Characterization of Transparent Lanthanides Doped $Y_3Al_5O_{12}$ And Y_2O_3 Ceramics, And Their Laser Oscillation

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Polycrystalline ceramic laser materials are an aggregate of crystalline grains, each randomly oriented with respect to neighboring grains. Ceramic materials are widely used in many fields, especially transparent polycrystalline ceramics can be used as laser materials, windows in furnaces, lenses in high temperature microscopes, lamp envelopes, etc. In this dissertation, fabrication process of highly transparent ceramic laser materials is summarized. Optical properties of rare earth ions doped $Y_3Al_5O_{12}$ (YAG) and Y_2O_3 laser ceramic materials were investigated. Highly efficient and high power laser oscillations were demonstrated.

Since 1999, we, Yanagitani and Yagi group in Konoshima Chemical, Co., Ltd. and Ueda group in University of Electro-communications, began to develop highly transparent neodymium doped YAG ceramics using vacuum sintering method, where the raw materials were prepared by nanocrystalline technology. Compared with YAG single crystal, transparent ceramic laser materials have the following advantages, namely: (1) Ease of fabrication; (2) Less expensive; (3) Fabrication of large size and high concentration; (4) Multi-layer and multi-functional ceramic structure; (5) Mass production, etc. Optical properties of Nd:YAG ceramics, such as absorption, emission and fluorescence lifetime, were found to be similar to these of Nd:YAG single crystal. The thermal conductivity of Nd:YAG ceramics was measured, which is also found to be very similar to that of Nd:YAG single crystal.

In 2000, we succeeded in demonstrating highly efficient laser oscillation on Nd:YAG ceramics. By sing 1 W LD end-pumping scheme, CW output power of 499 mW at 1064 nm was obtained with a slop efficiency of more than 60%. Its laser efficiency is comparable to that of Nd:YAG single crystal lasers, which means the light scattering loss inside ceramics should be the same level with that of single crystal. Highly neodymium doped Nd:YAG ceramic lasers were also developed. For 2% neodymium doped YAG ceramic, output power of 465 mW at 1064 nm was obtained with a slope efficiency of 58%. Fig. 1 shows the laser output versus pump power for 1%, 2% Nd:YAG ceramics and 0.9% Nd:YAG single crystal at 1064 nm. Output power of 221 mW at 1064 nm was obtained in 4% microchip Nd:YAG ce-

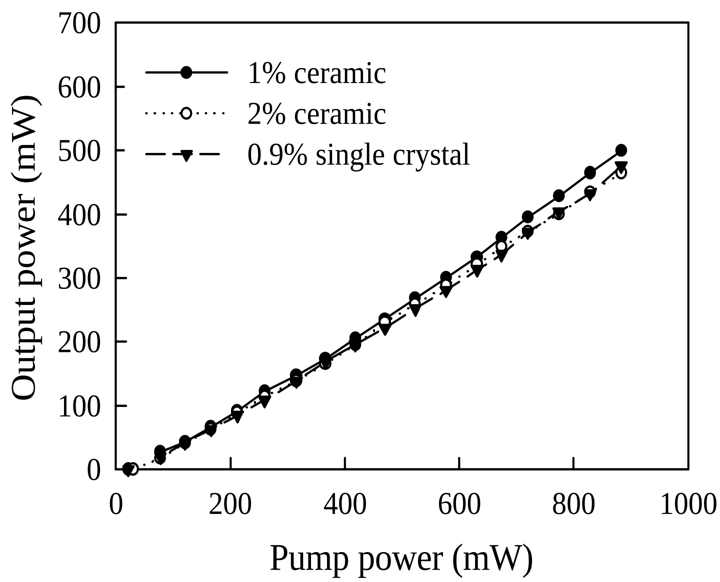

Fig. 1: CW laser output versus pump power of 1%, 2% Nd:YAG ceramic lasers and 0.9% Nd:YAG single crystal laser

ramic with a slope efficiency of 40%. High power laser oscillation was demonstrated for the first time. Using virtual point source (VPS) pumping system, output power of 31 W at 1064 nm was obtained under 290 W pumping in 2000, output power of 72 W and 88 W at 1064 nm were reported later. The thermally induced birefringence in Nd:YAG ceramics was also investigated. This year, cooperating with Toshiba Cooperation, high power Nd:YAG ceramic laser with output power of 1.46 kW was demonstrated. The optical-to-optical efficiency reached up to 42%. Cr^{4+} doped YAG ceramics were also fabricated and passive Q-switch laser operation was demonstrated for the first time. Passively Q-switched output of 45 mW at 1064 nm was obtained under 1 W LD pumping. Using the typical end pumping scheme, laser oscillation was also generated at 1.32 μm and 1.34 μm. For 1 W end pumping, Output power of 202 mW with a slope efficiency of 35% was obtained; Using VPS pumping system, output power of 36 W was obtained at 1319 nm.

Cubic Y_2O_3 crystal has been investigated for a long time as a laser host material for lanthanide ions due to its favorable properties,such as its refractory nature, stability, ruggedness, and optical clarity over a broad spectral region, in particular, thermal conductivity of Y_2O_3 is about two times larger than that of YAG, while their thermal expansion coefficients are very similar. Further more, the stimulated emission cross section of Nd:Y_2O_3 happened to be in the range that is required for laser fusion driver. This makes Nd:Y_2O_3 a potential candidate for being used in laser fusion system. However, it is extremely difficult to grow large-size high-quality Y_2O_3 single crystal by conventional growth methods because of its very high melting temperature ($\approx$2430°C) of Y_2O_3 and structural phase transition at 2280°C. What's more, the laser oscillation results of rare earth ions doped Y_2O_3 were not satisfying either. Recently, Nd:Y_2O_3 ceramics were developed as well by using the nanocrystalline technology and vacuum sintering method. Compared with single

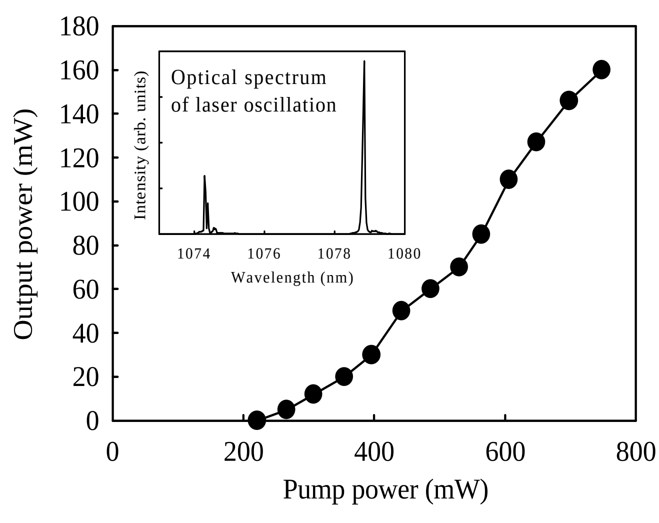

Fig. 2: Input-output curve of 1.5% Nd:Y_2O_3 ceramic laser generated at two wavelength of ${}^4F_{3/2} \rightarrow {}^4I_{11/2}$

crystal growth methods, it is easier to fabricate large size Y_2O_3 ceramics because of the lower sintering temperature - about 700°C lower than melting temperature of Y_2O_3. Some optical properties of Nd:Y_2O_3 ceramics were investigated and for the first time, CW room-temperature laser oscillation at two wavelengths (1074.6 nm and 1078.6 nm) of ${}^4F_{3/2} \rightarrow {}^4I_{11/2}$ channel was obtained with a slope efficiency of 32%. Fig. 2 shows the laser output versus pump power for 1.5% uncoated Nd:Y_2O_3 ceramic element.

In Table 1, we list the development progress of ceramic lasers from 1960s.

Based on the recent great progress of ceramic laser materials, the prospect of ceramic laser materials in the near future was also presented. The possible multi-functional structure laser ceramics was shown; The mass production scheme of ceramic laser chips was given; The possibilities of rare earth doped Y_2O_3 for being used in laser fusion system, femto-second lasers and high power industrial lasers were discussed.

Year	Author	Fabrication method	Achievement	remarks
1966	E. Carnall	Hot-pressing	CaF_2 ceramic laser, the first laser demonstration on ceramic laser material	Ref. 1
1972	R. C. Anderson	Cold-pressing	The first cold-pressed NDY ceramic laser	Ref. 2
1995	A. Ikesue	Solid-state reaction	The first laser oscillation was reported on Nd:YAG ceramics	Ref. 3
2000-2001	J. Lu, K. Ueda, H. Yagi, T. Yanagitani, Y. Hirano, Y. Akiyama, A. A. Kaminskii	Nanotechnology +Vacuum Sintering	499 mW → 31 W → 72 W → 88 W → 128 W → 1460 W Nd:YAG ceramic lasers	Ref. 4-10
2001	J. Lu, K. Ueda, H. Yagi, T. Yanagitani, A. A. Kaminskii	Nanotechnology +Vacuum Sintering	The first laser demonstration on Nd:Y_2O_3 ceramic	Ref. 11

Table 1: Development progress of ceramic lasers

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