1. INTRODUCTION

Transparent polycrystalline yttrium aluminum garnet (YAG, Y₃Al₅O₁₂) has attracted much attention for its potential applications in high power solid-state laser recently [1–6]. The polycrystalline Nd:YAG has similar upper-level lifetime (about 234 μs), absorption cross section ($8 \times 10^{-20}$ cm$^2$) and extinction ratio (>40 : 1) with single-crystal Nd:YAG in same doping concentration [7]. In addition, its thermal conductivity and laser-induced damage threshold (LIDT) are corresponding to single-crystal Nd:YAG. The thermal conductivity of ceramic Nd:YAG and single-crystal Nd:YAG are 0.105 J/cm °C and 0.107 J/cm °C respectively at 20°C. For the 4 ns pulse width 1064 nm laser, LIDT of ceramic Nd:YAG and single-crystal Nd:YAG are both 110 J/cm$^2$ (0.7-at % Nd$^{3+}$ doping concentration). Besides, ceramic Nd:YAG possesses simple preparation technology, low cost, high doping concentration, easy-to-volume production and so on, it is regarded as the most promising alternative for single-crystal Nd:YAG and has broad potential applications in all solid state laser research.

BBO is a negative uniaxial crystal with large birefringence, relatively small dispersion, high extinction ratio (2000:1@632.8 nm), small wavefront distortion ($<\lambda/10$@632.8 nm), high transmittance (>98.5%@420–2000 nm), small switched-capacitor (about 2 pF) and high damage threshold (>850 MW/cm$^2$) [8]. Because of the reasons mentioned above, BBO electro-optical crystal is widely used in laser systems with high-power, high repetition rate and narrow pulse width acting as the ideal electro-optic Q-switch witch can exceed and replace acousto-optical Q-switch [9, 10].

Up to now, there are reports about extracavity frequency doubling low repetition rate green laser with electro-optical Q-switch [11, 12], intracavity frequency doubling high repetition rate green laser with acoustic-optical Q-switch [13, 14] and saturable absorber [15–17]. However, the report of intracavity frequency doubling with electro-optical Q-switch high power and high repetition rate green laser is rarely available.

In this paper, we demonstrate the experiment of a high repetition rate intracavity frequency doubled green laser with LD side-pumped ceramic Nd:YAG based on BBO electro-optical Q-switch. Using a three-mirror V-folded cavity and a type I critical phase-matched LBO crystal, we obtained green laser average power up to 32.6 W at a repetition rate of 10 kHz, corresponding to a pulse width of 58.5 ns, peak power of 55.4 kW, and optical-to-optical conversion efficiency of 10.9% (808 nm to 532 nm).

2. EXPERIMENTAL SETUP

The experimental setup for the generation of a 808 nm LD side-pumped ceramic Nd:YAG rod/BBO electro-optical Q-switch 532 nm green laser is shown in Fig. 1, which is a simple three-mirror folded cavity.
The focal lengths of the sagittal and the tangential beams are expressed as follows [14]:

\[
f_s = \frac{R}{2 \cos \alpha}, \quad f_t = \frac{R \cos \alpha}{2},
\]

where \( R \) is the radius of the concave surface of the folded mirror, \( \alpha \) is the folding half angle, the subscripts \( s \) and \( t \) represents the sagittal plane and the tangential plane, respectively.

The folded mirror is placed off-axis, from the equations listed above, the focal lengths of the sagittal and the tangential beams are different, causing the beam radius and curvature radius of the equiphase-surfaces to be unequal at the sagittal and tangential planes, respectively. The resulting astigmatism in the cavity influences the laser beam quality and frequency doubling conversion efficiency. Therefore, the incorporation of astigmatism compensation in the design of resonators is essential to obtain equal spot radii on the sagittal plane and the tangential plane.

Based on the theory of astigmatic compensation and thermal stability, using the Laser Cavity Design Software (LASCAD), the cavity parameters were rationally optimized.

The highly efficient laser diode pumping module (total 808 nm pumping power of 300 W, 1064 nm output power of 120 W) was used to generate the fundamental beam at 1064 nm. Figure 2 shows the schematic diagram of the laser diode pumping module. In the pumping module, three two-dimensional LD arrays (120 degrees between adjacent two, Each array consisted of 15 laser diodes) symmetrically surround the ceramic Nd:YAG rod (4 mm in diameter and 65 mm in length with 0.7-at% Nd\(^{3+}\) doping concentration).

The end mirror \( M_1 \) is a plano-plano mirror with high-reflectivity (HR) at \( p \)-polarized 1064 nm \((R_p > 99.8\%)\). The other end mirror \( M_3 \) is a plano-concave mirror with radius of curvature of 100 cm. The concave surface has dual wavelength HR coatings at \( p \)-polarized 1064 nm \((R_p > 99.8\%)\) and \( s \)-polarized 532 nm \((R_s > 99.5\%)\). The folding mirror \( M_2 \) is also a plano-concave mirror with the concave surface coated for HR at 1064 nm \((15\)\(^\circ\) \( p \)-polarization incident, \( R_p > 99.8\%)\) and high-transmittance (HT) at 532 nm \((15\)\(^\circ\) \( s \)-polarization incident, \( T_s > 99.5\%)\), while the piano surface is coated for anti-reflectance (AR) at 532 nm \((15\)\(^\circ\) \( s \)-polarization incident, \( R_s < 0.2\%)\) to extract the green beam from the resonator. The radius of curvature of \( M_2 \) is 160 cm.

Despite its lower effective nonlinear optical coefficient than KTP crystal, LBO crystal has a higher LIDT \(<26\) GW/cm\(^2\)), so it is also fit for intercavity SHG experiment. A longer LBO crystal can efficiently make up the disadvantage. A type I critical phase-matched LBO used for the second-harmonic generation (SHG) was cut at \( \theta = 90^\circ, \varphi = 12^\circ \) with dimension of \( 4 \times 4 \times 14 \) mm\(^3\). Because the wave-plate effect of the type I critical phase-matching is less than that of the type II and the depolarization effect can be weakened in the type I critical phase-matching, this method would be advantageous to obtain high power SHG output. Both surfaces of LBO were AR coated at