1. INTRODUCTION

With the remarkable development of the high brightness and high power InGaAs laser diodes, trivalent ytterbium ion (Yb³⁺) has been recognized as a very attractive dopant for solid-state laser materials [1–12], this is mainly for the reason that Yb³⁺-doped materials have many outstanding properties, such as small quantum defect, long energy storage lifetime, simple energy-level scheme, very high doping level, desirable properties for diode pumping, as well as broad absorption and emission bandwidths, which are fundamental conditions to support femtosecond laser generation, and so on. So far, many ytterbium-doped materials have been demonstrated to be used for laser operations. Among these materials, Yb³⁺-doped crystals show very excellent characteristics and many studies have been reported, such as garnet Yb:YAG [13–16], and Yb:YGG [17, 18], tungstates Yb:KGW [19], oxyorthosilicates Yb:LYSO, and Yb:GSO [20–22], etc. Recently, transparent polycrystalline ceramic laser materials have attracted much more attention, because they have many favorable characteristics compared with single crystals, such as high doping concentration, low cost, easy fabrication, mass producible and multilayer or multifunctional structures [23, 24]. Crystals with cubic symmetry such as YAG and Y₂O₃, are suitable for ceramics fabrication. Cubic Y₂O₃ crystal is a promising solid state laser medium because of its excellent optical, thermal, chemical and mechanical properties. Especially, its thermal conductivity is twice as large as that of YAG.

However, it is extremely difficult to grow high-quality large-size Y₂O₃ single crystal due to its high melting point, which is 2430°C while the temperature of structural phase transition is 2280°C. Fortunately, transparent Y₂O₃ ceramics could be fabricated at a relatively low sintering temperature of 1700°C, which is about 700°C lower than its melting point [25]. The Yb:Y₂O₃ ceramics have shown remarkable laser properties in both CW and mode-locking operation. By adding La₂O₃ as a sintering aid in Y₂O₃ to form yttrium lanthanum oxide transparent ceramics Yb:(Y₁−ₓLaₓ)₂O₃, the sintering temperature could be further decreased to 1450–1650°C [26]. Similar to Y₂O₃, (Y₁−ₓLaₓ)₂O₃ has many remarkable advantages for laser materials—stable, hard, having a good thermal conductivity and so on. In particular, the lifetime of Yb³⁺ in (Y₁−ₓLaₓ)₂O₃ host is longer than that in Y₂O₃, which facilitates an enhanced energy storage for a high-power laser [27]. In continue-wave (CW) operation, Yb:(Y₁−ₓLaₓ)₂O₃ (x = 0.1) laser with 52% slope efficiency has been reported by Zhang et al. [18]. Mode-locking regime are also demonstrated by Li et al. [28] at 1032.5 nm with average power of 162 mW, but with relative long pulse width of 174 ps. In this letter, we report a diode-pumped passively mode-locked Yb:(Y₀.₉La₀.₁)₂O₃ ceramic sub-picosecond laser, laser pulse as short as 730 fs was obtained at the central wavelength of 1033 nm. Under the maximum pump power of 6 W at 976 nm, the output power is 92 mW.
2. EXPERIMENTAL SETUP AND RESULTS

Figure 1 shows the absorption and fluorescence spectra of the Yb:Y\(_{0.9}\)La\(_{0.1}\)\(_2\)O\(_3\) ceramic at the room temperature (the exciting light of 940 nm was filtered out).

It can be seen from the figure, there are three main absorption peaks overlapping with each other to some extent in 850–1050 nm broad absorption band, with the center wavelengths at 909, 951, and 977 nm, respectively. The bandwidth (FWHM) of each absorption peak is larger than 10 nm. The absorption cross section at the wavelength of 977 nm is 0.61 \(\times 10^{-20}\) cm\(^2\), the other two are about 0.49 \(\times 10^{-20}\) cm\(^2\) and 0.62 \(\times 10^{-20}\) cm\(^2\) for 909 and 951 nm, respectively. As a result, it is suitable for diode laser pumping. While there are two main emission peaks in the broad emission spectrum, with the center wavelengths at 1032 and 1075 nm, and the bandwidths (FWHM) of each emission peak are 20 and 24 nm, respectively, both support to generate sub-100 fs laser pulse in theory. Although the emission spectrum is similar to that of the Yb:Y\(_2\)O\(_3\) ceramics, both the emission cross sections of 1.0 \(\times 10^{-20}\) cm\(^2\) at 1032 nm and 0.7 \(\times 10^{-20}\) cm\(^2\) at 1078 nm are larger than that of the Yb:Y\(_2\)O\(_3\) ceramics [29].

The experimental schematic of the laser cavity and pumping geometry is shown in Fig. 2. We used a 5 at% doped Yb:Y\(_{0.9}\)La\(_{0.1}\)\(_2\)O\(_3\) ceramic sample as the gain medium at Brewster-angle configuration (with no antireflection-coatings on both surfaces), which is 2 mm in long and 4 \(\times\) 3 mm\(^2\) in aperture. To remove the heat load efficiently, the gain medium was placed in contact with a water-cooled copper mount at the set temperature of 9°C. A 7 W high brightness fiber-coupled diode laser emitting at 976 nm (Jenoptik, JOLD-7.5-BAFC-105) was used to end-pump the laser medium. The pump laser output from the fiber (with 50 \(\mu\)m core diameter and 0.22 numerical aperture) was coupled into the laser medium by a coupling system. The operating temperature of the pump laser was set to be 22°C in order to obtain stable laser output at the wavelength of 977 nm. The mode-locking experiment was carried out with a standard Z-fold cavity. M1 is a plane dichroic mirror with high transmission at 976 nm and high reflection at 1020–1200 nm; M2, M3, and M4 are concave mirrors with radii of curvature of 200 mm.

Passive mode-locking was started with a commercially available semiconductor saturable absorber mirror (SESAM) (BATOP GmbH), which has a modulation depth of 0.4% near 1040 nm, a saturation inten-

![Fig. 1. Room-temperature absorption and fluorescence spectra of Yb:Y\(_{0.9}\)La\(_{0.1}\)\(_2\)O\(_3\) ceramic.](image1)

![Fig. 2. (Color online) Schematic diagram of the mode-locked Yb:Y\(_{0.9}\)La\(_{0.1}\)\(_2\)O\(_3\) ceramic laser: LD, high brightness fiber coupled laser diode; M1, a plane dichroic mirror; M2, M3, and M4, concave mirrors with ROC of 200 mm; OC, output coupler.](image2)