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Efficient blue light generation from a diode laser pumped Nd:YAG laser

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Abstract

We report on efficient intracavity-doubling of a 946nm Nd:YAG laser with a LBO crystal at room temperature. A CW output power of 103mW at 473nm is obtained at a pump power of 2.58W with an optical conversion efficiency of 4.0%. To our knowledge, this is the highest efficiency to date for a diode laser pumped compact Nd:YAG blue laser with a simple flat-concave resonator using a bulk nonlinear crystal for intracavity-doubling.

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Keywords: blue light, diode laser pumped, intracavity-doubling.

Introduction

Low-cost, compact and reliable blue lasers are desirable for applications such as high-density optical data storage, colour displays, underwater communication, Raman spectroscopy and medical diagnostics. Although the blue semiconductor diode laser is expected to become important, frequency doubling of the 946nm Nd line is currently a more practical option, especially for high power operation. There are some difficulties associated with obtaining efficient laser operation at 946nm using Nd:YAG. First, since the lower laser level is the upper 857cm^{-1} crystal field component of the $^4I_{9/2}$ ground-state manifold, the laser is a quasi-three-level system which leads to significant re-absorption loss owing to population in this state at room temperature. Secondly, the stimulated emission cross-section is about one order of magnitude smaller than that of the $^4F_{3/2}\rightarrow{}^4I_{11/2}$ transition at 1.06μm. In recent years, a number of papers have dealt with diode laser pumped operation of Nd:YAG at 946nm and frequency doubling to 473nm [1-5]. D.G. Matthews *et. al.* reported a Nd:YAG/$KNbO_3$ composite microchip blue laser generating 25mW of 473nm CW radiation with 1.2W of diode laser pumping[4]. Accurate temperature control of the $KNbO_3$ crystal was needed due to its small temperature acceptance. By using a three-mirror folded cavity and BBO as a nonlinear crystal, a blue output power of 550mW at 473nm was achieved by T. Kellner *et. al.*[5], which is the highest value reported to date. The pump power and optical efficiency were 25.8W and 2.1% respectively.

In this paper we report the efficient frequency doubling of a 946nm CW Nd:YAG laser, end-pumped by a diode laser, by the insertion of a room temperature LBO crystal into the laser cavity. A simple flat-concave resonator was used and the laser cavity length was only 17mm, giving a device which was more compact than those employing multi-mirror folded cavities. A blue light output power of 103mW at 473nm was obtained at a laser diode laser pump power of 2.58W, giving a total optical conversion efficiency as high as 4.0%. To our knowledge, this is the highest efficiency achieved to date for this type of laser.

Experiments and results

The experimental arrangement of the diode laser pumped 946nm and intracavity-doubled 473nm Nd:YAG laser is illustrated in figure 1. The pump source was an Optopower fibre-coupled diode laser with a centre wavelength of 808nm at a temperature of 25°C. The maximum output power was 3W and the optical fibre diameter was 100μm. A FiberPort adapter was used to collimate the output from the end of the fibre and a Special Optics laser diode collimator, with an aperture of 18mm and NA of 0.6, was used to focus the collimated beam into the Nd:YAG crystal. A 2.0mm thick, 0.6-at.% Nd:YAG crystal was polished to obtain parallel flat surfaces. The flat front face of the Nd:YAG crystal which served as one of the resonator mirrors was coated for high reflectivity (HR) at 946nm and high transmission at the 808.7nm pump wavelength. The flat exit face of the Nd:YAG crystal was antireflection (AR) coated at 946nm to reduce intracavity reflection loss. The crystal was held on a copper mount, with good thermal contact between crystal and mount to minimise pump heating effects.

For the 946nm fundamental wavelength output, the laser resonator was formed by a 20mm radius of curvature output mirror and by the 946nm HR-coated surface of the Nd:YAG crystal. The output mirror was coated for 2.0% transmission at 946nm, and had sufficient transmission at 1.06μm to suppress oscillation of the $^4F_{3/2}\rightarrow{}^4F_{11/2}$ transition. The centre wavelength of the diode laser was optimised to the 808.7nm absorption peak of the Nd:YAG by tuning of the diode laser temperature. The pump light was focused into the Nd:YAG crystal through its 946nm HR coated end. Approximately 57% of the incident pump power was absorbed by the Nd:YAG crystal. The end coupling pump geometry facilitated a good overlap between the pump and laser modes, ensuring low pump threshold and high gain.

Figure 2 shows the 946nm output power as a function of diode laser pump power. With a pump power of 2.8W, an output power of 564mW in TEM_{00} mode was obtained. The threshold pump power and the total optical conversion efficiency were measured to be 396mW and 20.1% respectively. As the Nd:YAG crystal was only passively heat sunk with no active cooling, thermal effects led to a decrease of the slope efficiency at higher pump power as shown in figure 2. The output beam was essentially unpolarised.

For second-harmonic-generation (SHG) of the 946nm Nd:YAG laser, an 8mm-long LBO crystal with a cross-section of 3.0mm × 3.0mm and oriented for type I phase matching (θ=90° and φ=18.9°) was inserted into the laser cavity. The LBO crystal was mounted on a copper heat sink without active cooling or temperature control. Both sides of the LBO were polished to parallel flat surfaces and AR coated at 946 and 473nm. The coating of the output mirror was changed to HR for 946nm and AR for 473nm and 1.06μm, but its radius of curvature remained at 20mm. The blue light emission was sensitive to the cavity length. Changes in the cavity length led to periodic variations in the blue light output power. A maximum blue light output power of 10mW at 473nm was obtained at a pump power of 2.58W and a cavity length of 17mm. A threshold pump power of 306mW was measured and the total optical conversion efficiency was calculated to be 4.0%. It should be noted that this refers only to the output from the output mirror, as the blue light which was emitted toward the pumping end was not reflected back. The characteristic of the 473nm output power versus pump power is shown in figure 3. Unlike a theoretical SHG curve, figure 3 shows that the blue light output power increases linearly, not quadratically, with the pump power when far above threshold. This may be caused by thermal effects in the Nd:YAG and LBO crystals at higher pump power.

The polarisation of the output beams at 473nm and 946nm were examined and found to be strongly linearly polarised and orthogonal to each other under all experimental conditions, although the 946nm output was unpolarised without the LBO inside the cavity. When the LBO crystal was rotated by 90°, the polarisation of the 473nm and 946nm outputs were also rotated by 90° and remained orthogonal. This result is consistent with that observed by D.G. Matthews *et. al.* in an intracavity-doubled 473nm blue Nd:YAG laser using a $KNbO_3$ crystal[4]. Although the blue light output power in our case was significantly higher and the 946 nm output power was of the same order as that of the 473nm in our case, the nonlinear loss may still be small compared with the difference in the intracavity net gain for the two possible polarisation eigenmodes as analysed in reference 3.

Conclusions

A diode laser pumped compact 946nm CW Nd:YAG laser and efficient SHG at 473nm by intracavity-doubling using a LBO crystal were demonstrated. A single-ended output power of 103mW at 473nm was obtained at a diode laser pump power of 2.58W, the total optical conversion efficiency being as high as 4.0%. To our knowledge, this is the highest efficiency to date for this kind of compact Nd:YAG blue laser.

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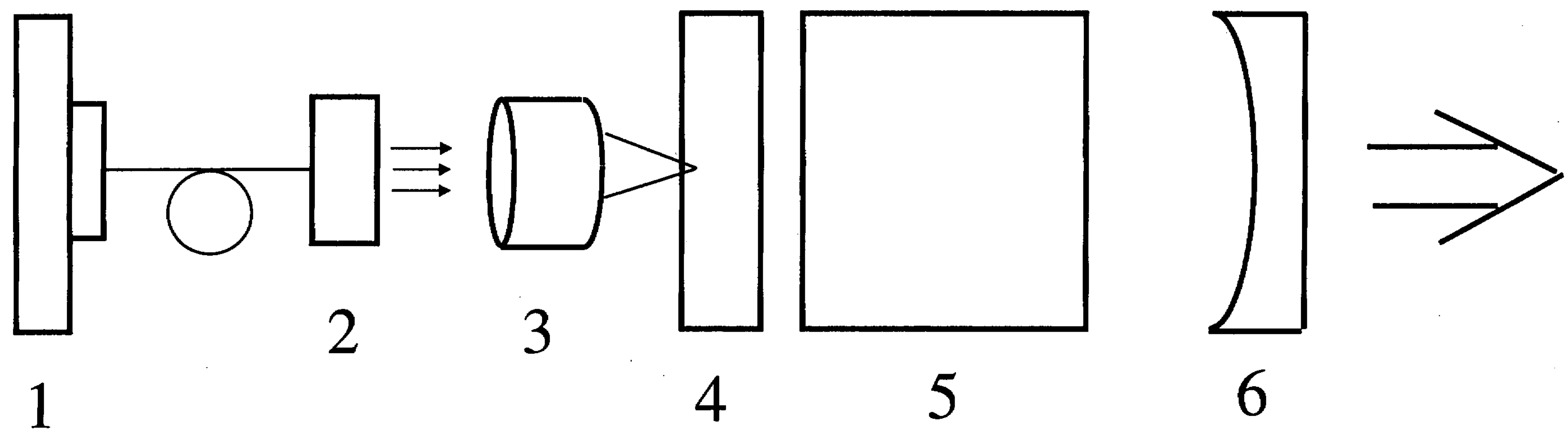
Figure and table captions

Fig. 1. Schematic diagram of the diode-laser pumped 946nm and intracavity-doubled 473nm Nd:YAG laser.

Fig. 2. Output power of the Nd:YAG laser at 946nm as a function of pump power.

Fig. 3. Output power of the intracavity-doubled Nd:YAG laser at 473nm as a function of pump power.


1
2
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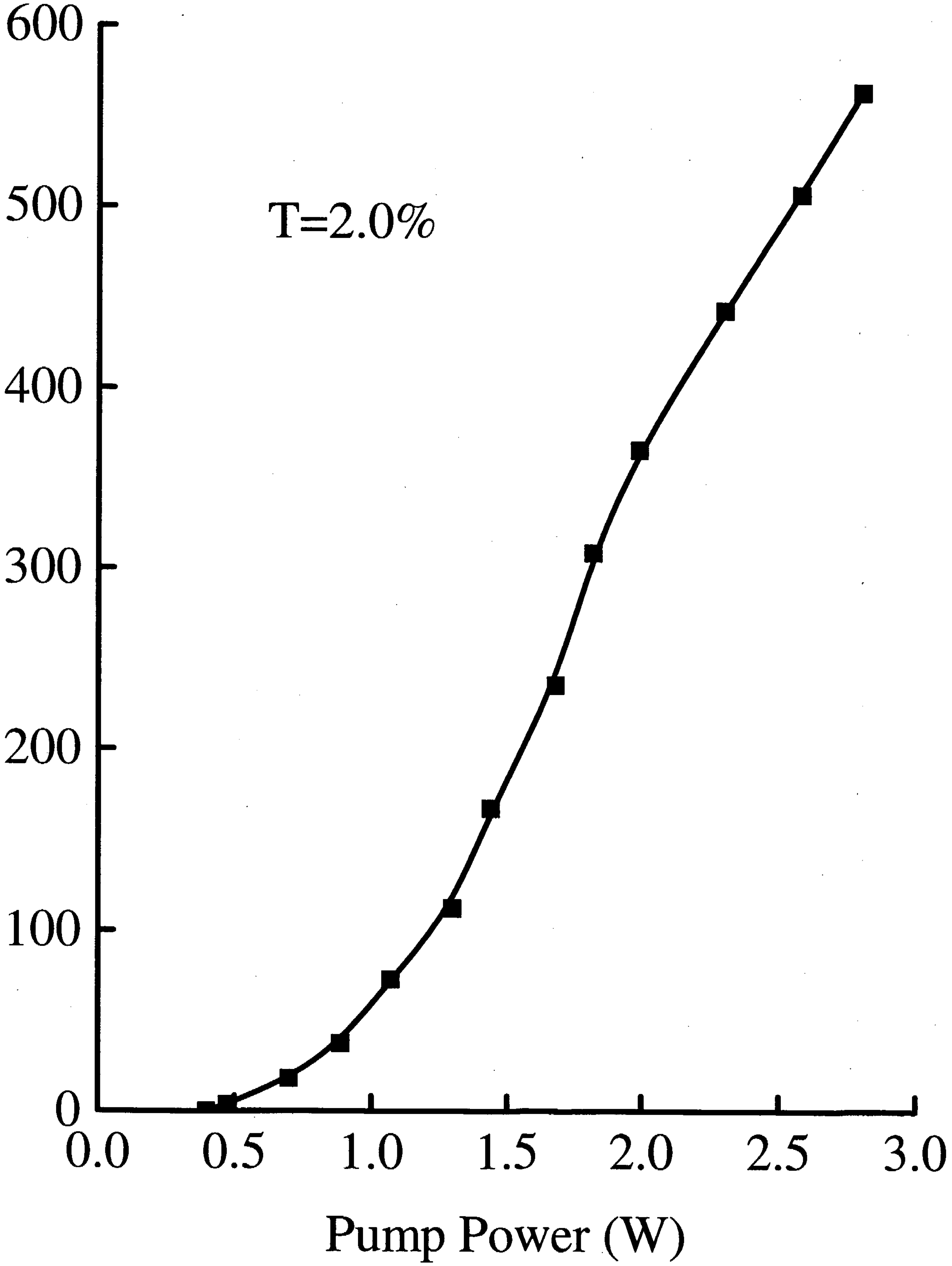
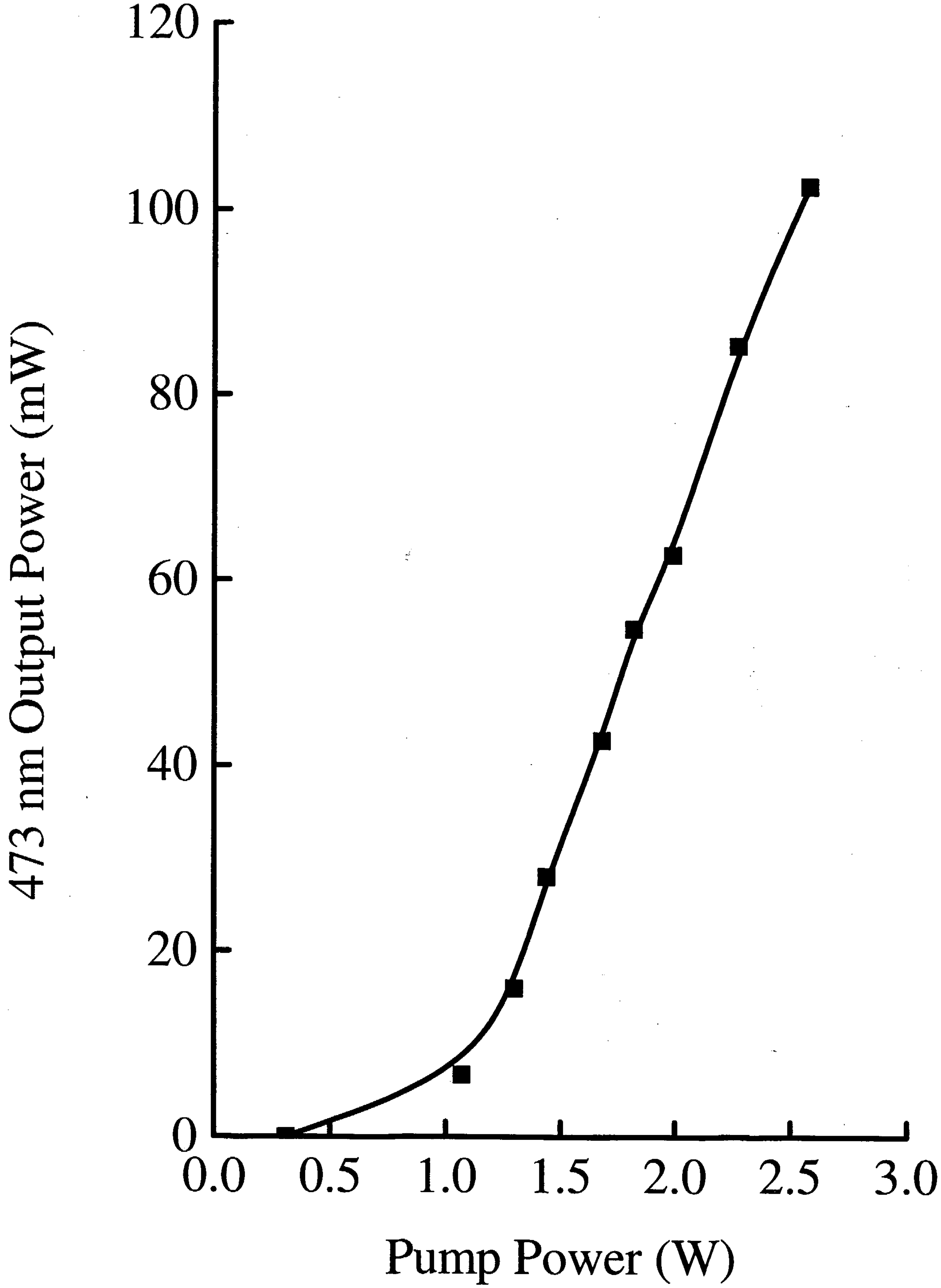


600
500
400
300
200
100
0
T=2.0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Pump Power (W)



120
100
80
60
40
20
0
473 nm Output Power (mW)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Pump Power (W)