position of the amplifier could be known.

In the amplifier, the spontaneous emission on the "emitting point" is amplified when it is propagated to the "observation point". The ASE intensity at the "observation point" is obtained by integrating ASE from the whole gain medium. Fig. 2 is the model of ASE calculation. Assuming the light is monochromatic, the ASE intensity from the emitting volume dV at Q is seen at the "observation point" P as [8,9]

$$dI_{ASE} = \frac{hfN^*(x,y,z)}{\tau_R}\frac{dV}{4\pi r^2}\exp\left(\int [g(l)-\alpha]dl\right) \quad (1)$$

where h is the Planck's constant; f is the frequency of the light; $N^*(x,y,z)$ is the upper-state population density; τ_R is the spontaneous lifetime of the upper-state; r is the distance between the observation point and the emitting point; $g(l)$ denotes the gain coefficient in the amplification with l being propagation distance in the gain medium, which depends on local light intensity; a is the nonsaturable absorption coefficient, and in the calculation a can be consider as zero. By integrating Eq. (1), total ASE intensity at P is

$$I_{ASE}(x_0,y_0,z_0) = \iiint \left[\frac{hfN^*(x,y,z)}{\tau_R}\frac{dV}{4\pi r^2}\exp([g(l)-\alpha]dl)\right] \quad (2)$$

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Fig. 1. Schematic of the master oscillator-power amplification configuration.

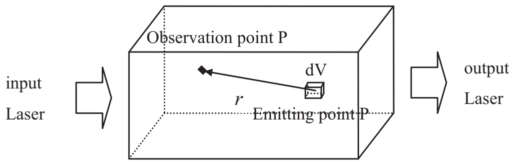

Fig. 2. Model of amplified spontaneous emission calculations.

And the total light intensity is the sum of ASE intensity and coherent laser intensity.

$$I(x_0, y_0, z_0) = \iiint \left[\frac{hfN^*(x, y, z)}{\tau_R}\frac{dV}{4\pi r^2}\exp([g(l)-\alpha]dl)\right] + I_f(x_0, y_0, z_0) \quad (3)$$

For the laser light propagating along the z-axis, the equation of coherent laser flux is expressed as [10]

$$\frac{dI_f(x, y, z)}{dz} = [g(x, y, z) - \alpha]I_f(x, y, z) \quad (4)$$

The gain coefficient are defined as

$$g(x, y, z) = \frac{g_0(x, y, z)}{1 + I(x, y, z)/I_s} \quad (5)$$

where the saturation intensity $I_s = hf/\sigma\tau_{eff}$. And τ_{eff} is the effective lifetime of upper-state populations, σ is the stimulated emission cross section. In this paper, it assumed that N^* and gain coefficient is determined from the local light intensity.

The finite difference expressions for the numerical calculation of Eqs. (3) and (4) are shown as follows:

$$I(n_0, m_0, t_0) = \sum_n\sum_m\sum_t \left[\frac{hfN^*(n, m, t)}{\tau_R}\frac{dV}{4\pi r^2}\exp\left(\sum_u (g_u - \alpha)\Delta l\right)\right] + I_f(n_0, m_0, t_0) \quad (6)$$

$$I_f(n_0, m_0, t_0) = I_f(n_0, m_0, t_0 - 1)\exp[g(n_0, m_0, t_0 - 1)\Delta z] \quad (7)$$

where n, m, t, n_0, m_0, t_0 are the coordinate coefficients of the space lattices; $dV = \Delta x \cdot \Delta y \cdot \Delta z$ is the volume of each space lattice; Δx, Δy, Δz is the step size along axis x, y, z; $I(n_0, m_0, t_0)$ is the whole light intensity in lattice (n_0, m_0, t_0); $N^*(n, m, t)$ is the upper-state population density in lattice (n, m, t); $I_f(n_0, m_0, t_0)$ is the coherent laser intensity in lattice (n_0, m_0, t_0).

We consider the gain medium as a cuboid of length L (z-axis), height H (y-axis), and width D (x-axis), and loaded by the longitudinal coherent flux. We assume that the input coherent light is a plane wave, and the small signal gain coefficient is uniformly distributed along the z- and y-axes, but has a parabolic distribution along the x-axis (Fig. 4) [11]. The mesh configuration used here – $7 \times 9 \times 60$ – is illustrated in Fig. 3. Spontaneous emission is considered to be emitted from the center of each element. The amplification of the light from the "emitting point" to the "observation point" is considered as follows: the path between these two points is divided into path elements. The gain is calculated for each path element, which is defined by the method of the nearest grid approximation, and the gain coefficient of a path element employs the value of the corresponding volume element. By using Eqs. (5)–(7), the

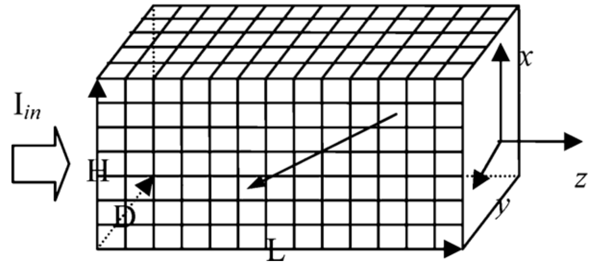

Fig. 3. Mesh configuration used in calculations.

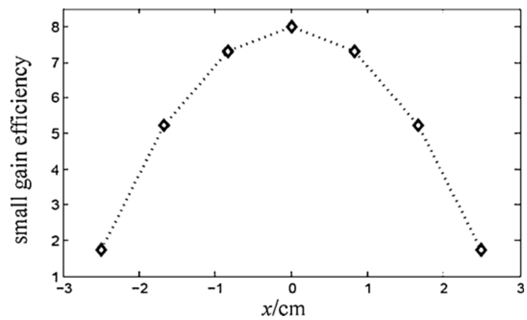

Fig. 4. The small signal gain coefficient along x-axis.

ASE flux and the coherent flux distributions in the amplifier can be calculated based on an iterative process. When a small signal gain coefficient is given, we can calculate the initial ASE flux and coherent flux distributions, the gain coefficient is then calculated. In each step of the iteration process, the ASE flux and the coherent flux are calculated using the gain coefficient obtained from the previous step. The quantities are renewed from time to time until the convergence condition $\left\|g^{new}(n, m, t) - g(n, m, t)\right\| \le 10^{-4}$ is reached. The amplification ratio and the energy extraction efficiency can calculation from the results of ASE flux and coherent laser flux. In combustion-driven DF chemical laser system, the width of gain medium is determined by inlet condition, but the length and the height of the gain medium is determined by the nozzle. Fig. 5 is the schematic of nozzle. In this letter we suppose the width of gain medium is invariable, but the length and the height of the gain medium can change; the laser's wavelength is 3.8 μm; the width of gain medium is 5 cm; the initial upper-state population density $N_0^* = 1.9 \times 10^{23}\ \mathrm{m^{-3}}$; the stimulated emission cross-section $\sigma = 2.09 \times 10^{-21}\ \mathrm{m^{-2}}$.

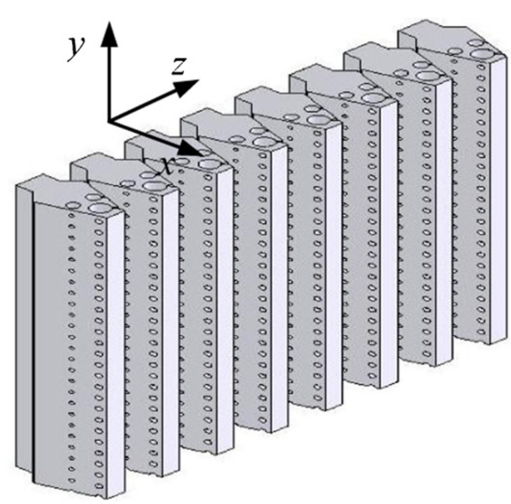

Fig. 5. The schematic of nozzle.

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