Journal of Ceramic Processing Research. Vol. 4, No. 3, pp. 109~111 (2003)

J O U R N A L O F
Ceramic Processing Research

Edge-defined film-fed growth of Yb:YVO_4 single crystals: approaches to produce a few crystals simultaneously

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The applicability of the EFG technique of yttrium orthovanadate was confirmed by successful growth of a few single crystals simultaneously. Yb-doped single crystals with a content of Yb^{3+} ions of 10 atomic % in the starting melt were grown by the EFG technique with a length up to 50 mm as 4 items simultaneously. Good homogeneity was observed for Yb-doped crystals. The segregation coefficient of Yb^{3+} ions was very close to unity. Absorption and photoluminescence (PL) spectra of grown crystals were measured.

Key words: Edge defined film-fed growth, Vanadates, Rare-earth.

Introduction

Single crystals of rare-earth vanadates possess various useful properties for laser and optical applications. Nd:YVO_4 is one of the most efficient laser host crystals currently existing for diode-pumped solid state lasers [1]. For applications in which a more compact design and a single-longitudinal-mode output are needed, Nd:YVO_4 shows its advantages against other commonly-used laser crystals. However, the Yb^{3+} ion has some advantages over the Nd^{3+} for laser applications. There is no excited state absorption reducing the effective laser cross-section, no up-conversion, no concentration quenching, and no absorption in the visible range [2]. The ionic radius of Yb^{3+} makes this ion preferable for the Y^{3+} substitution in YVO_4 lattice than Nd^{3+}. It may be expected that the distribution coefficient of Yb^{3+} ions in YVO_4 will be closer to unity in comparison with EFG-grown Nd:YVO_4 (k = 0.4-0.5) [3]. Yb-doped solid state lasers pumped with laser diodes have been intensively and successfully developed recently [4]. Yb-doped YVO_4 crystals can become the perspective candidate for a new generation of microchip lasers. However, growth difficulties limit seriously the production of high quality vanadate single crystals. Recently researchers have given attention to Edge-Defined Film-Fed Growth (EFG) as a possible way to attain high quality YVO_4 crystals. It is easy to select the desirable shape of crystal by the selection of an appropriate EFG arrangement. Earlier, YVO_4 crystals with square section, 10 mm per side were grown [5]. Moreover, this technique gives the possibility for the simultaneous growth of a few items. The size needed of YVO_4 samples for laser diode pumping is usually 2-3 mm with a rectangular shape. Thus, it seems more effective to grow a few smaller rectangular crystals simultaneously than one larger size crystal with the subsequent need to cut it into several smaller crystals.

In this study, a modified EFG technique has been developed for the simultaneous growth of 4 Yb- doped YVO_4 single crystals.

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Experimental

A composite iridium die with 4 square lugs of 3×3 mm was used for the simultaneous growth of 4 vanadate crystals. A schematic diagram of the arrangement

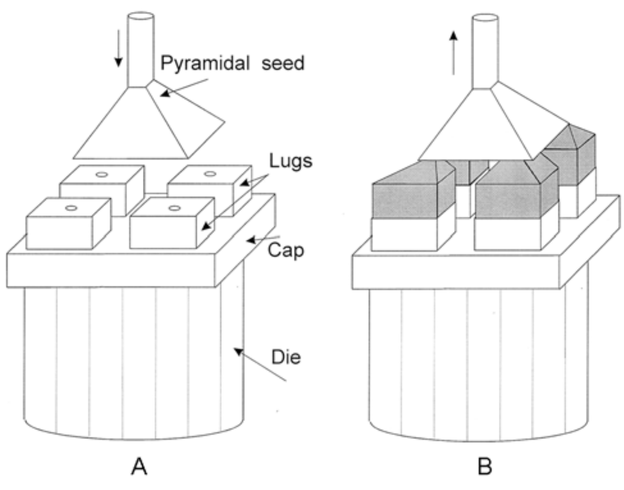

Fig. 1. Schematic diagram of the arrangement for the multiple growth of four vanadate crystals (A–before seeds touch, B–during the straight growth).

for such multiple growth is shown on Fig. 1. The hot zone structure was similar to the single EFG technique of vanadates [6]. However, the requirements of the hot zone symmetry for the multiple growth were higher due to the necessity to keep the same temperature conditions for every growing item. For this purpose a few additional windows were made in the ceramic parts of the hot zone. The optimal size and number of such windows were estimated experimentally.

All crystals were grown using YVO_4 seeds along the c-axis with a special pyramidal shape. Pulling rates were 1-1.5 mm/h. The stoichiometric composition was used as the initial charge. The growth atmosphere was a mixture of Ar + 1 vol.% O_2. Grown crystals received a heat treatment at 1300°C for 24 hours.

Ion distributions along the crystals were determined by microanalysis (EPMA). The absorption was investigated at wavelengths of 880-1080 nm. Photoluminescence spectra were measured by a photoelectric multiplier at an exiting wavelength of 988 nm. All spectra were measured at room temperature.

Results and Discussion

Multiple Yb:YVO_4 crystals were grown up to 50 mm in length simultaneously. All grown crystals were transparent, without visible inclusions inside their bodies. All the Yb- doped crystals were slightly yellow in colour. A quad Yb-YVO_4 (10 at. %) single crystal is shown in Fig. 2.

Knurl arrays with almost constant spacing due to step-faceting phenomenon were observed on the surface of grown crystals. This phenomenon is typical for all rare-earth vanadate crystals. The step amplitude was 0.1-0.2 mm. The generation of low-angle boundaries is a common quality problem of EFG produced vanadate crystals. A small meniscus height is the main reason for that phenomenon. However, small size crystals with a square section are much more stable to an increasing meniscus height. This gave the possibility

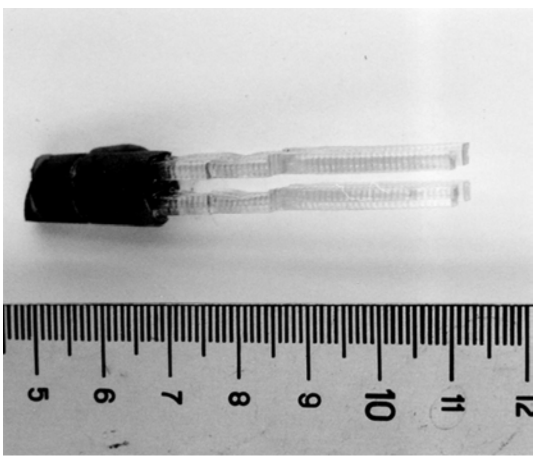

Fig. 2. 4 simultaneously grown Yb:YVO_4 crystals (10 at.%).

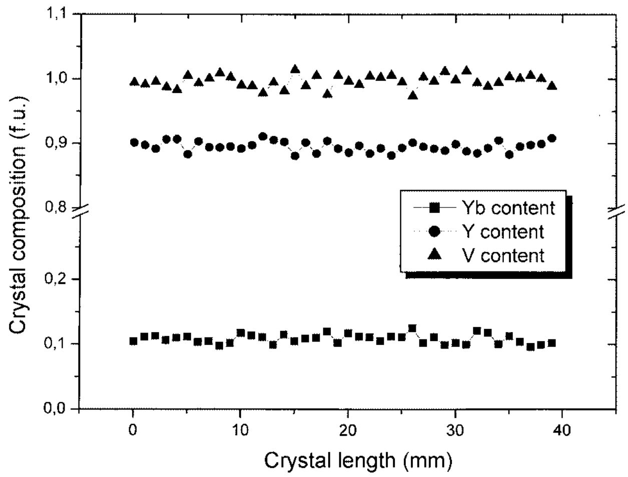

Fig. 3. The chemical composition along the growth direction of Yb:YVO_4 crystal using EPMA.

of decreasing the formation of low-angle boundaries in simultaneously grown vanadate crystals.

Figure 3 shows the results of composition measurements along the crystal. Good homogeneity was observed for all Yb-doped crystals. The segregation coefficient was very close to unity. This facilitates the use of a high doping level of Yb^{3+} ions. Also it allows one to apply higher growth rates for Yb:YVO_4 crystals in comparison with Nd:YVO_4.

The broad Yb^{3+} absorption lines in EFG-produced Yb:YVO_4 single crystals are well suited for laser diode pumping near 980 nm (Fig. 4). This spectrum shows the high value of the absorption coefficient at the laser diode (LD) emitting wavelength. It allows us to use small size samples of Yb:YVO_4 crystals for production of LD-pumped lasers. The photoluminescence (PL) spectrum of the same crystal where the source was light polarized parallel and perpendicular to the growth direction is shown on Fig. 5. The value of the lifetime of Yb^{3+} ions at a concentration of 10 at.% was measured as 0.85 ms.

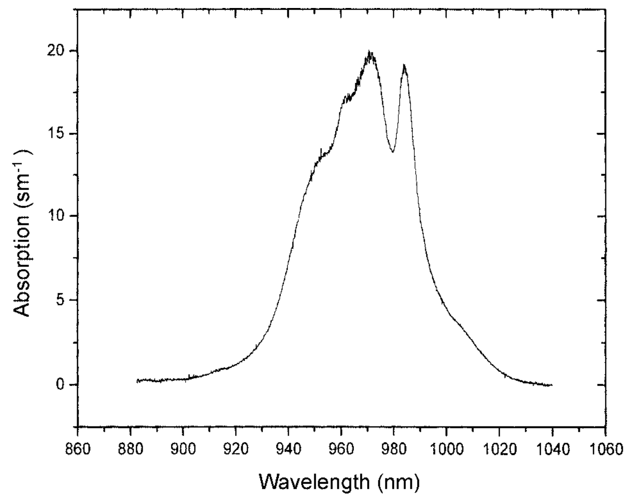

Fig. 4. Absorption spectrum of Yb:YVO_4.

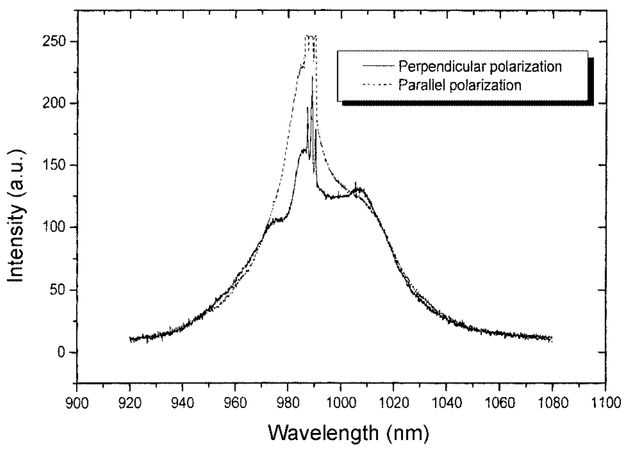

Fig. 5. PL spectra of Yb: YVO_4 single crystal at room temperature (excited with 988 nm radiation).

Conclusion

In summary, we have modified the EFG technique for the simultaneous production of 4 Yb: YVO_4 single crystals and produced successfully Yb-doped YVO_4 single crystals for optical applications up to 50 mm in length. The segregation coefficient of Yb^{3+} ions in YVO_4 was very close to unity. Absorption lines of Yb-doped YVO_4 crystals are well suited for laser diode pumping near 980 nm. A high value of absorption coefficient at the wavelength of InGaAs laser diode was observed.

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