Recent progress of laser performance in Nd-doped yttrium lanthanum oxide transparent ceramics

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Received April 2, 2012; accepted August 13, 2012; posted online December 20, 2012

$Nd_{0.02}Y_{1.78}La_{0.2}O_3$ transparent ceramic is fabricated by conventional ceramic sintering process. The transparent ceramic has excellent spectroscopic properties, with the absorption cross section of 1.53×10^{-20} cm^2 and broad full width at half maximum (FWHM) of about 8 nm at 806 nm, the emission cross section of 3.57×10^{-20} cm^2 at 1 078 nm, and the decay lifetime of 232 μs. For $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic laser, a maximum continuous wave (CW) laser output power of 1.38 W with a slope efficiency of 22.9% is obtained at 1 079 nm under an 808 nm diode pump.

OCIS codes: 140.3380, 160.3380, 160.5690.

doi: 10.3788/COL201210.S21417.

The cubic sesquioxide Re_2O_3 (Re=Y, Sc, and Lu) with excellent thermal conductivities (12.5–16.5 W/mK) isotropic construction are excellent laser materials. However, it is difficult to grow large-size high-quality Re_2O_3 single crystals because of their high melting temperature of 2 430∼2 480 °C. Now it is easy to fabricate high quality Re_2O_3 ceramics at a relatively low temperature, which is about 700 °C lower than their melting temperature by a nanocrystalline and ceramics sintering technology. The first laser oscillation in Nd-doped Re_2O_3 ceramics materials was reported in 1973[1], the laser material is Nd^{3+} doped Y_2O_3-ThO_2 (NDY) solid-solution transparent ceramics. Since 2000, the optical quality of Re_2O_3 transparent ceramic has improved greatly and is good enough to obtain laser oscillations. In 2001, 1.5 at.-% Nd:Y_2O_3 transparent ceramics fabricated by nanocrystalline and vacuum sintering technology realized laser output under LD pumping, a maximum output power of 160 mW with a slope efficiency of 32% was obtained[2]. Next year, 0.15 at.-% Nd:Lu_2O_3 transparent ceramics fabricated by the same technology realized laser output under LD pumping, output power of only 10 mW with a slope efficiency of 13.6% was obtained[3]. This is the first report of Nd:Lu_2O_3 ceramic laser. In 2009, another 1 at.-% Nd:Y_2O_3 ceramics fabricated by a new technology including laser synthesis of nanopowders and the magnetic pulsed compaction got laser oscillation, the highest output power near 100 mW with a slope efficiency of 15% under LD pumping has been obtained[4]. Almost at the same time, 1.5 at.-% Nd:$Y_{1.8}La_{0.2}O_3$ transparent ceramic fabricated by solid-state reaction method realized laser output, a maximum output power of 62 mW was obtained under diode pumping[5].

In this letter, $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ transparent ceramic was fabricated by a solid-state reaction method, the spectroscopic properties and laser performance were investigated. $Y_{2-2x}La_{2x}O_3$, a solid solution of Y_2O_3 and La_2O_3, has lower sintering temperature than Y_2O_3 ceramics, and what is more, it has cubic glass-like structure, which make it possible to have broad absorption bandwidth.

High purity Y_2O_3, La_2O_3 and Nd_2O_3 nanopowders were used as starting materials (All purchased from Rare-Chem. Hi-Tech Co., Ltd, China). The composition of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ nanopowders was mixed with ZrO_2balls in anhydrous alcohol for 5∼10 h, calcined at 1 100∼1 200° for 5∼10 h. Finally the disks with 15 mm in diameter and 6∼8 mm in thickness were isostatically pressed at 200 MPa and sintered at 1 650∼1 700° for 40∼50 h in H_2 atmosphere.

The sintered specimen was double polished for spectral analysis and laser performance. The absorption spectrum was measured with a spectrophotometer using Xe light as pump source (Model V-570, JASCO, Japan). The fluorescence spectra excited by 808 nm LD was measured with a fluorescence spectrum analyzer (Fluorolog-3, Jobin Yvon Spex, France). All the spectroscopic analyses were made at room temperature.

The ceramic employed in continuous wave (CW) laser experiment has a dimension of 5×3×3 (mm). Both faces of the ceramic are finely polished and antireflection coated at 808 nm (R<1.8%) and from 1 040 to 1 090 nm (R<0.2%). A plano-concave cavity was used. The pump source is a commercial fiber-coupled diode laser (LIMO GmbH, Germany) emitting at 808 nm with a core diameter of 200 μm (NA=0.22) which was focused into the crystal with a refocus module with a magnification of 1.

Figure 1 shows the transmittance of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ transparent ceramic. The in-line transmittance around wavelength of 1 100 nm is over 80%. The room-temperature absorption spectrum is presented in Fig. 2. The strongest absorption peak is located on 580 nm and the absorption band from 780 to 850 nm is suited for LD pumping. The effective bandwidth ($\Delta\lambda_{\rm eff}$) is used to calculate the full-width at half-maximum (FWHM) due

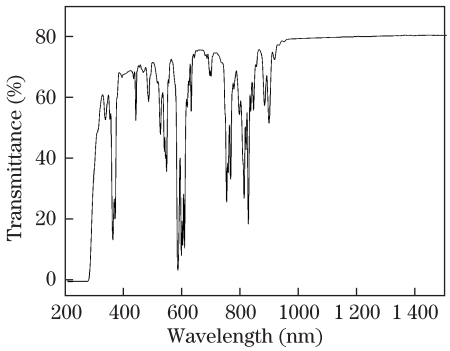

Fig. 1. Transmittance of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ transparent ceramic.

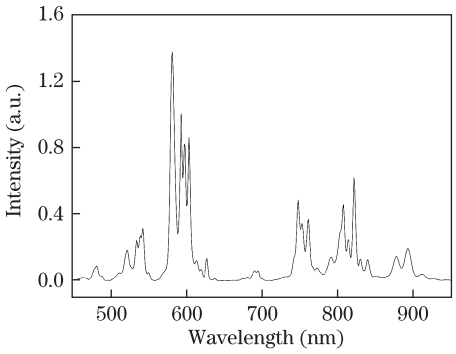

Fig. 2. Room-temperature absorption spectrum of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic.

to the unsymmetry of absorption peaks.

$$\Delta\lambda_{\text{eff}} = \int \frac{I(\lambda)}{I_{\text{p}}} \mathrm{d}\lambda, \tag{1}$$

where $I(\lambda)$ is the absorption intensity, and I_p is the intensity at the absorption peaks. The calculated FWHM of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic at 806 nm is about 8 nm, which is two times that of Nd:Y_2O_3 ceramic (4 nm)[5]. Since $Y_{1.8}La_{0.2}O_3$ transparent ceramic has a disorder glasslike structure, the absorption spectrum is broaden imhomgeneously. With broad absorption bands, $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic is lower dependent on temperature control of diode pumping and is advantageous to be a kind of material for miniaturization laser devices application.

Based on the absorption spectrum, the absorption cross section σ_{abs} of Nd^{3+} at wavelength λ can be calculated as

$$\sigma_{\text{abs}} = \frac{2.303\lg(I_0/I)}{L \cdot N}, \tag{2}$$

where $\lg(I_0/I)$ is the optical density, N is the number of active ions in unit volume, and L is the thickness of specimen. The absorption cross section σ_{abs} at wavelengths of 806 and 820 nm have been calculated as 1.53×10^{-20} and 1.96×10^{-20} cm^2, respectively.

Figure 3 shows the emission spectrum, and the strongest peak is at 1 078 nm, corresponding to the $^4F_{3/2}\rightarrow{}^4I_{11/2}$ transition of Nd^{3+}, with the FWHM of 5 nm, which is wider than those of Nd:Y_2O_3 (2.6 nm)[6]. With broader absorption and emission bandwidths $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ can be a very promising laser material that is favourable to achieve the miniaturized LD pumping apparatus, widely tunable and mode-locked pulse laser.

The decay lifetime (τ_{s}) at 1 078-nm wavelength is 232 μs. Based on the Judd-Ofelt theory, the calculated radiation lifetime of the $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic is 477 μs. The stimulated cross sections σ_{em} of the ceramic is determined by

$$\sigma_{\text{em}}(\lambda) = \frac{1}{8\pi n^2 c}\frac{1}{\tau_{\text{rad}}}\frac{\lambda^5 I(\lambda)}{\int \lambda I(\lambda)\mathrm{d}\lambda}, \tag{3}$$

where the $I(\lambda)$ is the intensity of emission spectrum, n is the refractive index of material, and c is the light velocity.

The stimulated emission cross section calculated is 3.57×10^{-20} cm^2 at 1 078 nm. The values is smaller than the reported values of 7.63×10^{-20} and 6.35×10^{-20} cm^2 at 1 074.6- and 1 078.6-nm wavelengths in 1.5 at.-% Nd:Y_2O_3 ceramic, respectively[6].

Figure 4 shows the output power of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic laser versus the absorbed power. The laser had a threshold of 1.0 W. With a pump power of 7.2 W, a maximum output power of 1.38 W at wavelength of 1 079 nm was obtained. The slope efficiency was measured to be 22.9%. This is, to our best knowledge, the first report of Watt-level CW laser output power in Nd-doped Re_2O_3 laser materials.

$Nd_{0.02}Y_{1.78}La_{0.2}O_3$ transparent ceramic has broader absorption and emission bandwidth than that of Nd:Y_2O_3, so it is a promising high power and ultrafast pulse solid-state laser material.

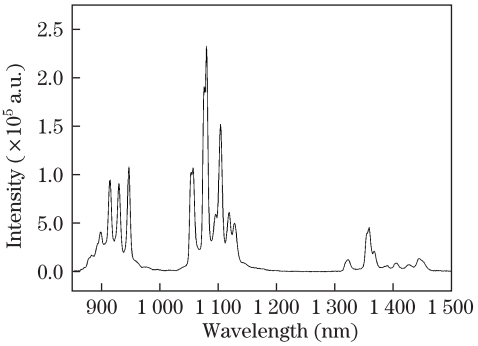

Fig. 3. Room-temperature emission spectrum of $Nd_{0.02}Y_{1.78}$-$La_{0.2}O_3$ ceramic.

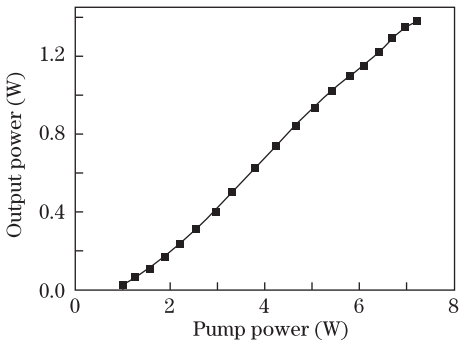

Fig. 4. The output power versus the absorbed power of $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic laser.

$Nd_{0.02}Y_{1.78}La_{0.2}O_3$ transparent ceramics has broader absorption and emission spectra due to its glass-like structure. The FWHM of absorption peak at LD pumping wavelength of 806 nm is about 8 nm and the absorption cross sections is 1.53×10^{-20}cm^2. The strongest emission peak was centered at 1 078 nm with the stimulated emission cross section of 3.57×10^{-20} cm^2, FWHM of 5 nm and the decay lifetime of 232 μs. For $Nd_{0.02}Y_{1.78}La_{0.2}O_3$ ceramic laser, a maximum output power of 1.38 W with a slope efficiency of 22.9% was obtained at 1 079 nm under an 808-nm diode pump.

The work was supported by the Key Basic Research Project of Science and Technology Commission of Shanghai under Grant No. 09JC1406500.

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