Supplementary Materials

Controllable photoinduced scattering and optimized light emission intensity in Nd^{3+} doped (Pb,La)(Zr,Ti)O_3 perovskite ceramics

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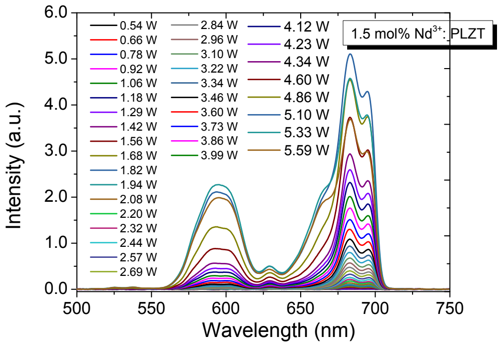
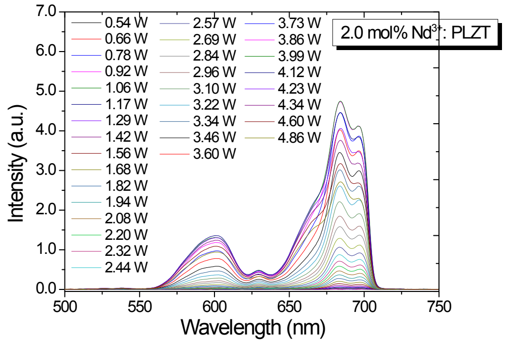
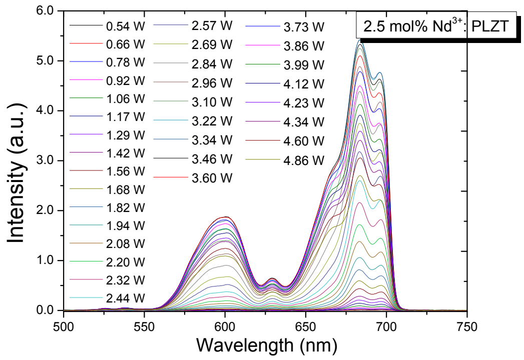
Materials 1. Luminescence Spectra in different Nd^{3+} ions doped (Pb,La)(Zr,Ti)O3 perovskite ceramics



(a)



(b)

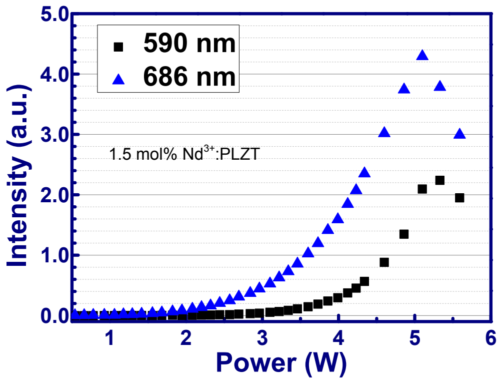


(c)

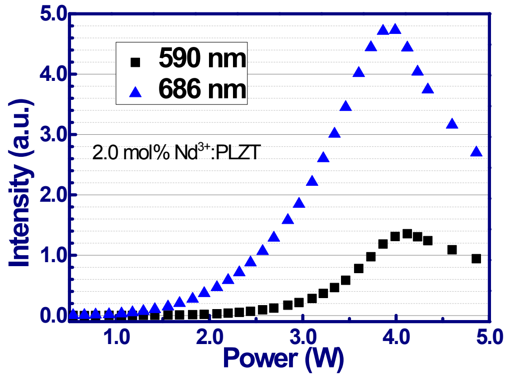
Fig. S1 Light emission spectra in 1.5 mol%, 2.0 mol%, and 2.5 mol% Nd^{3+} doped (Pb,La)(Zr,Ti)O_3 perovskite ceramics

Materials 2. Light emission intensity at 590 nm and 686 nm in different Nd^{3+} ions doped

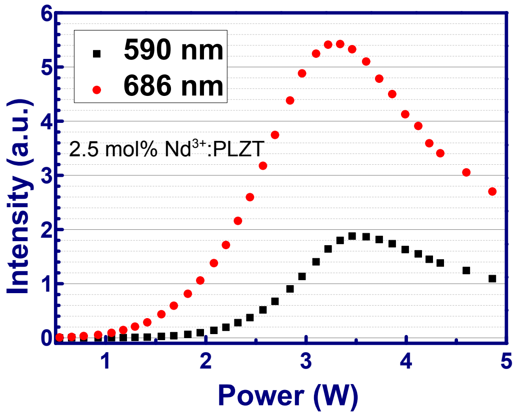
(Pb,La)(Zr,Ti)O3 perovskite ceramics



(a)



(b)



(c)

Fig. S2 Light emission intensity under different pumping power in 1.5 mol%, 2.0 mol%, and 2.5 mol% Nd^{3+} doped (Pb,La)(Zr,Ti)O_3 perovskite ceramics

Materials 3. Photoinduced scattering effect in different Nd^{3+} ions doped (Pb,La)(Zr,Ti)O3 perovskite ceramics

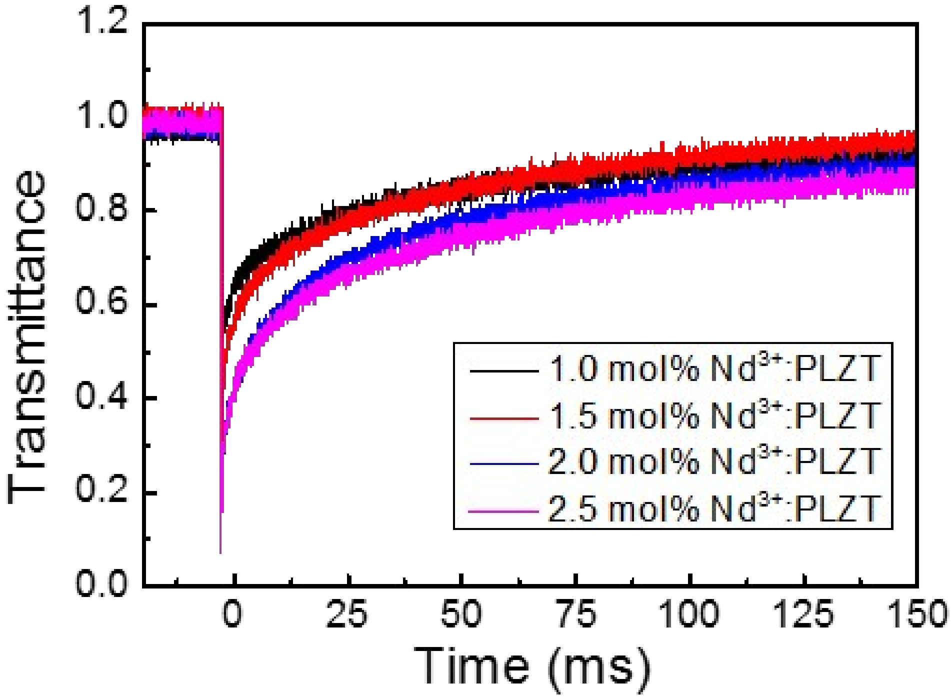


Fig. S3 Photoinduced scattering effect under pumping energy of 10 mJ in different Nd^{3+} in 1.5 mol%, 2.0 mol%, and 2.5 mol% Nd^{3+} doped (Pb,La)(Zr,Ti)O_3 perovskite ceramics

Materials 4. The change of effective absorption coefficient in different Nd^{3+} ions doped (Pb,La)(Zr,Ti)O_3 perovskite ceramics

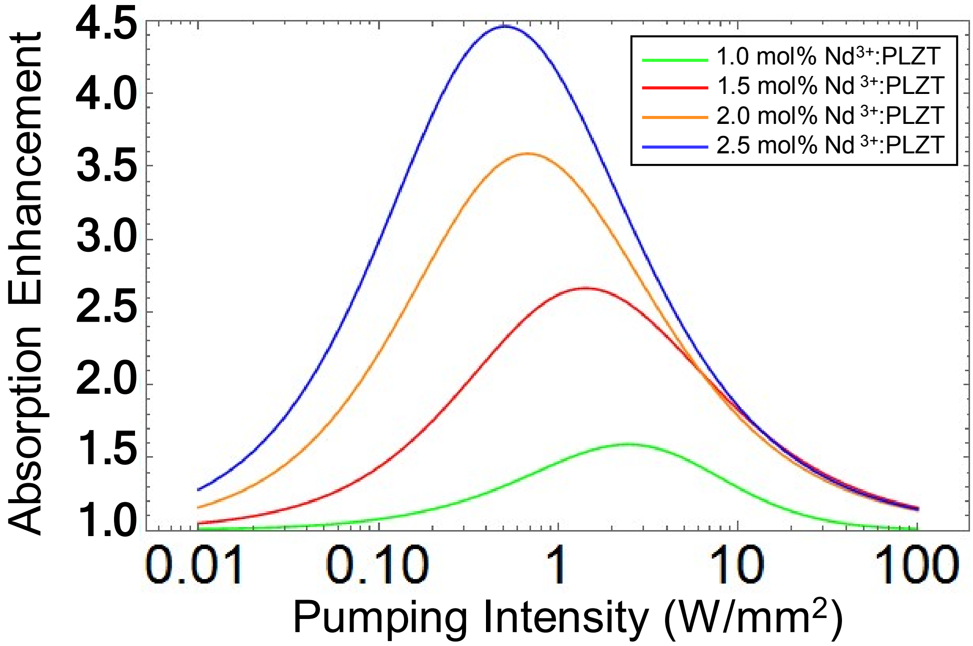


Fig. S4 The change of effective absorption coefficient along with increasing pumping energy in different Nd^{3+} in 1.5 mol%, 2.0 mol%, and 2.5 mol% Nd^{3+} doped (Pb,La)(Zr,Ti)O_3 perovskite ceramics

Materials 5. Detail description about the simulation techniques used in the manuscript.

(1) The changes of transmittance ($T(\lambda)$) and reflectance ($R(\lambda)$) of light under increasing intensity of diode laser

Light propagation dynamic process in disordered medium could be described by the diffusion equation [1],

$$\frac{\partial W(\vec{r},t)}{\partial t} = D\nabla^2 W(\vec{r},t) \tag{S1}$$

Where D is the diffusion coefficient, which could be expressed as $D=\frac{cl_t}{3n}$, here c is light velocity in vacuum, n is the effective refractive index of the specimen, and l_t is the transport mean free path length of light in the scattering medium. Discuss the condition of a point source at a depth L, the transmittance and reflection of light can be written as the following relations [2]

$$R(l,t) = 4\pi D\frac{\partial}{\partial l}W(l=0,t) \tag{S2a}$$

$$T(l,t) = -4\pi D\frac{\partial}{\partial l}W(l=L,t). \tag{S2b}$$

And then Eq. (S1) could be solved by the time-reversal method, and the transmittance and reflection of light could be expressed as [3],

$$T(t) = -\frac{2\pi D}{(L+2z_e)^2}\sum_{n=1}^{\infty} n\sin\left(n\pi\frac{l_t+z_e}{L+2z_e}\right)\cos\left(n\pi\frac{L+z_e}{L+2z_e}\right)\exp\left[-\frac{n^2\pi^2 Dt}{(L+2z_e)^2}\right] \tag{S3a}$$

$$R(t) = \frac{2\pi D}{(L+2z_e)^2}\sum_{n=1}^{\infty} n\sin\left(n\pi\frac{l_t+z_e}{L+2z_e}\right)\cos\left(n\pi\frac{z_e}{L+2z_e}\right)\exp\left[-\frac{n^2\pi^2 Dt}{(L+2z_e)^2}\right] \tag{S3b}$$

And then the total transmittance and reflection of light in disordered media could be written as

$$T = \int_0^{\infty} T(t)dt, R = \int_0^{\infty} R(t)dt. \tag{S4}$$

Where L is the optical length of the sample, and z_e is the extrapolation length of the incoming light ($z_e = \frac{2}{3}l_t\frac{1+r_i}{1-r_i}$), and r_i is the average internal reflection coefficient and can be calculated by Fresnel coefficient. Based on Eqs. (S3)-(S4), we can get the changes of transmittance and reflection of light along with the transport mean free length l_t. It is worth noting that l_t was not constant but vary with the pumping intensity in PLZT ceramics, which could be calculated based on the rate equations below [4].

$$\frac{dn(t)}{dt} = [N - n(t)]\,\mathrm{A}_C\, n_C(t) - \mathrm{A}_E\, n(t) \tag{S5a}$$

$$\frac{dh(t)}{dt} = [H - h(t)]\,\mathrm{A}_C\, n_v(t) - h(t)\,\mathrm{A}_R\, n_C(t) \tag{S5b}$$

$$\frac{dn_C(t)}{dt} = NA_aE_p - [N - n(t)]A_C n_C(t) - h(t)A_R n_C(t) \tag{S5c}$$

$$\frac{dn_V(t)}{dt} = NA_aE_p - [H - h(t)]A_C n_V(t) \tag{S5d}$$

Where N, $n_c(t)$, $n_t(t)$, and $n_v(t)$ represent the total free electron concentration, the concentrations of the electrons in the conduction band, the TDT level, and valence band, respectively. A_c and A_E are the possibilities of electron trapped by traps and escaping from traps. $\mathrm{A_a}$ and $\mathrm{A_R}$ are the cross section of absorption and possibilities of electron-hole combination, respectively. According to the Eqs. (S5a)-(S5e), the calculation results of the number of the photoinduced scatterers (n) and transport mean free path length (l_t) were exhibited in Fig. 3(e) in the manuscript. And then, the changes of transmittance ($T(\lambda)$) and reflectance ($R(\lambda)$) of light under increasing intensity of diode laser could be simulated based on Eqs. (S3a)-(S5e), as seen in Fig.3(c) in the manuscript.

(2) The effective absorption enhancement

The average time of light resident in the specimen could be estimated as

$$\langle t \rangle = \int tT(t)dt + \int tR(t)dt \tag{S6}$$

In a thin sample which meet the relation of $l_t = L$, the average time of light travelling in the sample could be written as

$$\langle t \rangle \approx \frac{L(l_t + z_e)}{2D}. \tag{S7}$$

And the average length of light travelling in the sample could also be estimated as

$$\langle l \rangle = v\langle t \rangle = \left(\frac{3}{2} + \frac{1+r_i}{1-r_i}\right)L. \tag{S8}$$

We can see that the larger r_i is, the longer the average length of light travelling in the sample is. At this time, light propagation length in scattering media could not be described only by the thickness of the specimen, and the absorption law of the specimen also changed along with the increased photoinduced scattering events, which could be modified in weak absorption media as

$$I = (1-R)I_0 e^{-\alpha'\langle l \rangle}. \tag{S9}$$

In weak absorption media (⍰$\alpha L \ll 1$), the effective absorption coefficient could be written as

$$\alpha' = \frac{[1-R]\sum_i \langle l_i \rangle}{L}\alpha. \tag{S10}$$

Where $\langle l_i \rangle$ is the average length of light travelling in each small region, and $\langle l \rangle = \sum_i \langle l_i \rangle$.

While the reflection of light *R* could also increase along with the growing number of scattering events, as a result, the enhancement factor of absorption coefficient of 1.0 mol% Nd^{3+} doped PLZT ceramics at 804 nm was not just increased but declined at a critical value, as seen the simulation result in Fig. 4(a), that's why there is a threshold beyond which the change in absorption is negative.

References

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