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Cation diffusion at the interface of composite YAG/Re: LuAG (Re = Nd or Yb) transparent ceramics

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ABSTRACT

Composite structures of YAG/1 at% Nd-doped LuAG/YAG, YAG/1 at% Nd-doped LuAG and YAG/5 at% Yb-doped LuAG transparent ceramics were successfully fabricated by non-aqueous tape-casting method and vacuum sintering technology. Cation (Y^{3+}, Lu^{3+}, Nd^{3+}, Yb^{3+}) diffusion behavior across the contact boundaries between ytterbium (Yb) or neodymium (Nd) doped lutetium aluminum garnet (LuAG) and un-doped yttrium aluminum garnet (YAG) was studied by the electron probe X-ray micro-analysis (EPMA). The diffusion concentration profile curves were well modeled by Harrison type B kinetics. Curves of concentration *vs* depth were well fitted by Fick's second low and the log of the average concentration varies as 6/5 power of penetration depth in the diffusion range was demonstrated. Meanwhile, the bulk diffusion coefficient and grain boundary diffusion coefficient were calculated. For YAG/Nd:LuAG transparent ceramic, under an 808 nm diode laser pumping, the 1064 nm continuous wave (C.W.) laser output beam with good quality was achieved.

1. Introduction

Ikesue et al. firstly reported Nd:YAG ceramic laser material fabricated by traditional ceramic technology [1]. Some physical properties of Nd:YAG ceramics, such as refractive index and thermal conductivity were measured and very similar to those of Nd:YAG single crystal. Highly efficient end-pumped Nd:YAG lasers, which were comparable in efficiency with single crystal Nd:YAG lasers, were developed in 2000 and 2001 [2,3]. In comparison with YAG single crystals, the YAG ceramics technology has several advantages such as easy fabrication, size scalability, availability of high ion concentration, the relative ease of achieving composite structure, better homogeneity of the doping ions, and so on. Up to now, researches on laser ceramics are mainly focused on rare earth doped YAG host materials, such as Nd:YAG [4,5], Yb:YAG [6,7], Cr:YAG [8] and Tm:YAG [9] ceramics, because of its cubic structure and excellent optical, mechanical and thermal properties. Among laser active elements, Nd and Yb ions are the most widely used two dopants in YAG host lattice. In the operation of high power solid-state laser, there is unavoidably a large amount of heat generation. As a result, thermal lensing and thermal birefringence effects coupled to thermal gradient and thermal stress significantly restrict the output power and beam quality of solid-state lasers, and even lead to permanent laser gain medium damage. Therefore, selection on the kinds of laser gain host material as well as the structure of the laser gain medium becomes especially important for high power lasers. YAG has a relative large thermal conductivity, which, however, drops significantly with the Yb doping concentration increase. While, Yb:LuAG has a higher thermal conductivity than Yb:YAG when Yb doping concentration gets larger than 5% [10]. Therefore, LuAG is a better alternative for the host material. To have a better thermal management, a composite structure consisting of activator-doped gain medium and un-doped medium is very helpful. The first composite un-doped YAG/Nd-doped YAG laser rod was reported by Hanson in 1995 [11]. Tsunekane et al. demonstrated the improvement of high-power laser performance using a composite rod with an un-doped YAG end, as a result of the absence of thermally induced birefringence [12]. These results indicated that composite materials have a better laser performance than the non-composite gain medium.

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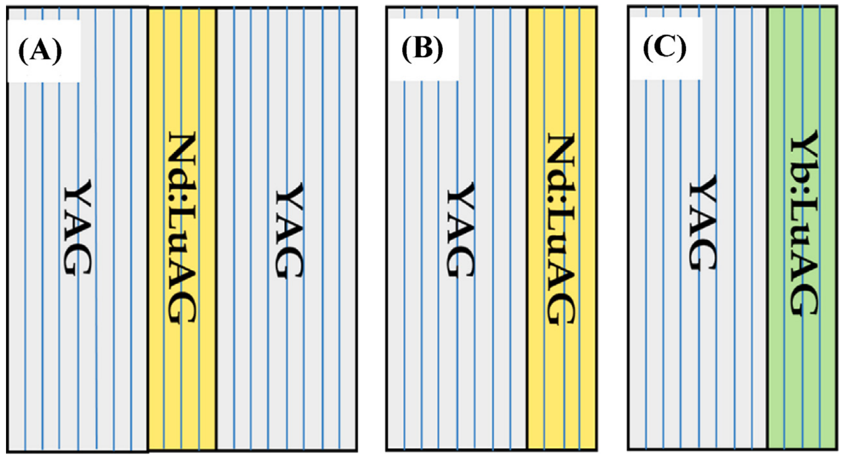

Fig. 1. Scheme of the composite green bodies of sample (A) YAG/Nd:LuAG/YAG, sample (B) YAG/Nd:LuAG, and sample (C) YAG/Yb:LuAG, along the sickness direction. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

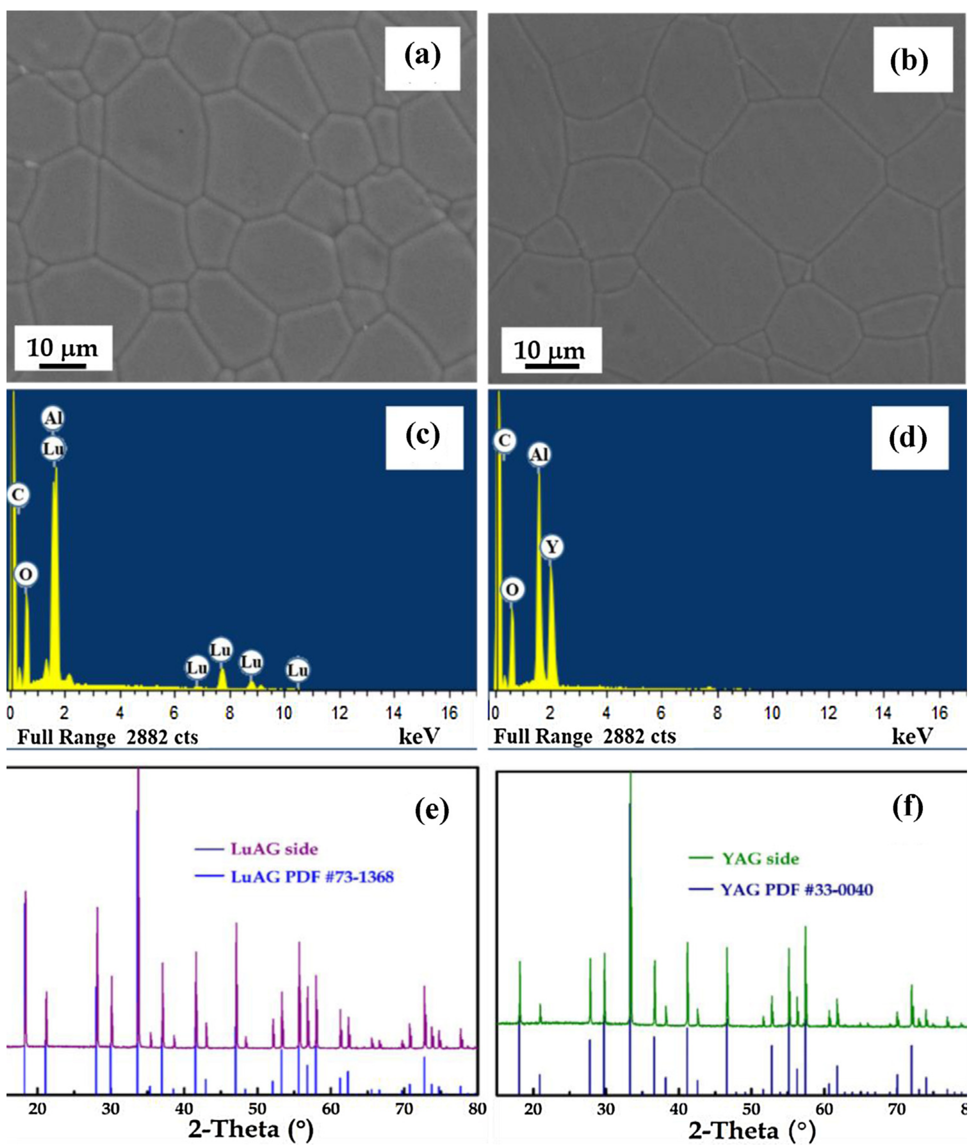

Fig. 2. Secondary electron images (a,b), corresponding EDS spectra (c,d), and corresponding XRD patterns (e,f) for un-doped YAG side and Yb-doped LuAG side of the composite YAG/Yb:LuAG ceramic, respectively.