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Diode-pumped medium-aperture-size square Nd,Y:CaF_2 rod amplifier for Inertial Confinement Fusion laser drivers

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ABSTRACT

We demonstrate, for the first time, an 12 mm × 12 mm 0.5%Nd,5% Y:CaF_2 crystal rod having a uniformly-distributed fluorescence spectrum and capable of operating as an amplifying medium at high repetition frequencies. A small gain of 2.7 is experimentally achieved at repetition frequency of 10 Hz for a pump center wavelength of 802 nm, power and absorption efficiency, 61.2 kW and 63.7%, respectively. Spatial-uniformity degradation of the output near-field beam distribution is observed, which should be attributed to the inhomogeneity of Nd,Y:CaF_2 crystal. For a pump power of 61.2 kW, the stored energy of Nd,Y:CaF_2 amplifier is 3.73 J. When the input energy is 50 mJ, the output laser energy is 1.4 J of extraction efficiency up to 37.53% after four-pass amplification.

1. Introduction

Conventional laser-driven Inertial Confinement Fusion (ICF) employ Nd-doped phosphate glass as the gain medium. However, the repetition frequency operation of such laser systems is restricted due to the low thermal conductivity of the phosphate glass [1–3]. To attain a high ICF performance, the laser driver must be capable of operating at a repetition frequency no less than 10 Hz. Typically, an Nd-doped laser glass operate at repetition frequencies well below 10 Hz. Nd:CaF_2 has been proposed as a gain medium that can operate at high repetition frequencies, mainly due to the very high thermal conductivity (9.7 W/mK) and very low nonlinear refractive coefficient (0.43 × 10−13/esu) of CaF_2 [4,5]. However, during the process of doping Nd^{3+} ions into a CaF_2 crystal, Nd^{3+} clusters in the CaF_2 cause concentration quenching that significantly reduces the fluorescence lifetime [6,7]. Typically, clustering effects are observed once the doping concentration of Nd^{3+} reaches 0.05%. Y^{3+} can break the clustering structure, thus reducing the concentration quenching effect and increasing the emission quantum efficiency of the amplifying medium [8]. Compared with Nd:YAG crystals, Nd,Y:CaF_2 crystals (doped with Y^{3+}) have several advantages, namely, big segregation and absorption coefficients that enable more Nd^{3+} ions to be doped, broad pump absorption spectral range, which makes them suitable for laser-diode pumping, simple temperature control, broader fluorescent spectrum lines, which enable ultra-short laser pulses to be generated, and ability to operate over a wide temperature range, due to the low temperature dependence of their energy conversion efficiency. All these above-mentioned advantages make Nd,Y:CaF_2 an ideal gain medium for high-energy laser-driven ICF in repetitive operations.

Diode-pumped Nd,Y:CaF_2 has previously been used as a gain medium [9–14]. In 2013, Su et al. demonstrated that the spectroscopic properties of Nd:CaF_2 can be tailored by co-doping it with Y^{3+} ions, allowing true CW laser operation with high efficiency [9]. In 2014, Qin et al., demonstrated a mode-locked laser, employing Nd,Y:CaF_2 disordered crystal as the gain medium, capable of generating pulses of duration as short as 103 fs and an average output power of 89 mW, at a repetition rate as high as 100 MHz [10]. In 2015, Zhu et al. demonstrated a passively mode-locked femtosecond laser based on an Nd,Y:CaF_2 disordered crystal, generating 264 fs pulses with an average output power of up to

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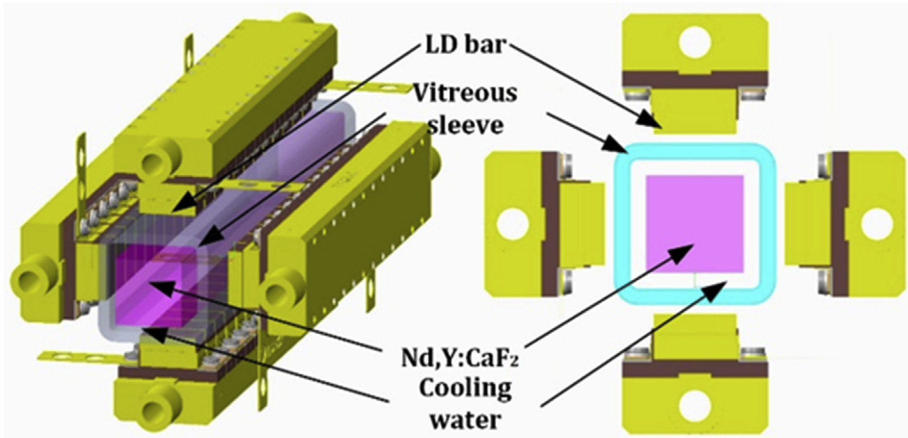

Fig. 1. Illustration of the Nd,Y:CaF_2 square rod amplifier and pumping configuration.

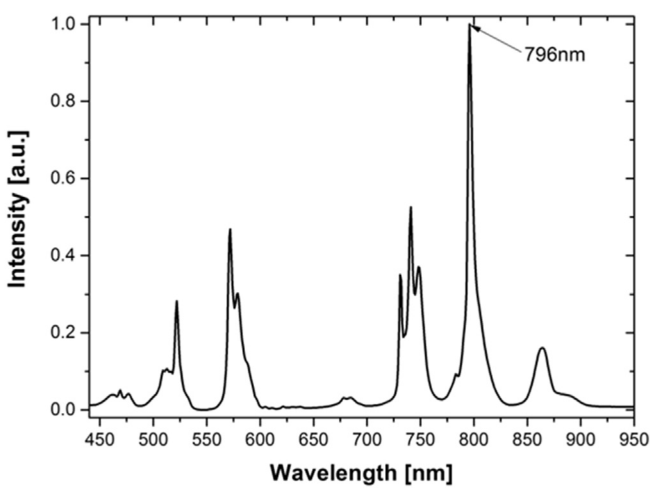

Fig. 2. Room-temperature absorption spectrum of the 0.5%Nd,5%Y:CaF_2 crystal.

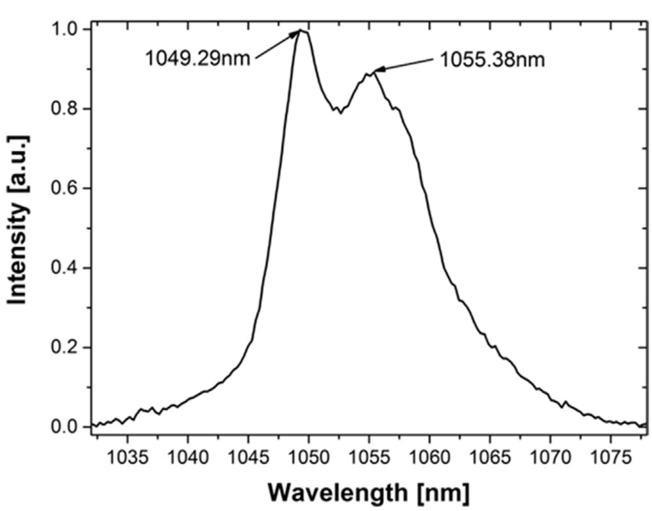

Fig. 3. Room-temperature emission spectrum of the 0.5%Nd,5%Y:CaF_2 crystal (over the spectral range 1032 nm–1078 nm).

180 mW at a repetition rate of 85 MHz [11]. In the same year, Zhang et al. reported a diode-pumped, highly efficient laser employing 0.5% Nd, 10% Y:CaF_2 and 0.6% Nd, 10% Y:CaF_2 crystals, demonstrating slope efficiencies over 30% and 27%, and a maximum output power of up to 901 mW [12]. For all of the above-mentioned lasers, the crystals used had a small size of 3 mm × 3 mm × 6 mm. In order to increase the fill factor and energy extraction efficiency of the laser drivers for ICF, a square beam shape is typically used [13,14].

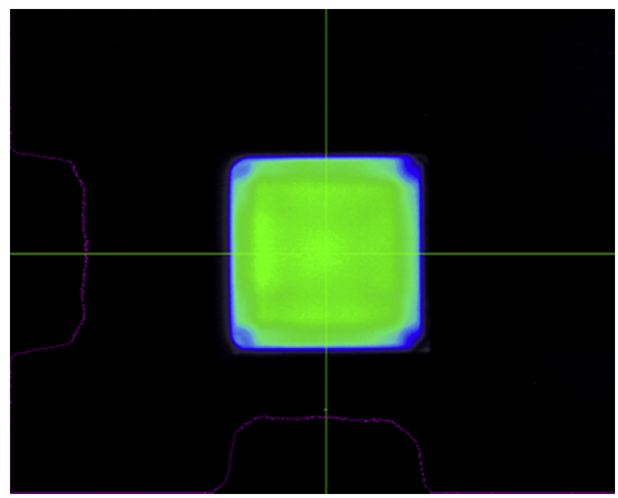

Fig. 4. Measured fluorescence distribution of the Nd,Y:CaF_2 Amplifier.

To optimize the performance of large-aperture gain medium in an ICF laser driver, experimental investigations must address three main aspects, namely, whether the laser medium can operate repetitively and whether the laser amplifier can produce adequate gain levels, and if the near-field output beam is uniform enough over the relatively large aperture. In this paper, a laser diode array (LDA) side-pumped square-rod Nd,Y:CaF_2 amplifier of aperture 12 mm × 12 mm is designed and its performance is experimentally investigated. Experimental results show that the fluorescence spectrum is uniformly distributed over the amplifier cross section, and at a repetition frequency of 10 Hz, 61.2 kW pump power and a 10 mJ injected seed laser, a small signal gain of 2.7 is demonstrated. Spatial-uniformity degradation in the output near-field beam distribution is observed, which is attributed to the impurity of Nd,Y:CaF_2 crystal. For a pump power of 61.2 kW, the stored energy of Nd,Y:CaF_2 amplifier is 3.73 J. When the input energy is 50 mJ, the output laser energy is 1.4 J of extraction efficiency up to 37.53% after four-pass amplification.