Diode pumped all solid state lasers (DPSSL) have played an important role in high power lasers in recent years for their compact structure, high efficiency, long lifetime and good beam quality. Nd\textsuperscript{3+} doped vanadate laser crystals [1–9], such as Nd:YAG, Nd:YVO\textsubscript{4}, Nd:GdVO\textsubscript{4}, Nd:YLF, were very popular to be gain medium in DPSSLs. In particular, Nd:GdVO\textsubscript{4} firstly developed in 1992 [10] was outstanding for its excellent thermal conduction (11.7 W m\textsuperscript{-1}K\textsuperscript{-1}) [11], which was more than twice that of Nd:YVO\textsubscript{4} (5.23 W m\textsuperscript{-1}K\textsuperscript{-1}) [12] and as large as that of YAG (14 W m\textsuperscript{-1}K\textsuperscript{-1}) [13]. In addition, the stimulated emission cross section of Nd:GdVO\textsubscript{4} (7.6 $\times$ 10\textsuperscript{-19} cm\textsuperscript{2}) at 1.06 $\mu$m [14] was much larger than that of YAG (2.8 $\times$ 10\textsuperscript{-19} cm\textsuperscript{2}) [13]. Thus, it was considered as a suitable crystal for powerful continuous-wave, Q-switched lasers operating at its three main emission lines [15–23]. In 2005, A. Minassian et al. [24] achieved 50.1 W of multimode and 40 W of predominate TEM\textsubscript{00} output at 1063 nm, M\textsuperscript{2} factors were 1.05 and 1.1 at the output power of 34 W. Recently, Zhang et al. [25] generated an output power of 52 W at 1063 nm for CW with a one a-cut rod crystal of 0.5 at % doped Nd:GdVO\textsubscript{4} with dimensions 23 $\times$ 61 mm\textsuperscript{3}.

LD partially end-pumped slab laser with hybrid resonator was a good choice to produce high power output with near diffraction limited beam quality [26, 27]. With this geometry, some kinds of crystals including Nd:YAG, Nd:YVO\textsubscript{4} have been used to generate high power laser with excellent beam quality in continuous-wave and Q-switched operation. In this paper, a compact, high beam quality LD end-pumped GdVO\textsubscript{4} slab oscillator was demonstrated with the highest output power of 83 W, the optical-to-optical conversion efficiency was 34.8%. So far as we known, this is the highest power for LD end-pumped laser with one piece of GdVO\textsubscript{4}.

The experiment setup was shown in Fig. 1. The central wavelength of LD stack (including four bars) was 808.6 nm and the emission from each diode laser bar was individually collimated by microlens. A 12.0 $\times$ 0.4 mm homogeneous pumping line was generated inside the Nd:GdVO\textsubscript{4} slab. The GdVO\textsubscript{4} crystal (12 $\times$ 10 $\times$ 1 mm) was a-cut with the c-axis along the 12 mm direction and mounted between two water-cooled heats sinks with two large faces (12 $\times$ 10 mm). Two end faces (12 $\times$ 1 mm) of the slab crystal were polished and coated for high transmission (HT) at 808 and 1063 nm. Indium foil was used for effective and uniform thermal contact and cooling. Both the LD stacks and laser crystal were temperature controlled by circulating water with temperature of 24°C. Line-shaped pumping line and efficient heat removal through two large faces induced a quasi-one-dimensional temperature gradient along y-axis.

A spherical mirror M\textsubscript{1} ($R_1$ = 500 mm) and a cylindrical mirror M\textsubscript{2} ($R_2$ = −350 mm) were used as resonator mirrors, both of them were coated for high reflectivity (HR) at 1063 nm and HT at 808 nm. M\textsubscript{1} and M\textsubscript{2} built up a plane-concave stable resonator in vertical direction and an off-axis confocal positive-branch unstable resonator in horizontal direction. The magnification of the unstable resonator was $M = -R_1/R_2 = 1.4$, and the output coupling was $T = 1 - 1/M = 30\%$. M\textsubscript{2} was cut and polished at one edge where the laser beam was coupled out. Taking the inserted Nd:GdVO\textsubscript{4} slab into account, the cavity length was adjusted to 80 mm.
Figure 2 gave the output power as a function of pumping power. It was shown that the output power of GdVO$_4$ laser increased with the pumping power. At the pumping power of 238 W, the highest output power of 83 W was obtained with an optical-to-optical conversion efficiency of 34.9%. A slope efficiency of 39.4% was achieved by linear fitting. The laser-action threshold was measured to be ~25 W. When the pumping power was over 200 W, the output power tended to saturation and no longer increased if we kept on adding the pumping power. While with the same pumping system and resonator as this experiment, the slope efficiency and optical-to-optical efficiency of 0.3 at % Nd:YVO$_4$ were 59 and 44%, respectively. In [28], the pumping power was measured after the beam shaping optic, which was about 91% of the LD output power. If we considered the efficiency of coupling system, the slope efficiency and optical-to-optical efficiency would get to 43.3 and 38.3%, respectively. According to [29, 30], the efficiency of 0.5 at % dopped GdVO$_4$ should be close to that of 0.3 at % dopped Nd:YVO$_4$. However, in this experiment the slope efficiency and optical-to-optical efficiency of GdVO$_4$ was 15.7 and 5.7% lower than that of YVO$_4$, respectively. The main reason might be that considered the doped concentration and absorption coefficient of Nd:GdVO$_4$ was higher here and to decrease the thermal effect, a wide pumping size (~0.6 x 12 mm) was formed and resulted in worse mode matching. To further scale the output power, a lower doping concentration crystal might be adopted for the next step.

Figure 2 showed the beam quality $M^2$ factors. The beam quality $M^2$ factors at output power of 70 W for GdVO$_4$ were shown in Fig. 3. To get beam quality, the beam radiuses in different position were measured by knife-edge method. Using $M^2$ factor, the propagation of the high order laser beam can be described as [31]:

$$\omega(z) = \omega_0 \sqrt{1 + \left( \frac{M^2 \lambda z}{\pi \omega_0^2} \right)^2},$$

where $\omega_0$ was the beam waist; $\omega(z)$ was the radius of beam at the point $z$; $\lambda$ was the wavelength of laser and $z$ was the distance to the beam waist. According to (1), beam radiuses at different position in both directions were fitted and the beam quality $M^2$ factors at output power of 70 W were calculated to be 1.2 in stable direction and 1.3 in unstable direction, respectively.

In summary, an 83 W continuous wave LD pumped GdVO$_4$ slab laser with a hybrid resonator at 1.06 $\mu$m with the slope efficiency of 39.4% was reported. The beam quality $M^2$ factors were measured to be 1.2 in stable direction and 1.3 in unstable direction at the