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# Influences of diffusive reflection intensity and pulse shaping of ultra-short laser on turbid media

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The influences of the absorption $\mu_a$, the scattering $\mu_s$ and the anisotropy coefficient $g$ on the optical properties of ultra-short pulse in turbid media has been simulated that is based on the diffusive approximation theory. The laser pulse intensity will be attenuated and the diffusive scattering pulse shape will be widened in the turbid media. The various medium parameters have different influence on the reflection of the laser pulse. The intensity loss of the diffusive reflection light is obtained when the $\mu_a$ and $\mu_s$ is increased in turbid media. The pulse width is rapidly increased of the diffusive reflection pulse far away from the incident point and the same time the pulse time are delayed have been numerical simulated in the boundary condition of semiinfinite homogenous media.

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**1. Introduction.** In turbid medium, the picosecond (ps) laser is scattered and absorbed due to the in-homogenous and absorption characteristics of the medium. The diffusive scattering is mainly existed when the red and infrared radiation incident to the turbid material [1], it is the statistics reaction of the interaction between the ps laser and absorption medium that is the parameters of a scattering intensity and pulsewidth by the properties of a tissue optics and scattering of the pulse laser in the diffusive reflectance and transmittance [2]. The widely increasing application of ultrashort pulse laser in diagnostic and therapeutic medicine has obtained the need to determine noninvasive the optical parameters of turbid medium by the interaction of the medium and radiation light [3, 4]. These properties have been devoted to the measurement of the optical properties of turbid tissue specimens, and the detection of diffusion reflected and transmitted light have been studied by authors [5]. Recently, the relationship has been researched in the absorption and scattering coefficient of tissue and the spatial dependence of diffusive reflecting near a finite light resource [6, 7]. Theoretical studies of light pulse propagation in multiple scattering media based on the diffusion approximately theory have been researched by Shimmer [8] and Furutsu [9]. The time resolved reflectance of a plane wave has measured by Shimizu et al. [10] from suspensions of microspheres and suggested that this technique might be used to determine the optical properties of tissue. The studies of time resolved reflectance and transmittance for the noninvasive measurement of tissue optical properties have produced by Patterson et al. [4]. In vivo technique for a small source. In this paper, the laser pulse energy will be attenuated in the turbid media and the pulse shape will be changed by scattering and absorption. Besides, the diffusive scattering widens the ultra-short pulse. The various medium parameters have different influence on the reflection of the laser pulse. Based on the diffusion approximation theory, the boundary condition of semi-infinite homogeneous media by a small narrow line-width laser beams, the influence of the absorption $\mu_a$, the scattering $\mu_s$, and the anisotropy coefficient $g$ on the ultra-short pulse in the condition has been obtained.

**2. Theoretical analysis and numerical simulation.** The biological tissue is made of the cells of different size and composition that is called turbid media [3]. The spectral ranges from about 600 to 1300 nm are of particular interest wavelengths, since at these wavelengths the absorption of light by most soft tissues is a minimum [11]. The relatively low absorption in this so-called "therapeutic window". The optical properties information of the turbid medium is shown in the diffusive reflection and transmittance light. The geometry of narrow line width ultrashort pulse beam is normally incident on the surface of a semiinfinite homogeneous tissue slab that is shown in Fig.1a. We simulated a practical in Monte Carlo methods in which a ps as produced on turbid tissue surface of semiinfinite medium by a small narrow linewidth pulse beams, the diffusion equation of

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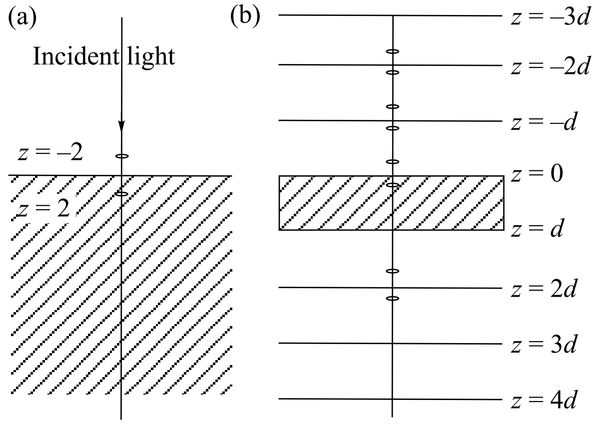


Fig.1. Diagram of ultrashort pulse incident on semiinfinite and infinite homogeneous tissue: (a) and (b)

the diffusive photon fluency intensity $\phi(\mathbf{r},t)$ can be written [4]

$$\frac{1}{\nu}\frac{\partial}{\partial t}\phi(r,t) - D\nabla^2\phi(r,t) + \mu_\alpha\phi(r,t) = \delta(0,0) \quad (1)$$

where $D = [3(\mu_\alpha + (1-g)\mu_s]^{-1}$ is the diffusion coefficient, $\mu_a$ is the linear absorption coefficient, $\mu_s$ is the linear scattering coefficient, $g$ is the mean cosine of scattering angle, $v$ is the speed of the light in the tissue, and $\delta(0,0)$ is an isotropic point photon source. It may be shown that in a semiinfinite turbid medium the solution of Eq. (1) is

$$\Phi(\mathbf{r},t) = \nu(4\pi D\nu t)^{-3/2}\exp\left(-\frac{r^2}{4D\nu t} - \mu_a\nu t\right). \quad (2)$$

All the incident photon is initially scatted at a depth $z_0 = [(1-g)\mu_s]^{-1}$ so that the actual source becomes the simple delta function described above. Patterson [4] et al. have shown that a useful assumption is that $\phi(\mathbf{r},t) = 0$ on the physical boundary $z = 0$. The fluency rate per incident photon can then be written in cylindrical coordinates as the sum of contributions as follow

$$\Phi(\rho,z,t) = \nu(4\pi D\nu t)^{-3/2}\exp(-\mu_a\nu t)\times$$
$$\times\left\{\exp\left[-\frac{(z-z_0)^2+\rho^2}{4D\nu t}\right] - \exp\left[-\frac{(z+z_0)^2+\rho^2}{4D\nu t}\right]\right\}. \quad (3)$$

The number of photon reaching the surface per unit area per unit time is $|J(\rho,0,t)|^2$, which can be calculated from Fick's law [12]: $J(\rho,0,t) = -D\nabla\Phi(\rho,z,t)|_{z=0}$, which leads to the final expression for the reflectance $(\rho,t)$ that is ultra-short pulse incident to the semiinfinite homogeneous tissue medium

$$R(\rho,t) = |J(\rho,0,t)| =$$
$$= (4\pi D\nu)^{-3/2}z_0t^{-5/2}\exp(-\mu_a\nu t)\exp\left(-\frac{\rho^2-z_0^2}{4D\nu t}\right). \quad (4)$$

Where $\rho^2 \gg z_0^2$ is noted that the observation is known

$$\lim\frac{d}{dt}\log_e R(\rho,t) = -\mu_a\nu. \quad (5)$$

From Eq. (5), the absorption coefficient of the tissue can be determined from the asymptotic slope of the curve of the $\log_e R(\rho,t)$ versus time $t$. The speed of light depends on the index of refraction $n = 1.4$ of the tissue which is known to a few percent, $v = 0.214$ mm/per second [13].

The propagation scattering coefficient $\mu_s$ can also be calculated using the $\log_e R(\rho,t)$ versus $t$ in the slope is zero and the $t_{\max}$. Solving Eq. (4) can be written the expression

$$(1-g)\mu_s = \frac{1}{3\rho^2}(4\mu_a\nu^2t_{\max}^2 + 10\nu t_{\max}) - \mu_a. \quad (6)$$

The optical properties of a semiinfinite slab of tissue from Eq. (5) and Eq. (6) could in principle be obtained by simulated the diffusive reflected light some distance

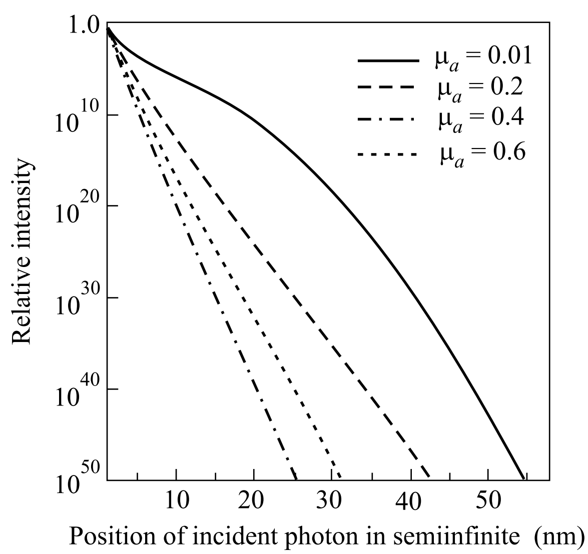


Fig.2. Intensity of backscattered light versus position of incident photon medium

from the source as a function of time. The total diffusive reflection rate $R(\rho,t)$ can be obtained from the spatial integral of $R(\rho,t)$

$$R(t) = \int_0^\infty R(\rho,t)2\pi\rho d\rho =$$
$$= (4\pi D\nu)^{-1/2}z_0t^{-3/2}\exp(-\mu_a\nu t)\exp\left(-\frac{z_0^2}{4D\nu t}\right). \quad (7)$$

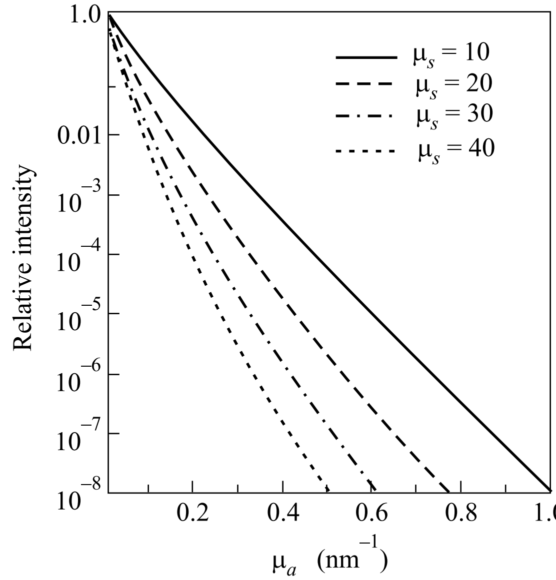


Fig.3. Curves of diffusion reflection intensity

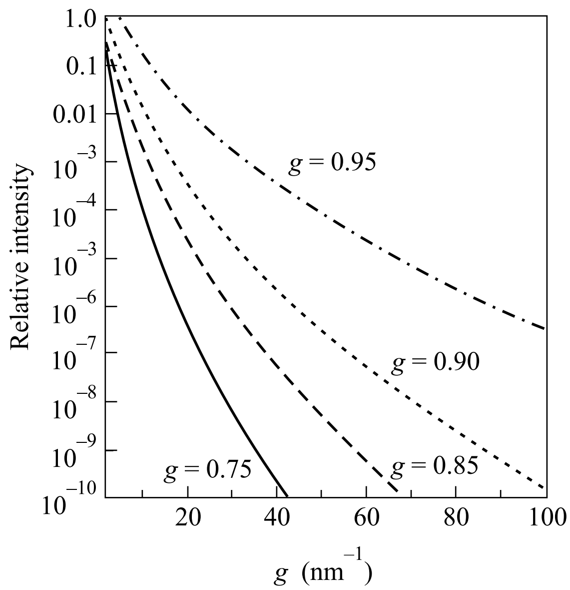


Fig.4. Curves of backscattered light intensity versus $\mu_s$

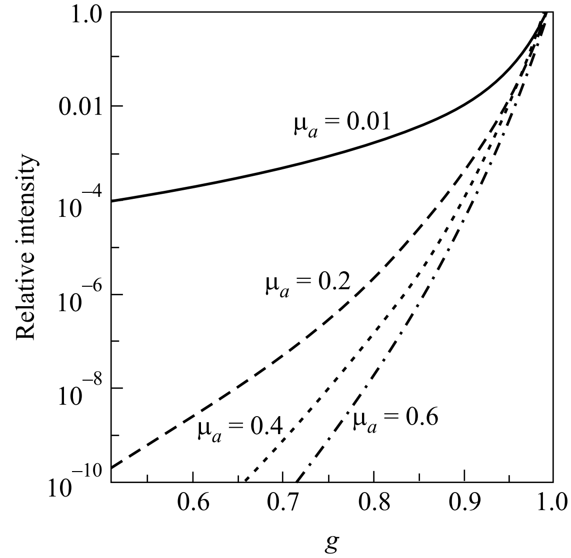


Fig.5. Curves of intensity and scattering $g$

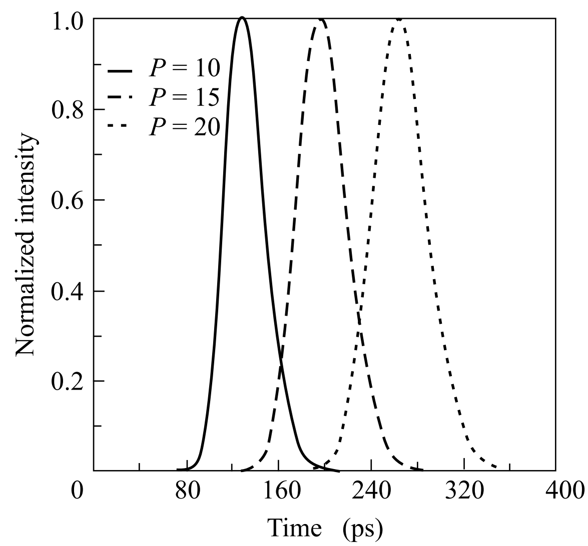


Fig.6. Curves of pulse shaping with incident position into medium

This expression agrees with the results of Patterson [4] et al. that for a non-absorption medium the total diffusive reflectance should depend on $t^{-3/2}$.

An important question is how simulation of the diffusive reflection are affected by $\mu_a$, $\mu_s$ and $g$ in a semiinfinite tissue material. According to the theoretical analysis and computer simulation from Eq. (4). We have obtained the theoretical curves of the backscattering intensity of diffusive reflectance light caused at the different transport simulation $P$, $\mu_a$, $\mu_s$ and $g$ as shown in Fig.2, Fig.3, Fig.4 and Fig.5. From Fig.2 and Fig.3, it can be clearly shown that the affect of the absorption coefficient versus the intensity loss of the diffusive reflection light, which is decreased when the $\mu_a$, $\mu_s$. The backscattered intensity is increased when $g$ is increased and $\mu_a$ is small, as shown in Fig.4, and Fig.5. From Fig.2 to Fig.5, it is shown that the intensity of diffusive reflection is very use to obtain the physical parameters of the optical properties in the internal turbid medium. The pulse width of the diffusive reflection pulse is affected by the optical parameters of the turbid medium, the pulse width is rapidly increased of the diffusion reflection pulse laser far away from the incident point and the same time the pulse time are delayed as shown in

Fig.6. The pulse-width of the reflection light is narrowed in Fig.7. The time delay of the diffusive reflection light

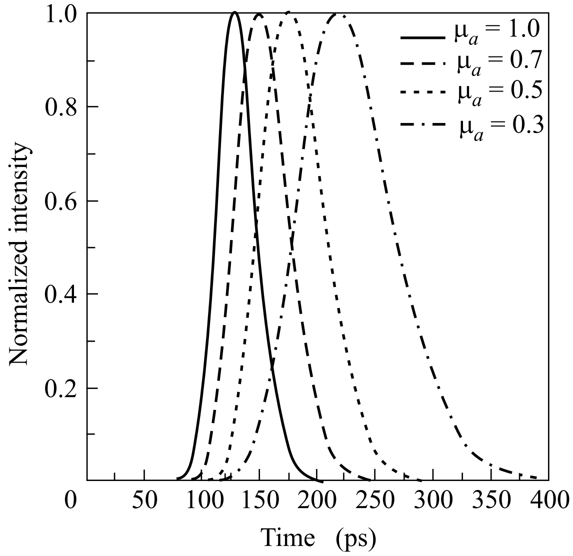


Fig.7. Diffusion scattering pulse shaping and intensity versus $\mu_a$

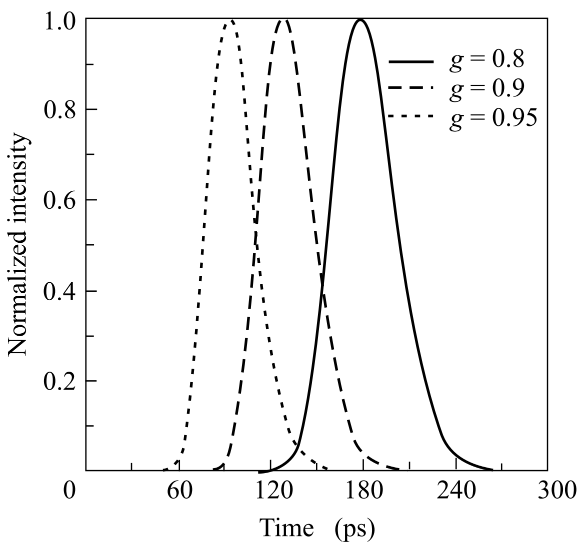


Fig.8. Curves of pulse shaping versus $\mu_s$

caused by the $\mu_s$ is increased as shown in Fig.8. The pulse width of the diffusion reflection light is rapidly narrow and the time delay of the reflection pulse at $g$ is increased as shown in Fig.9. From Fig.2 to Fig.9, it is shown that the interaction of the ultra-short pulse and the turbid tissue is very used as researching the optical parameters of the turbid medium.

**3. Conclusions.** The purpose of this paper has been researched the relations of diffusive reflection rate

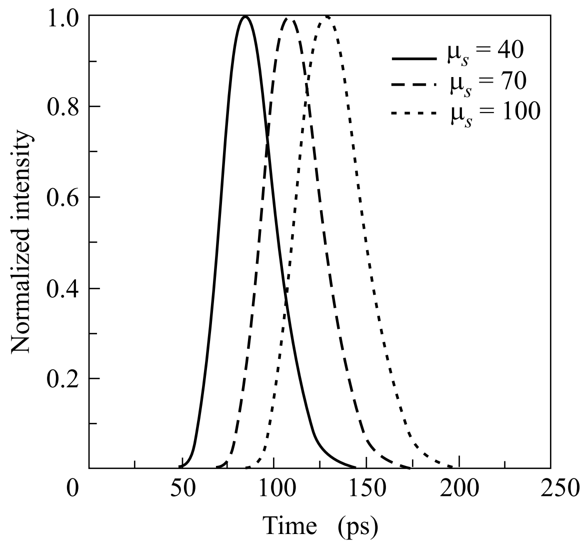


Fig.9. Curves of pulse shaping versus $g$

$R(\rho, t)$ and optical properties in turbid media. The results of principle simulation have corrected in coherence with experiments [14] by computer numerical analysis. It is calculated that the parameters $\mu_a$, $\mu_s$ and $g$ in the tissues use a indirect and lossless methods according to the theory foundation. It is useful for the development of laser biology and medicine measurement.

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