The study on THz light-waves in one-dimensional random media

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Abstract. The research on optical properties of the light-waves in random media has become research hotspot in laser physics. Many theoretical models have been developed to explain the experimental results. With the further research on the optical properties of the light-waves in different random media, the great importance of THz section is attached. We research on the THz light-waves in one-dimensional random media, and mainly focus on the Frequency spectrum and threshold property. The results show that each of these THz modes also has a typical threshold gain behavior and different threshold pumping rate.

1. Introduction

The research on optical properties of the light-waves in random media has become research hotspot in laser physics\textsuperscript{[1-11]}. In the past decade, several experiments on these two types of random lasers have been reported, and the output wavelengths almost all concentrated in a few hundred nanometer band\textsuperscript{[1-2]}. Many theoretical models have been developed to explain the experimental results\textsuperscript{[8-10]}. In our prior research\textsuperscript{[12-14]}, we create a numerical model of random media by simultaneously solving Maxwell’s equations and rate equations. Based on the model, the electromagnetic field inside the disorder system can be researched particularly. And we calculate and investigate the particular characters of the light-waves existed in the random media.

With the further research on the optical properties of the light-waves in different random media, the great importance of THz section is attached. Terahertz radiation is a newly developed coherent far infrared source, which has been applied in many research fields. In this paper, we improved the theoretic model and changed the parameters in order to find some difference of THz light-waves in one-dimensional random media. As the peak frequencies in the power spectrum reflect the frequency character of the localized modes, we can study the property of THz light-waves in disordered media.

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Supported by the National Natural Science Foundation of China (Grant No. 10876080) and China University of Mining and Technology Development Funds (Grant No. 2009A021).
from the spectrum. We research on the THz light-waves in the random media, and mainly focus on the frequency spectrum and threshold property. In the paper, we mainly study the spectrum property of THz modes in random gain media. And the semi-classical model equations of transverse electric of random laser are presented. For scattering particles with same spatial distribute, the properties of random system are computed numerically. It is denoted that the emission frequency and spatial pattern of modes are dependent on the parameters of the random media heavily. The results are similar as before.

In addition, the pumping rate dependence of the peak intensity of the individual lasing THz mode in two-dimensional active media is investigated. The results show that each of these modes has a typical threshold gain behavior and different threshold pumping rate. The newly research on the THz light-waves in random media have important impact on the application of THz bandwidth. And the new-style THz device enjoys easy fabrication and low cost.

2. Theoretical Model

In isotropic, non-magnetic, homogeneous dielectric random media, the Maxwell equations shown as following:

\[ \nabla \times \mathbf{H} = \varepsilon_0 \varepsilon \frac{\partial \mathbf{E}}{\partial t} + \frac{\mathbf{P}}{\varepsilon} , \quad (1.1) \]
\[ \nabla \times \mathbf{E} = - \frac{\partial \mathbf{H}}{\partial t} . \quad (1.2) \]

In one-dimensional case, for that propagates along the z direction, the equation (1) simplified as:

\[ - \frac{\partial H_y}{\partial z} = e_0 c^2 \frac{\partial E_x}{\partial t} + \frac{P_x}{\varepsilon} , \quad (2.1) \]
\[ \frac{\partial E_x}{\partial z} = - m_b \frac{\partial H_y}{\partial t} . \quad (2.2) \]

Eventually, \( \tilde{P} \) is described as obeying the quantum population equation of motion. There-into,

\[ \Delta N = N_2 - N_1, \quad \Delta \omega_\ell = \frac{1}{\tau_{32}} + \frac{2}{\tau_2}, \quad \kappa = 6\pi e_0 c^3 / (\omega_\ell^2 \tau_{32}) \]

\[ \frac{d^2 P_x}{dt^2} + \Delta \omega_\ell \frac{dP_x}{dt} + \omega_\ell^2 P_x = \kappa \Delta N(t) E_x , \quad (3) \]

The three-level rate equations read as following:

\[ dN_1 / dt = N_2 / \tau_{21} + N_3 / \tau_{31} - N_1 W_p , \quad (4.1) \]
\[ N_1 = N_T - N_2 - N_3 , \quad (4.2) \]
\[ dN_2 / dt = N_3 / \tau_{32} - N_2 / \tau_{21} + (E_x / \hbar \omega_\ell) dP_x / dt , \quad (4.3) \]
\[
dN_i / dt = N_i W_p - N_i / \tau_{31} - N_i / \tau_{32} - (E_i / h \omega_l) dP_i / dt ,
\]

(4.4)

Where \( W_p \) is the pump rate; \( N_i \) is the population density in level \( i \) (\( i = 1 \) to 3), \( \tau_{21} \), \( \tau_{32} \), and \( \tau_{31} \) are the lifetime of corresponding level, respectively; \( \omega_l \) is the transition frequency between levels 3 and 2.

The values of those parameters in above equations that will be used in simulating the active part in the following numerical calculations are taken as: \( l = 5000 \mu m \), \( d = 50 \mu m \), \( T_2 = 10^{-11} \) s, \( \tau_{32} = 10^{-10} \) s, \( \tau_{31} = \tau_{21} = 3 \times 10^{-3} \) s, \( N_f = \sum_{j \neq 1} N_j = 10^{27} m^{-3} \). We use a broadband Gaussian pulse with random amplitude as an excitation source, and the electromagnetic fields can be calculated by use of the FDTD methods and PML absorbing boundary manner to solve equations above \(^{[13]}\).

3. Results and Discussions

First, we obtained the spectrum which is shown in figure 1, in which we select the THz mode marked by \( \lambda_1 \) with \( \lambda_1 = 0.47 \mu m \), \( \lambda_2 = 0.50 \mu m \) and \( \lambda_3 = 0.52 \mu m \). Obviously, the mode \( \lambda_2 \) can be stimulated with the pumping rate \( W_p = 10^{16} \) s\(^{-1}\).

![Figure 1](image_url)

**Figure 1** The spectrum of THz modes (a) Passive mode (b) Active mode and \( W_p = 10^{16} \) s\(^{-1}\)

As can be seen, the peak intensity of the THz mode with pumping is much stronger than that of the THz mode in passive case. It indicates that THz modes also can be excited. In fact, in our foregoing studies, we have demonstrated the point. In order to have a further research on the threshold property of THz mode, we trace out the evolution curves of marked THz modes by recording the peak intensities of them at different pumping rate which are shown as figure 2. There-into, the thresholds of
the marked THz modes are \( W_{\text{ph}_2} = 6.8 \times 10^{14} \text{s}^{-1} \), \( W_{\text{ph}_3} = 7.1 \times 10^{14} \text{s}^{-1} \) and \( W_{\text{ph}_1} = 8.35 \times 10^{14} \text{s}^{-1} \), respectively.

![Figure. 2 The pumping rate dependence of the power of the three marked modes in the active system](image)

The evolution process indicates the threshold property of THz modes distinctly. Therefore, we can study the property of THz modes in two-dimensional random media with the similar method. As we know each lasing mode has its own spatial region in a 2D medium, pumping this region locally would exalt the mode preferentially, thus offering an effective method to obtain some special THz modes we want.

## 4. Conclusion

In the paper, we studied the threshold property and spectral property of THz light-waves in the random media. The results show that each of these modes has a typical threshold gain behavior and different threshold pumping rate. It is denoted that the emission frequency and spatial pattern of modes are similar as forgoing study. The THz modes have similar property. Simultaneity, we can introduce the fabrication and testing of the THz random media film as the common case we studied before. The newly research on the THz light-waves in random media have important impact on the application of THz bandwidth. And the new-style THz device enjoys easy fabrication and low cost.

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