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INFLUENCE OF TIME DEPENDENCE OF DYNAMIC LASER PARAMETER ON THE THREE MODES RANDOM LASER OPERATION

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Abstract. *In this report we demonstrate the influence of the photon density on the operation of a three modes random laser when the gain coefficients of modes depending on time. Supposing gain coefficients had Gaussian profile and using Matlab language, we have solved the basic equations describing the operation of the three modes random laser. The received results give us more real knowledge about the appearance of modes in random laser.*

I. INTRODUCTION

Random laser appeared in the early 1990's since Lawandy et al. [1] reported stimulated emission from dye solution which contains micro-particles. After this report, many experimental and theoretical studies on random laser have been published [2-8]. In fact, the mechanism of light amplification in disordered media up to now is not clear. Therefore one has proposed hypothesis, supposition and realized many experimental or theoretical studies for explaining the operation of random laser.

With this aim, in the article [9] we have studied characteristics of modes generated by two and three modes random laser. The transformation of these mode characteristics depends mainly on the change of laser parameters like the gain and loss coefficients or the field coupling and photon hopping coefficients. However, in [9] that transformation corresponded only to the variation of the values of coefficients indicated above, while each coefficient, in fact, depended on time in the process of laser operation, and this time dependence was not disscussed.

Starting from this situation, in this work we examine the case in which the gain coefficient depends on time and we hope that the received results will give us a general and nearly real scenario about mechanism of random laser.

II. BASIC EQUATIONS AND METHOD OF RESOLUTION

Supposing random laser generated three modes with photon densities n_1, n_2, n_3, respectively, and where n_2 belongs to the middle mode. Following [4], equations describing the variation on time of modes are written, as follows:

$$\frac{dn_1}{dt} = \alpha_1 n_1 - \beta_1 n_1^2 - \theta_{12} n_1 n_2 + \gamma_{12} n_2 \quad (1)$$

$$\frac{dn_2}{dt} = \alpha_2 n_2 - \beta_2 n_2^2 - (\theta_{21} n_1 + \theta_{23} n_3)\, n_2 + \gamma_{21} n_1 + \gamma_{23} n_3 \tag{2}$$

$$\frac{dn_3}{dt} = \alpha_3 n_3 - \beta_3 n_3^2 - \theta_{32} n_2 n_3 + \gamma_{32} n_2 \tag{3}$$

Here α_i, β_i $(i = 1, 2, 3)$ are gain and loss coefficients and θ_{ij}, γ_{ij} $(j = 1, 2, 3)$ are field coupling and photon hopping coefficients, respectively.

In case the gain coefficients depend on time, we choose for α_i:

$$\alpha_i = \alpha_{0i} e^{-\Delta T\, t^2} \tag{4}$$

this α_i is corresponding to Gaussian profile of generated pulse mode.

For solving this system of equations with α_i following (4), we use numerical method on the base of Matlab language. Initial conditions are given:

$$n_1(0) = n_2(0) = n_3(0) = 0.2 \text{ (in a.u)}$$
$$\Delta T_1 = \Delta T_2 = \Delta T_3 = 2 \text{ (ns)}$$

Other values of coefficients α_{0i}, β_i, θ_{ij}, γ_{ij} are given in:

$$\alpha_{01} = 0.9 \text{ s}^{-1};\ \beta_1 = 0.4 \text{ cm}^3.\text{s}^{-1};\ \theta_{12} = \theta_{21} = 0.4 \text{ cm}^3.\text{s}^{-1};\ \gamma_{12} = 0.8\text{s}^{-1}.$$
$$\alpha_{02} = 1.3 \text{ s}^{-1};\ \beta_2 = 0.3 \text{ cm}^3.\text{s}^{-1};\ \theta_{23} = 0.4 \text{ cm}^3.\text{s}^{-1};\ \gamma_{21} = \gamma_{23} = 0.7 \text{ s}^{-1}.$$
$$\alpha_{03} = 0.9 \text{ s}^{-1};\ \beta_3 = 0.5 \text{ cm}^3.\text{s}^{-1};\ \theta_{32} = 0.4 \text{ cm}^3.\text{s}^{-1};\ \gamma_{32} = 0.8 \text{ s}^{-1}.$$

The distribution of mode photon densities $n_i(t)$ is presented in Fig. 1

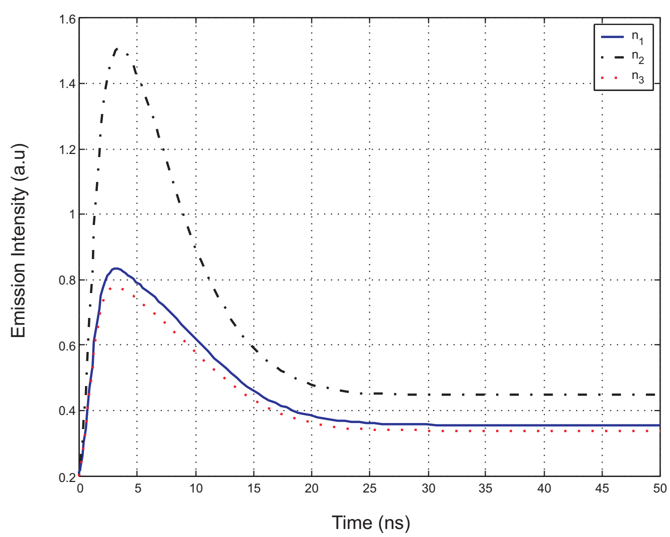

Fig. 1. The curves of $n_i(t)$ versus time.

From Fig. 1, we see that the profile of curves $n_i(t)$ in case the gain coefficient depending on time has same form as the gain coefficients are constant.

For examining the evaluation of photon density $n_i\,(t)$ when the profile of gain coefficients α_i varies, we note the three parameters of these curves as following:

The $\Delta\omega_i$ is the pulse width of the i^{th} mode.

The $I_i^{\max}$ is the maximum photon density of i^{th} mode.

The $T_i^{\max}$ is the time for reaching maximum photon density of i^{th} mode.

III. INFLUENCE OF THE VARIATION OF GAIN COEFFICIENTS

III.1. The influence of ΔT

Starting with the formula (4), we can vary one of two parameters ΔT and α_{0i}. Giving different values of ΔT and remaining invariable all values of coefficients presented above, we can receive curves $n_i(t)$ presented in figures 2, 3 and 4. From these figures we determine pulses mode parameters. The results are given in Table 1.

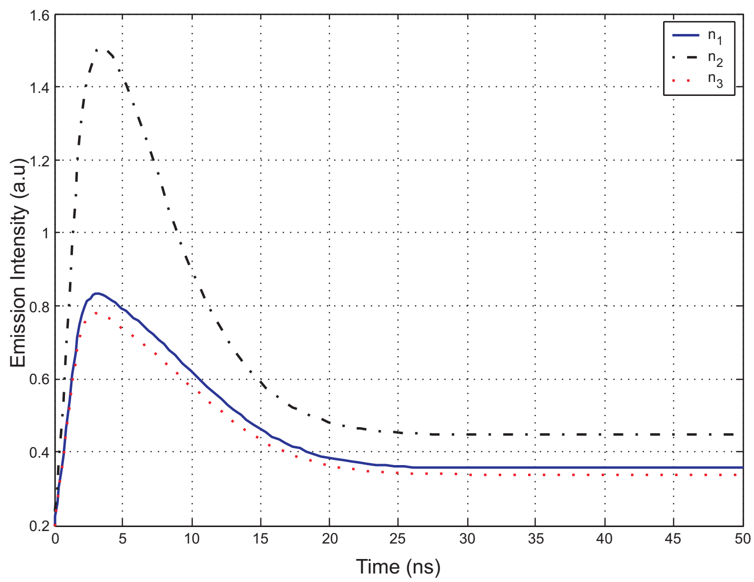

Fig. 2. The curves of $n_i(t)$ with $\Delta T = 2$ ns.

Table 1. Computation results of the influence of ΔT on the characteristics of modes of random laser

ΔT (ns)	$T_1^{\max}$ (ns)	$I_1^{\max}$ (a.u)	$\Delta\omega_1$(ns) (ns)	$T_2^{\max}$ (ns)	$I_2^{\max}$ (a.u)	$\Delta\omega_2$ (ns)	$T_3^{\max}$ (ns)	$I_3^{\max}$ (a.u)	(ns) (ns)
1	2.3848	0.6927	4.3548	2.2465	1.1050	4.8378	2.2465	0.6547	4.0092
2	3.4101	0.8284	9.4009	3.4908	1.5038	9.5391	3.2258	0.7751	9.2166
3	3.9174	0.8526	26.7281	6.1060	1.6854	29.9539	3.8018	0.7965	26.0368
4	6.4516	0.8620	94.0092	10.0230	1.7556	97.2458	3.8018	0.7965	87.5576
6			$\to\infty$			$\to\infty$			$\to\infty$

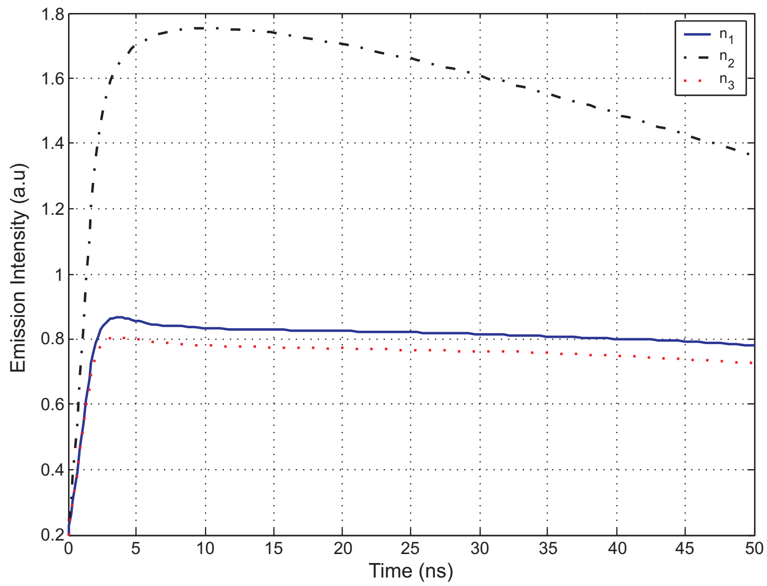

Fig. 3. The curves of $n_i(t)$ with $\Delta T = 4$ ns.

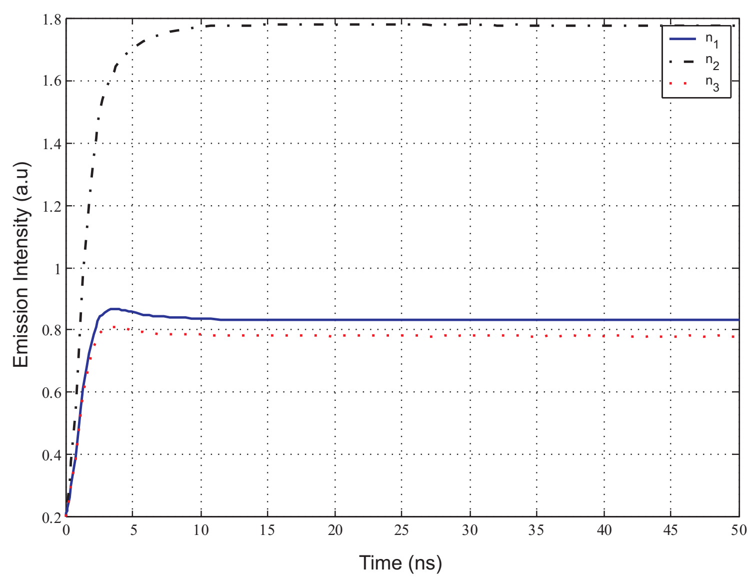

Fig. 4. The curves of $n_i(t)$ with $\Delta T = 6$ ns.

From received results, we see that: The more the values of ΔT are small, the quickly the time for reaching maximum photon density of mode attains and analogously the smaller the values of maximum photon density and pulse width have.

III.2. Influence of initial values of gain coefficients α_{0i}

By the same method of calculation, here we change in turn the values of α_{0i} ($i = 1$, 2, 3). Obtained results are given in Table 2, 3, 4.

Table 2. Computation results of the influence of α_{01} on the characteristics of modes of random laser

α_{01} (s^{-1})	T_1^{max} (ns)	I_1^{max} (a.u)	$\Delta\omega_1$ (ns)	T_2^{max} T_2^{max}(ns)	I_2^{max} I_2^{max}(a.u)	$\Delta\omega_2$ (ns)	T_3^{max} (ns)	I_3^{max}) (a.u)	$\Delta\omega_3$ (ns)
0.1	4.0438	0.4658	7.8111	3.9747	1.8000	8.7788	2.6613	0.7553	8.8479
0.3	3.9747	0.5205	8.9171	3.9055	1.7509	9.0553	2.7304	0.7591	9.2627
0.5	3.2834	0.5906	9.1244	3.8364	1.6854	9.3318	2.8687	0.7684	9.4700
0.7	3.2143	0.6936	9.7465	3.7673	1.6012	9.8847	2.9378	0.7778	10.0921
0.9	3.1452	0.8365	10.3686	3.4908	1.5079	10.1612	3.0530	0.7833	10.1785
1.1	3.3525	1.0289	10.9908	3.0069	1.4015	10.4378	3.2834	0.7956	10.2304
1.3	3.5599	1.2950	11.6820	2.7304	1.2991	11.3364	3.6290	0.8120	10.7834
1.5	3.9747	1.6620	10.7834	2.5230	1.2082	9.6774	3.9747	0.8339	9.3318

Table 3. The influence of α_{02} on the characteristics of modes of random laser

α_{02} (s^{-1})	T_1^{max} (ns)	I_1^{max} (a.u)	$\Delta\omega_1$ (ns)	T_2^{max} (ns)	I_2^{max} (a.u)	$\Delta\omega_2$ (ns)	T_3^{max} (ns)	I_3^{max} (a.u)	ω_3 (ns)
0.2	2.8687	0.8105	9.6774	3.9055	1.7556	8.9171	3.6982	0.4784	7.6037
0.4	3.0069	0.8199	9.8848	3.8364	1.6947	9.2627	3.5599	0.5345	8.2949
0.6	3.0760	0.8246	9.9539	3.7673	1.6339	9.3318	3.4908	0.6140	9.3318
0.8	3.1452	0.8325	10.2304	3.6290	1.5488	9.5318	2.9397	0.7178	10.0230
1.0	3.3525	0.8447	10.3329	3.4217	1.4629	10.2304	3.0069	0.8570	10.6452
1.2	3.4908	0.8611	10.6451	3.1452	1.3687	10.4378	3.1452	1.0412	10.0230
1.4	3.8364	0.8816	10.9907	2.7304	1.2746	11.4746	3.2143	1.2827	10.0922
1.6	4.1820	0.9102	11.6129	2.5230	1.1927	11.6820	3.4217	1.5898	10.2995

Table 4. The influence of α_{03} on the characteristics of modes of random laser

α_{03} (s^{-1})	T_1^{max} (ns)	I_1^{max} (a.u)	$\Delta\omega_1$ (ns)	T_2^{max} (ns)	I_2^{max} (a.u)	$\Delta\omega_2$ (ns)	T_3^{max} (ns)	I_3^{max} (a.u)	$\Delta\omega_3$ (ns)
0.5	4.3894	1.1079	9.4009	3.1452	0.6898	9.2627	4.1820	0.9792	9.4009
0.7	4.3203	1.0465	9.4700	3.1665	0.8096	9.5391	4.1129	0.9383	9.6774
0.9	4.1820	0.9778	9.6082	3.1943	0.9731	9.7465	3.8364	0.8865	9.7466
1.1	3.6982	0.9032	9.7330	3.2143	1.1965	9.8847	3.4908	0.8330	9.8157
1.3	3.0760	0.8325	9.8848	3.4908	1.5038	9.8156	2.9378	0.7792	9.9539
1.5	2.7304	0.7763	10.0230	3.6982	1.9289	9.8848	2.6613	0.7395	10.0230
1.7	2.2465	0.7346	10.1613	3.7673	2.4598	10.0230	2.3848	0.7054	10.2304
2.0	1.9700	0.6908	10.0231	3.6290	3.3823	9.8856	2.0392	0.6601	10.5069

From tables 2, 3 and 4, we see:

- The variation of α_{01} and α_{03} give the same effect for the evaluation of pulse mode parameters $T_i^{\max}$, $I_i^{\max}$, $\Delta\omega_i$.

- When α_{02} augments, the photon density of 2^{th} mode increases quickly. This point demonstrates that the more value of α_{02} is large, the quicker the photon hopping from near modes to middle mode grows.

IV. CONCLUSIONS

We have simulated the influence of the dynamic laser parameters (such as variation of gain coefficients) on the characteristics of three modes of random laser by rate equations. We demonstrate the influence of the photon density curves on the operation of a three modes random laser when the gain coefficients of modes depend on time. Especially, when the gain coefficient α_{0i} of any mode becomes largest, this mode will be brought in relief and laser generating three modes becomes laser generating single mode.

The numerical method used here in the case of three modes random laser, will be applied completely for the case of multimode random laser.

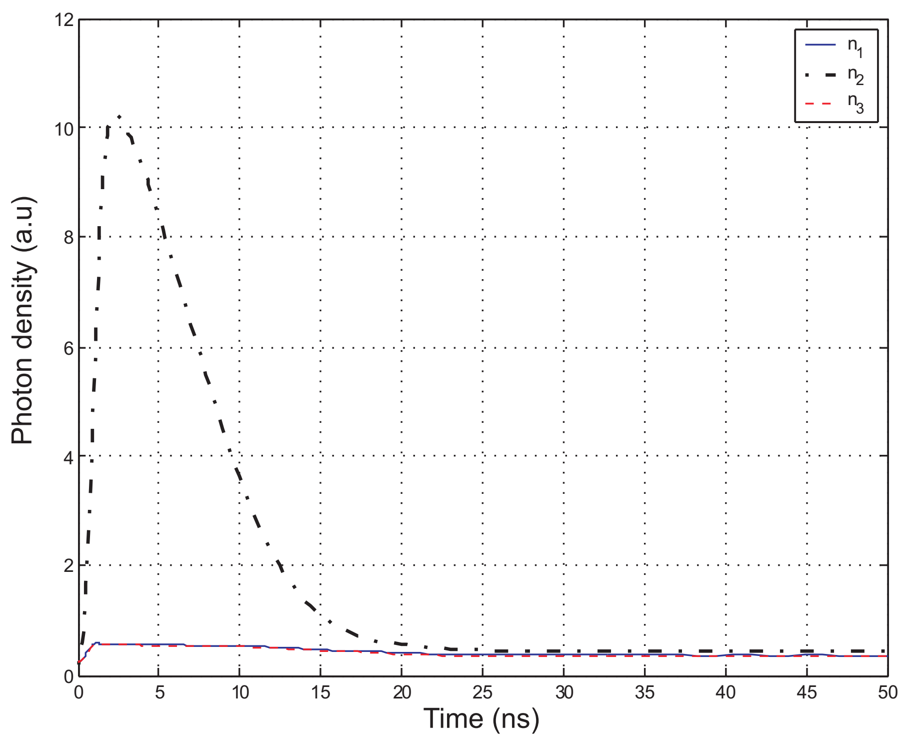

Fig. 5. The curves of $n_i(t)$ with $\alpha_{02} = 4\ \text{s}^{-1}$.

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