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Fabrication, microstructure and laser performance of composite Nd:YAG transparent ceramics

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ABSTRACT

"Sandwich" structure YAG/Nd:YAG/YAG ceramics with different core (Nd^{3+} doped area) lengths of 1 mm, 5 mm and doping concentrations of 1 at.%, 2 at.% were prepared by dry pressing and vacuum sintering of oxide powder mixture. Smaller average grain size was found in the specimen with the larger core and higher doping concentration. With the increase of core length, the optimum transmission of output coupler increases from 10% to 19% and better laser performance can be obtained. However, longer core length causes the noticeable thermal lens effect, which influences the beam quality significantly. It is also reflected in the thermally induced depolarized beam pattern, which becomes more obvious with the longer core length and higher Nd^{3+} doping concentration.

1. Introduction

In the last decade, laser diode (LD) pumped solid-state lasers (DPSSL) have a rapid development due to the improvement of optical quality of gain media [1–3]. Among these media, neodymium doped yttrium aluminum garnet (Nd:YAG) is the most widely used laser gain material in solid-state lasers [4–6] for the excellent physical and chemical properties. However, there still remains great challenges to solve the technical and economic issues of the Nd:YAG single crystal growth. Therefore the researchers have made great efforts to find a new material to be used in DPSSL. Since Ikesue et al. firstly fabricated the highly transparent Nd:YAG ceramics [7], which are believed to be a promising candidate for solid-state lasers because of their obvious advantages over single crystals, such as high doping concentration, relatively low cost, short fabrication period and potential of sophisticated design [8–11]. Henceforward, Nd:YAG transparent ceramics have made a quick progress, especially in the high power laser systems [12,13].

In the high power laser systems, thermal management is a key issue, which limits the power scaling of the solid-state lasers [14,15]. Inhomogeneous temperature distribution in the gain media results in mechanical and thermal stress and variation of refractive index. It will further evolve into the thermal lens effect and thermal induced depolarization, which decreases the output power and makes the laser beam quality worse [16,17]. The thermal effect can be considerably reduced if the gain media has a dopant profile. In the case of single crystals the dopant profile can be designed with thermal diffusion bonding techniques, which is complicated and expensive, while the fabrication of composite ceramics is simple and rapid [18,19]. Some researchers have been done on the composite ceramics [20–22]. Yagi et al. demonstrated the fracture strength of the composite Nd:YAG ceramics was comparable with one of the single crystal, and the destruction point was not located in interface region [23]. Tang et al. prepared Nd:YAG composite ceramics and achieved the laser output [24]. Liu et al. reported the preparation of composite ceramics by solid-state reactive sintering, its microstructure and optical properties [25].

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In view of the advantages of composite structure ceramics, we reported the fabrication of "sandwich" structure YAG/Nd:YAG/YAG ceramics with different Nd^{3+} ion doping profile lengths and concentrations in this paper. The microstructure, concentration distribution, in-line transmittance of the composite ceramics were investigated in detail. The laser output and thermal effects were also compared for different composite ceramics.

2. Experimental procedure

Commercially available high-purity powders of α-Al_2O_3 (99.98%, Alfa Aesar, USA), Y_2O_3 (99.999%, Alfa Aesar, USA) and Nd_2O_3 (99.99%, Alfa Aesar, USA) were used as starting materials. Tetraethoxysilane (TEOS, 99.999%, Alfa Aesar, USA) and magnesium oxide (MgO, 99.99%, Alfa Aesar, USA) were used as sintering aids. These powders were blended together with the stoichiometric ratio of $(Nd_xY_{1-x})_3Al_5O_{12}$ (x = 0.01, 0.02) and mixed in ethanol for 12 h. Then the slurry was dried and sieved through a 200-mesh screen. After calcining at 800 °C, the powders were uniaxially pressed into disks at about 15 MPa and further pressed by cold isostatic pressing (CIP) at 250 MPa. The as-obtained green bodies were sintered under vacuum at 1810 °C for 50 h. The ideal schematic of designed ceramic slab along the thickness direction after cutting and polishing is shown in Fig. 1. Two types of YAG/Nd:YAG/YAG ceramics with different core (Nd^{3+} doped area) lengths were employed. The cross section of all specimens is 3 × 3 mm^2. The specimens were annealed in air at 1450 °C for 10 h to get rid of internal stress and

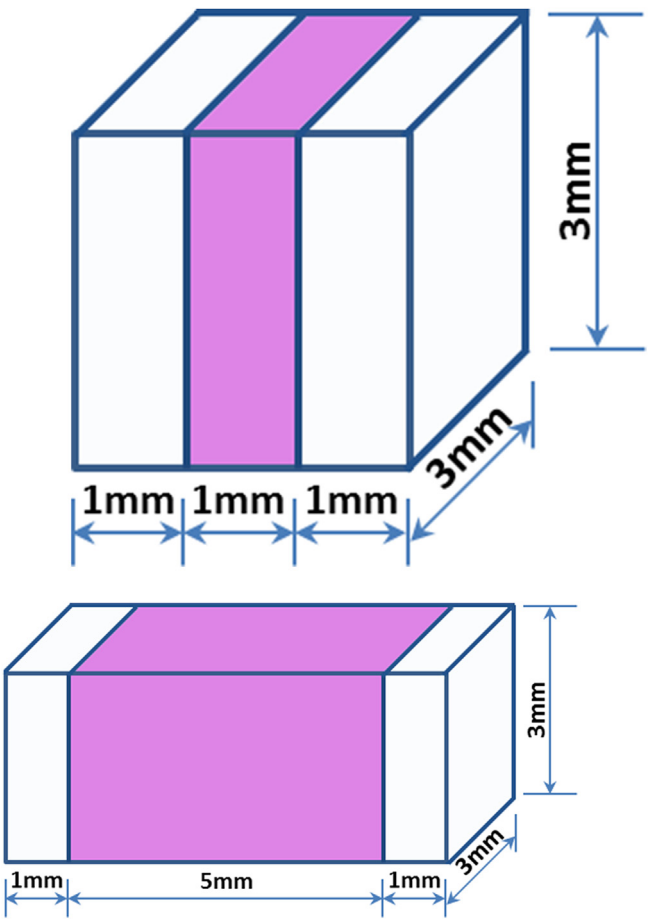

Fig. 1. Schematic of designed ceramic slabs along the thickness direction after processing.

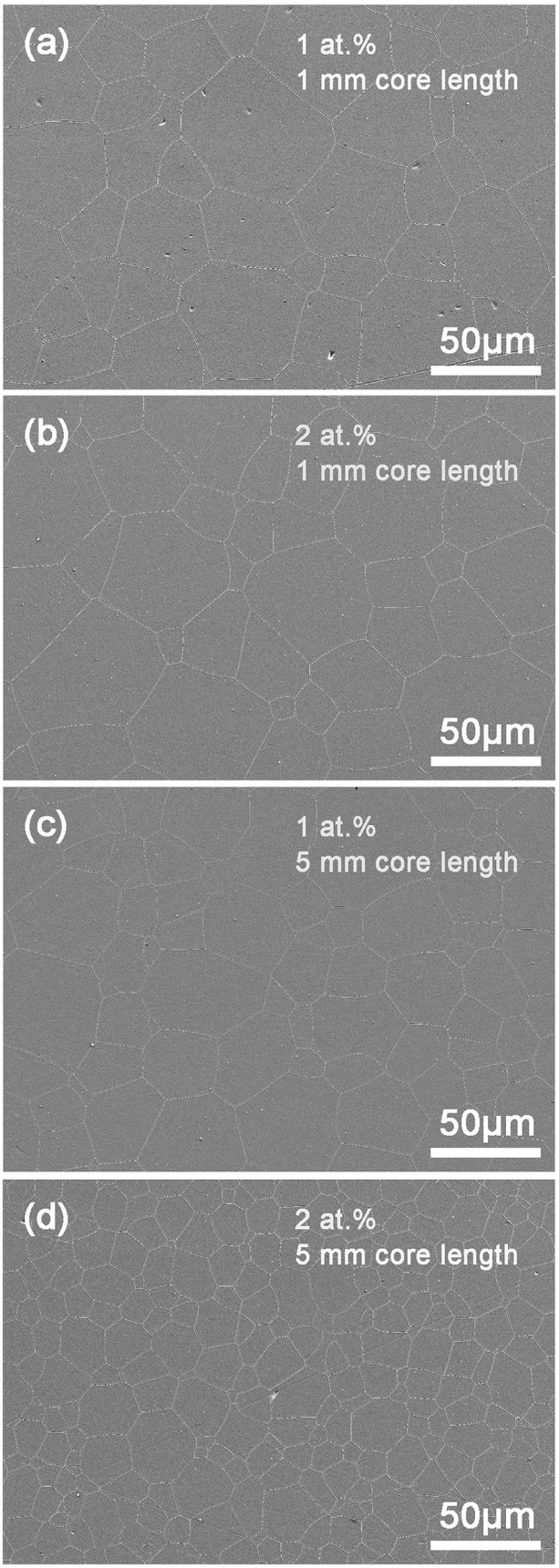

Fig. 2. FESEM images of the polished and thermally etched surface of the YAG/Nd:YAG/YAG ceramics.

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