Selective Transverse Modes in a Diode End-Pumped Nd:Yag Pulsed Laser

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Abstract—The output beam quality of multi transverse modes of laser, are relatively poor. In order to obtain better beam quality, one may use an aperture inside the laser resonator. In this case, various transverse modes can be selected. We have selected various transverse modes both by simulation and doing experiment. By inserting a circular aperture inside the diode end-pumped Nd:YAG pulsed laser resonator, we have obtained TEM_{00}, TEM_{01}, TEM_{20} and have studied which parameters, can change the mode shape. Then, we have determined the beam quality factor of TEM00 gaussian mode.

Keywords—Beam shape, Transverse mode , Beam quality factor

I. Introduction

Output beam of laser is multi transverse modes. In certain application, such as trapping and spectroscopy, TEM_{00} or another high order transverse modes are used. In order to obtain single transverse mode, we have to select these modes. There are many methods for selecting transverse modes, such as using an aperture and phase element in a laser resonator or changing mode volume. We have used an aperture inside a resonator. In order to determine the mode content in the resonator, it is necessary to solve the round-trip propagation equation [1].For solving this equation, it is usually used propagation-matrix diagonalization. In this study, we have used new method that is based on diffraction theory [3]. If we numerically solved the round-trip propagation equation, we can simulate desired mode pattern and its dependence to the resonator parameters. In experiment, for selective mode, an end pump system is an obvious choice for the pump geometry because of these advantages [2]:

1-This pump geometry can create a "gain aperture"for naturally generating the TEM_{00} resonator mode.

2-Highest optical conversion efficiency and pump-coupling efficiency are available with this type of diode pumping, as the pump light can be deposited entirely within the fundamental mode volume.In the last part of this paper, we have obtained beam quality factor for a TEM_{00} gaussian mode and have shown parameters that are changing this factor.

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II. Theory

The round-trip wave-beam propagation equations were solved in circular symmetry to yield the Laguerre-Gaussian transverse modes. The field distribution of a nondegenerated Laguerre-gaussian TEM_{pl} mode inside a laser resonator is expressed by [2]:

$$E_{pl}(r,\theta) = E_0\left(\frac{2r^2}{w^2}\right)^{1/2} L_p^l\left(\frac{2r^2}{w^2}\right)\exp\left(-\frac{r^2}{w^2}\right)\exp(il\theta) \quad (1)$$

In this paper, we have described methods to determine the mode of given resonator. We have used the diffraction integral method. We began with analyzing the bare resonator configuration, not into account the gain medium effects. Put an aperture inside the resonator to select desired transverse mode. We have calculated diffracted electric field after an aperture and when it is passing through the mirrors in one round-trip propagation. For this reason, we consider Fresnel and Collins integral.

The diffracted electric field by a circular aperture with radius R, is given by [3] :

$$u_2(r_2^*) = -(-i)^{m+1}2\pi N\exp[-ikL]\int_0^1 u_1(r_1^*) \cdot\exp[-i\pi N(r_1^{*2}+r_2^{*2})]J_m(2\pi N r_1^* r_2^*)r_1^* dr_1^* \quad (2)$$

In this equation $N=\frac{R^2}{\lambda L}$ is Fresnel number and $r_i^*=\frac{r_i}{R}$ and J_m(x) is a Bessel function of order m.If the electric field propagates from a plane 1 to plane 2 and an optical system with a ray transfer matrix M (A,B,C and D are elements of matrix) is located between the planes, electric field after optical element is given by [3]:

$$E_2(x_2,y_2)=\frac{i}{\lambda B}\exp[-ikL]\iint E_1(x_1,y_1) \cdot\exp[i\frac{\pi}{\lambda B}(Ax_1^2+Dx_2^2-2x_1x_2+Ay_1^2+Dy_2^2-2y_1y_2)]dx_1dy_1 \quad (3)$$

By using MATLAB software, we have solved Fresnel and Collins integral numerically in circular symmetry and have selected the desire transverse modes in a bare resonator (without gain medium effects). We have assumed the Gaussian beam that is passing through a circular aperture in a plano-concave bare resonator with front mirror R=1m. By adjusting a radius of aperture (r) and its distance from front mirror (l), various transverse modes, have been obtained. To give an example, we have shown in Fig1, TEM00 and TEM01 modes, for indicated parameters.

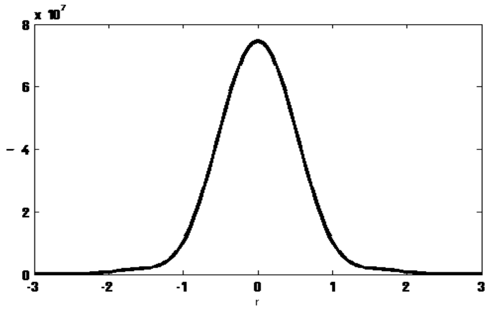


Fig. 1 intensity distribution of (a) TEM00 , with r=0.5mm, l=30mm

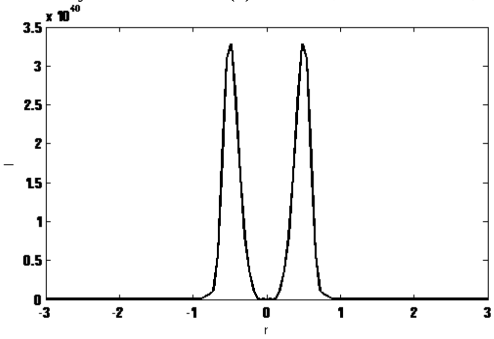


Fig. 2 intensity distribution of TEM01 , with r=1.05mm, l=30mm

III. Experiment

We set up a diode end-pumped Nd:YAG pulsed laser in a plano-concave resonator, front concave mirror with R=1m and coated back mirror. We have determined output energy as a function of pumped pulse duration and resonator length. The results are shown in table 1 and 2 respectively. As it can be seen, by increasing the pulse duration, the output energy, increases as expected because of gain enhancement.In order to obtain the highest output energy for our set up, we have obtained optimum resonator length L=20 mm and T=200 μs for pulse duration.

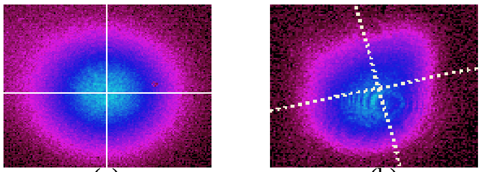
TABLE I
OUTPUT ENERGY AS A FUN CTION OF RESONATOR LENGTH

Resonator length(mm)	Output energy (μJ)
20	339
35	322
44	273

TABLE II
OUTPUT ENERGY AS A FUNCTION PULSE DURATION

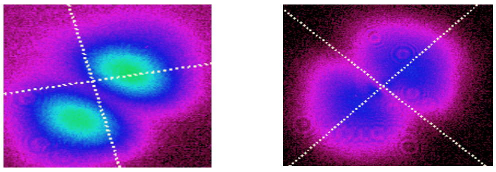
Pulse duration (μs)	Output energy (μJ)
100	287
150	314
200	375

Now, we selected desired transverse modes and researched the effect of parameters that are changing the mode shaping.By inserting a circular aperture inside the resonator and by changing its radius (r) and also its coordinate x ,y, z , and its distance from rod (z), the desired transverse modes have been selected.(l=The distance an aperture from front mirror=30mm) In Fig.3, 4, 5 the near and far field profile of selected $TEM_{00}, TEM_{01}, TEM_{20}$ modes are shown.



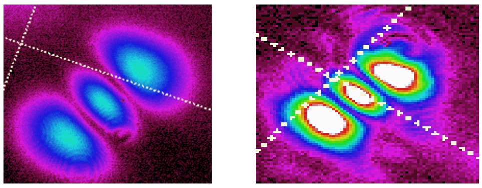
(a) (b)

Fig. 3 (a) Near field and (b) Far field of TEM00 mode, r=0.44mm, z=7.9mm



(a) (b)

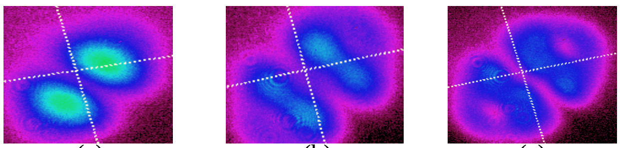
Fig. 4 (a) Near field and (b) Far field of TEM01 mode, r=0.89 mm, z=7.7 mm



(a) (b)

Fig. 5 (a) Near field and (b) Far field of TEM20 mode, r=1.8 mm, z=6.74 mm

Next, for an example, we have considered a TEM01 mode that is selected in before part. We would like to see what effect the coordinate changes, as well as aperture radius have, on it's mode shape. We have summarized this effects in Fig 6,7,8. In Fig .6 and Fig.7, we have changed x and y coordinate of an aperture. As shown, the beam shape of this mode, have changed.



(a) (b) (c)

Fig. 6 TEM01 mode (b) $\Delta x = 0.02$ (c) $\Delta x = 0.04$

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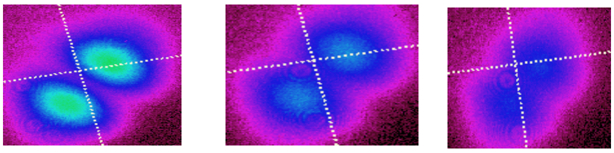
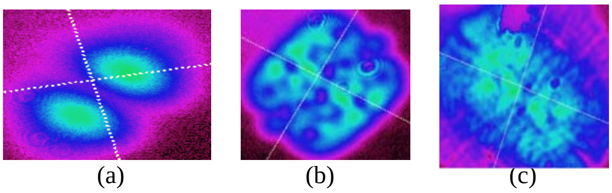


(a) (b) (c)

Fig. 7 TEM01 mode (b) $\Delta y = 0.05$ (c) $\Delta y = 0.06$

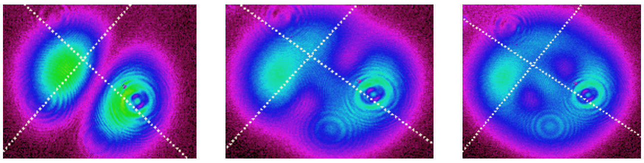
Fig. 8 shows that by changing the radius of an aperture, mode shape of this mode ,will be changed.



(a) (b) (c)

Fig. 8 (a) r=0.89 (b) r=1.82 (c) r=2.38

By changing the radius of an aperture and z coordinate, we could select TEM_{01} mode in the new position.Fig.9 (a) shows this mode. If we change z coordinate ,in a constant radius of an aperture, we see that mode shape of TEM_{01} mode will be changed.(Fig.9.(b),(c))



(a) (b) (c)

Fig. 9 (a) r=0.89mm, z=6.95mm (b) r=0.89mm, z=10.95mm (c) r=0.89mm, z=12.95 mm

IV. Calculation of Beam Quality Factor

In order to determine beam quality factor (M^2) , we put a lens with focal length of f = 65(mm) out of the resonator. Focusing lens is used to create a beam waist. The beam diameter d_0 of the waist, is measured and two additional beam diameters are determined at symmetric planes to the left and to the right of the beam waist. ($d_1 \approx d_2$). [4]

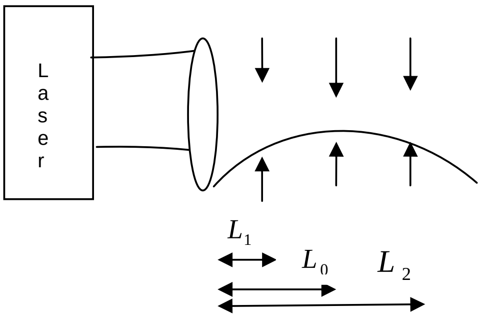


Fig. 10 measurement of the beam parameters by generating a beam waist with a lens

The beam propagation factor is given by [4]:

$$M^2 = \frac{\pi d_0^2}{2\lambda(L_2 - L_1)} \sqrt{\frac{d_1^2}{d_0^2} - 1} \qquad (4)$$

For example, we have obtained TEM_{00} mode as shown in Fig.10 .The parameters of resonator for obtaining this mode are:

r = radius of an aperture = 0.89 mm
L = resonator length = 34.85 mm
z = distance of an aperture from rod = 8.22 mm

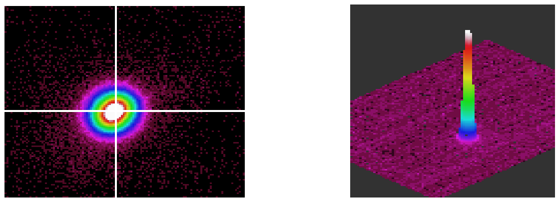


Fig. 11 profile of a TEM00 gaussian mode

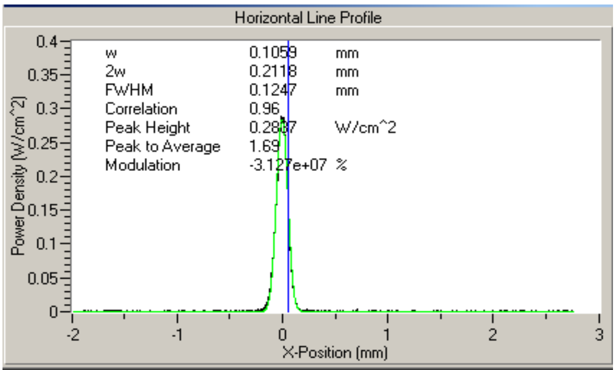


Fig. 12 power density of Gaussian beam with 96% correlation

We have measured parameters that are used in equation (4) for this gaussian beam.

$$L_0 = 85.48mm \qquad d_0 = 0.2118mm$$
$$L_1 = 50.98mm \qquad d_1 = 0.2562mm$$
$$L_2 = 93.45mm$$

In this way, we have obtained value of $M^2 = 1.05$ for this TEM00 mode.Now we have changed resonator length (L) and the distance an aperture from rod (z), then we have shown that by changing these parameters, the beam quality factor, have changed.

r = radius of an aperture = 0.89 mm
L = resonator length = 34.03 mm

z = distance of an aperture from rod = 4.84 mm

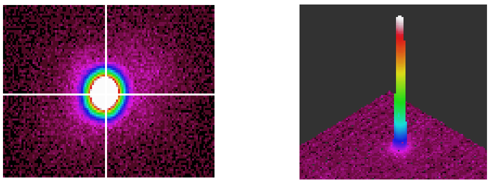


Fig. 13 profile of a TEM00 gaussian mode

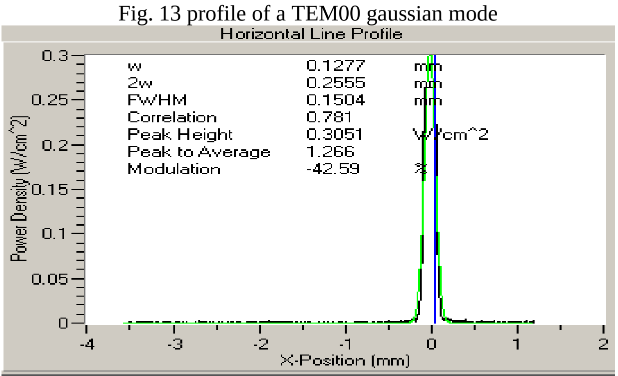


Fig. 14 power density of Gaussian beam with 78% correlation

$L_0 = 74.34\text{mm}$ $\quad d_0 = 0.2555\ mm$

$L_1 = 57.11\text{mm}$ $\quad d_1 = 0.2941\ mm$

$L_2 = 92.75\text{mm}$

We have obtained value of $M^2 = 1.38$ for this TEM00 mode.

V. Conclusion

By simulation and experimental set up we have obtained these results:

a) By considering an aperture and solving diffractional integral numerically by MATLAB software, transverse modes could be selected.

b) By optimizing resonator length and pulse duration, the maximum output energy obtained.

c) By inserting a circular aperture in a laser resonator of diode end-pumped, Nd:YAG laser, and adjusting the parameters of resonator and aperture, the desired transverse modes selected.

d) There as a little difference between simulation results and a experiment. The reason is that, we didn't have into account gain medium in simulation method.

e) The effects of coordinates changes and aperture radius on the profile of special mode, are shown.

f) By changing the parameter of resonator and aperture, the beam quality of gaussian beam, have been changed.

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