80-W green KTP laser used in photoselective laser vaporization of the prostate by frequency doubling of Yb^{3+}-doped large-mode area fiber laser

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ABSTRACT

Photoselective laser vaporization of the prostate (PVP) is the most promising method for the treatment of benign prostatic hyperplasia (BPH), but KTP lasers used in PVP with lamp-pumped are low efficient .To increase the efficiency , we develop a 80-W, 400kHz, linearly polarized green laser based on a frequency-doubled fiber laser. A polarization-maintaining large-mode area (LMA) fiber amplifier generate polarized 1064nm fundamental wave by amplifying the seed signal from a composite Cr^{4+}:YAG—Nd^{3+}:YAG crystal fiber laser. The fundamental wave is injected into a KTP crystal with confined temperature management to achieve second harmonic generation (SHG). The overall electrical efficiency to the green portion of the spectrum is 10%.80-W maintenance-free long-lifetime KTP laser obtained can well satisfy the need of PVP.

Keyword: double frequency, KTP, fiber laser, PVP, LMA.

1. INTRODUCTION

Symptomatic benign prostatic hyperplasia (BPH) usually occurs in men over the age of fifty. More than half of men in their sixties and as many as 90 percent in their seventies and eighties have some symptoms of benign prostatic hyperplasia[1], which although not cancerous or precancerous, can severely interfere with daily life. For some, the condition causes no problems, for others, it results in irritating symptoms such as urinary frequency, poor stream quality and urine leakage, impotence, or a serious condition such as acute urinary retention. With an increase in the ageing population, the number of men suffering from BPH is expected to increase in the next decade, therefore the more efficient and less risky treatment of BHP will be cried out for.

Until now, there are many treatment methods for BPH and all methods including laser prostatectomy has its benefits and harms. The clinical manifestations of BPH are felt to arise from bladder outlet obstruction. Medical and surgical intervention aims to relieve the obstruction. Prostatectomy and minimally invasive therapies resect or ablate the obstructing tissue. Interstitial thermal ablation techniques (transurethral microwave thermotherapy , transurethral needle ablation , and interstitial laser coagulation) using various sources of energy to induce coagulative necrosis and delayed prostate shrinkage have several advantages: minimal or no bleeding, avoidance of transurethral resection of the prostate syndrome, and need for less anaesthesia. Patients can also be treated on an out-patient basis. However the development of postoperative oedema and delayed sloughing of tissue due to the energy-induced coagulative necrosis

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lead to prolonged urinary obstruction, and patients may require catheterization for up to 3 weeks after treatment. Some of these techniques have a high re-treatment rate (about 40%) for recurrent obstruction over the next few years and further more aggressive therapy is required. These techniques have thus been largely abandoned. Minimally invasive therapies have evolved based on the principle of prostatectomy with immediate removal of the obstructing tissue. Such therapies include transurethral vaporization of the prostate (TUVP), Holmium laser resection of the prostate, and photoselective vaporization of the prostate (PVP) with KTP laser. Transurethral vaporization is associated with a high rate of postoperative irrigative voiding symptoms, distrait, urinary retention, and need for unplanned secondary catheterization as a result of postoperative oedema and delayed sloughing of issue. Helium laser resection of the prostate attempts to mimic standard TURP by excising and removing pieces of prostatic tissue transurethrally, thus gradually creating a cavity. Development of a mechanical tissue morcellator has improved the handling of the excised prostatic tissue and has made resection of larger pieces of tissue feasible. Nonetheless, the procedure takes longer operating time than the standard TURP, and has not been widely adopted by urologists as it is technically challenging. Furthermore, Holmium laser equipment is high cost. PVP using high power green KTP laser is a relatively new promising treatment approach. [2,3,4] KTP laser vaporization offers better control and precision than previous procedures. KTP is superior to earlier BPH treatments in the sense that it's the first truly ablative treatment one has been able to offer. It physically destroys the prostate tissue with minimal blood loss, and can even be used for patients on anticoagulation medication. During this procedure the patient experiences little or no pain. Another distinct advantage of the KTP laser vaporization is the ability to use normal saline irrigation intraprocedurally [5], as opposed to past ablative procedures, which required water irrigation because saline interfered with the electric current. Water irrigation often caused electrolyte imbalances in the patient after the procedure, a side effect that the use of normal saline eliminates.

At present the KTP laser widely used in the PVP surgical operation is made from doubling 1064nm infrared laser by KTP crystal to 532nm green laser. A lot of doctors that come from many hospitals of the world-wide locations (include several hospitals of China) and scholars of research institute use Laserscope company's products [5] But these machine use traditional flash light which has the lifetime of several hundreds hour to provide pump energy therefore the cost of maintenance is very high. The other shortcoming of the system is electric-optical inefficient, so the laser system will waste a great deal of electric power and need bulky water cool system. At this energy lacking ages this kind of machine obviously is unpopular and shall be discarded! Certainly some researcher have already used laser diode to pump Nd:YAG to make doubly frequency source[6, 7, 8].This kind of design raised an electric-optic conversion efficiency for certain. The efficiency is increased to 3% but the diffuse of heat of the laser system is difficult so the laser system still need a huge cooling set and its efficiency is lower as of old[9].

Just as fiber lasers is substituting solid lasers pumped by flash lamp or laser diode, the KTP laser from fiber laser double frequency will also substitute the traditional KTP lasers. An outstanding advantage of fiber laser has high electric-optical efficiency and the other is that it doesn't need to be supported as a result of its high reliability [10]. Because people can use breeze cooling system to replace water cooling system the weight of the laser is alleviated consumedly. Anping Liu applied the frequency doubling of a 110-W linearly polarized diffraction-limited Yb-doped fiber oscillator power amplifier (FOPA) to generate 60-W near-diffraction-limited linearly polarized green output [11], but the power shows slightly insufficient in PVP procedure because the laser system does not design for the medical treatment. For acquiring better beam quality, the design of the laser system is very complicated thus raising the cost of system so the equipments will be expensive. However the most important parameter of the green laser used in medical treatment is the power of laser, so to design a simple , credible, cheap, maneuverable, free-supported and high power green fiber laser equipments is necessary.

2. 80-W KTP LASER

As shown in figure 1,our experimental laser system is composed of three parts. The first part is seed laser consists of laser diode(LD), crystal fiber, isolator and polarizer; the second part is fiber amplifier consists of input coupling lenses , polarization-maintaining(PM) Yb-doped fiber and pumping source; the third part is frequency doubling system consists of a input coupling lens ,KTP crystal ,temperature management device and output filter.

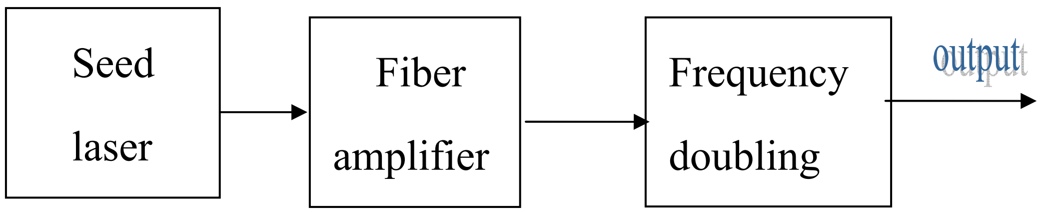

Figure 1.sketch map of KTP laser

Fiber lasers have established themselves as a very attractive and power scalable solid-state laser concept. This fact is due to their inherent properties such as outstanding thermo-optical feature and high optical-to-optical efficiency but also due to robustness, compactness and simplicity of operation. In continuous wave operation output powers approaching the kW-level with diffraction-limited beam quality are come true. This power level is reached by applying so-called large-mode-area fibers which feature a reduced nonlinearity, what usually constitutes the main performance limitation of fiber laser systems. So we adopt completely fiber laser in the experiment setup.

2.1 Seed fiber laser

In the first part LD and composite crystal fiber form seed fiber laser. LD is the pumping source of seed fiber laser achieved by the growth of a composite Cr^{4+}:YAG --- Nd^{3+}:YAG crystal fiber by means of Laser Heated Pedestal Growth (LHPG). The diameter and the length of the crystal fiber is 200µm and 5cm respectively. Q-switched laser oscillation was realized in quite low threshold. The pulse duration and the repetition rate of the output signal of the crystal fiber can vary along with the pump power of LD. The pulse duration of the seed source can be varied from several tens of nanoseconds to nanoseconds, and the repetition rate can be varied from a few kilohertz to hundreds of kilohertz. The average output power is determined by pump power after the crystal fiber is chosen. At a 10 ns pulse duration and the repetition rate of 100 kHz the composite crystal fiber produces an average output power of 200 mW. A prominent advantage of the composite crystal fiber laser is self-modulate without external modulator hereby simplifying greatly the design of the system. The light signal from the composite crystal fiber through an isolator pumps into a fiber polarizer that converts the seed laser into linearly polarized light output.

2.2 Fiber amplifier

The seed signal from the fiber polarizer converts the signal laser into a polarization mode to match and transfer to the followed fiber power amplifier. The fiber power amplifier uses an Yb-doped polarization-maintaining double-clad Large Mode Area (LMA) fiber with a fundamental mode-field diameter of 30µm and a numerical aperture of 0.06. LMA fibers differ from conventional telecommunication fibers in that they are double-clad structures, typically having larger diameter cores and smaller numerical apertures (typically 0.06). The former design attribute significantly increases the threshold for non-linear processes such as Stimulated Brillouin Scattering (SBS) or Stimulated Raman Scattering (SRS), compared to telecom fibers, which enables higher power operation and reduce the fiber length. A smaller numerical aperture helps reduce the capture of Amplified Spontaneous Emission (ASE) by the fiber core, thus reducing its amplification within the fiber cavity.

The linearly polarized pulsed signal from the polarizer is launched into the LMA core with a set of specially designed lenses that achieve mode matching between the signal laser and the LMA fiber to improve beam quality. The pump light is injected into the LMA fiber opposite the pump end, as shown in Fig. 2. The pump wavelength is set to the strongest absorption peak near 980 nm to shorten the fiber, therefore minimizing possible nonlinear effects. The dielectric filter for separating the pump light and the amplified signal provides .99% reflectance at 980 nm and 1% reflectance at 1064 nm to introduce pump energy into the large mode area fiber amplifier and export 1064 nm Laser.

2.3 Frequency doubling system

The nonlinear crystals used in common are as follows: $KTiOPO_4$(KTP), periodically poled $KTiOPO_4$(PPKTP), β-BaB_2O_4(BBO), LiB_3O_5(LBO) and so on. KTP with a big nonlinear coefficient, a wide receiver angle and an easy phase matching is recognized an excellent and all-powerful crystal, furthermore is widely applied especially in the conversion of 1.06μm to 532nm due to its ripeness, lower cost and excellent function. An intensive fundamental power density is indispensable to an efficient frequency conversion but it causes damage of KTP crystal (so-called gray tracking) at the same time to limit the boost to conversion efficiency. Luckily if we put the KTP crystal to a good temperature management, the gray tracking will be avoided largely even entirely. Therefore we keep the KTP crystal at the temperature of 100□ to gain good frequency doubling efficiency.

The antireflective-coated KTP crystals are 5mm×5mm×5mm and cut for noncritical phase matching at the 1064-nm operating wavelength. The KTP crystal is mounted in a temperature management device, i.e. TM as shown in fig.2. The KTP operating temperature be controlled at 100℃ by the temperature device to avoid the production of gray tracking. Following the crystals, two dielectric filters are used to separate green and fundamental beams in order to the green laser can be output merely.

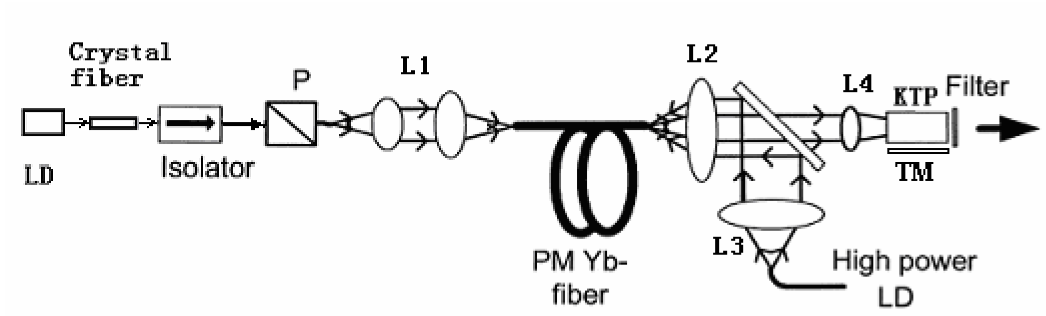

Figure. 2. Experiment setup for 80 W green KTP laser. LD, laser diode, pumping source of the crystal fiber; P, fiber polarizer; L1, L2, L3, L4, coupling lens.

3. EXPERIMENT RESULTS

In the experiment the LMA fiber length of 10 m is adopted .It absorbs 98% of the pump power at 980 nm. The linearly polarized pulsed signal from the seed laser is magnified by the 10 m LMA fiber amplifier. All lenses in the experiment device are antireflection coated for both pump and signal wavelengths to reduce undesirable backreflection. The maximum output power from the fiber-coupled laser diode is 220W, and the coupling efficiency between the laser diode and the fiber is approximately 80% for the loss of the connecting system. The relation of output power of the fiber power amplifier versus launched pump power is illustrated in figure 3. At a 400kHz repetition rate and 10 ns pulse duration the fiber power amplifier produces as much as 127 W of output power, corresponding to a slope efficiency of 58% with respect to the launched power.

The efficiency of conversion to green light output may be increased by the augment of the pulse peak power which may cause nonlinear effects in the fiber. Among fiber nonlinear effects, SBS has the lowest threshold but SBS can be prevented by a simple reduction of the pulse duration to well below 16 ns. Once the SBS is suppressed, the maximum peak power of the fiber power amplifier is limited largely by either SRS or material damage. We can calculate the SRS threshold of a linearly polarized beam by use of the expression

$$P_{th} = \frac{16A_{eff}}{g_R L_{eff}} \qquad (1)$$

where P_{th} is the SRS threshold power, A_{eff} is the effective area of the mode field of the LMA fiber, g_R is the maximum value of Raman gain coefficient and L_{eff} is the effective length of the LMA fiber. If assuming a uniform signal distribution along the fiber length for a 10m-long fiber with a mode field diameter of 30μm and considering $g_R \approx 5\times10^{-14}$m/W the P_{th} can be calculated is almost 40kW. For the fiber power amplifier is end pumped in the experiment, the signal distribution is nonuniform along the fiber length that will make the SRS threshold much higher than the calculated value afore. Therefore, when we used 10ns pulse duration and a 400kHz repetition rate, 32-kW peak power is generated from the fiber power amplifier at the maximum average power of 127 W. So the peak power is less than the SRS threshold power. The output power of green laser as a function of the fundamental power is shown in Fig. 4. At 127W fundamental power, 80 W of green laser power is produced, corresponding to maximum conversion efficiency of 63%.

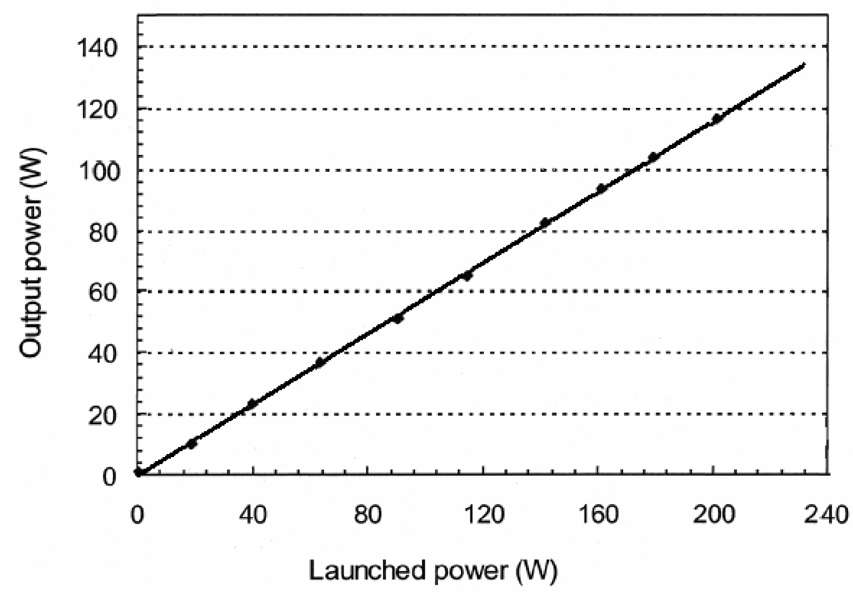

figure 3. Output power of the fiber power amplifier versus launched pump power.

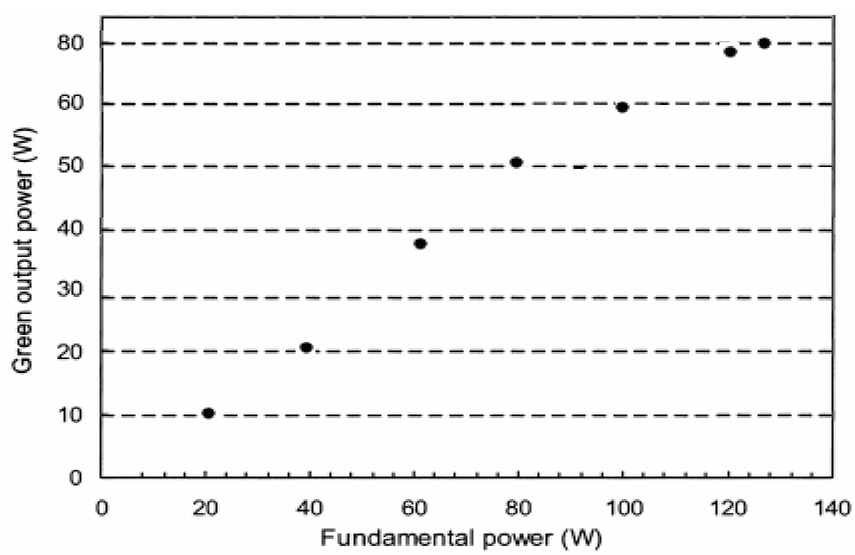

Fig. 4. The output power of the green laser as a function of the fundamental power.

On all accounts, a highly efficient, linearly polarized 80-W green KTP laser based on the frequency doubling of a fiber laser has been demonstrated. The overall electrical-optical efficiency achieves 10%.

4. CONCLUSION

The framework of the 80-W Green KTP Laser By Frequency Doubling Of Yb3+-Doped Large-Mode Area Fiber Laser is compact in the extreme, the volume is small and the weight is light. The electrical-optical efficient of the KTP laser has attained considerable 10% which is far greater than of the lamp pumped KTP laser widely used nowadays. The equipment owns a well situated cost and advantages of maintenance-free, long-lifetime so it will be a PVP surgical operation system that has the good market foreground

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