OUTPUT CHARACTERISTICS OF A PLANAR RF-EXCITED CO2 LASER WITH UNSTABLE -WAVEGUIDE HYBRID RESONATOR

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ABSTRACT

Output characteristics of a planar RF-excited waveguide CO_2 laser with 150W output power is investigated, including the divergences in stable and unstable directions, and influences of mirror misalignment and resonator length variations on the output power and mode structure of the radiation.

1. INTRODUCTION

In this paper the results of the numerical and experimental investigations concerning the performances of two positive branch hybrid unstable-waveguide resonators [1] with different magnifications, in terms of modal structure, power extraction and their sensitivity to misalignment and resonator length variations are described. Also the far-field distribution and divergences of the beam in stable and unstable directions are investigated.

In our experiments we have used two off-axis confocal (one dimensional) unstable resonators with magnifications M=1.25 and M=1.14, both of them are designed to fit a discharge channel with dimensions $(d=3)\times(a=40)\times(l=490)$ mm^3. The resonator with M=1.25 consists of a concave back mirror with R_1=5000 mm and a convex edge cut out-coupling mirror with R_2= - 4000 mm. The other resonator also consists of mirrors with R_1=8000 mm and R_2= - 7000 mm. All of them are spherical gold coated silicon mirrors with reflectivities $\geq$ 99.5%.

The electrodes are made of copper and are cooled with water circulation. To uniform the power distribution along the electrodes, we used several parallel coils, located symmetrically along right and left sides of the input RF connection. The impedances and locations of the coils are computed using a computer code according to an existing method [2,3]. A homemade RF oscillator with 1800W output power at 81.36 MHz frequency is used for laser excitation. RF power coupling is done by a L-section impedance matching network and 50 ohms cables. All experiments were performed without gas flow, using a premixed gas with mixing ratio CO_2:N_2:He:Xe = 1:1:3:5% and total pressure P = 50 mbar.

2. NUMERICAL ANALYSIS

For numerical computation of the output spatial distributions, we have concentrated on field distribution along unstable direction using Fox and Li iterative method and one dimensional Fresnel-Kirchoff's integral (Eq.1). For including saturation effects, we considered two thin layers of active medium on each mirror and for far field calculations Fraunhofer approximation (Eq.2) is used.

$$U(x',L)=\frac{\exp(i\pi/4)}{(\lambda L)^{1/2}}\int_{-\infty}^{\infty}U(x,0)\,\exp(-ikr)\,dx \qquad (1)$$

$$U(X)=\frac{\exp(-i\,kL/2)}{(L)^{1/2}}\int_{-\infty}^{\infty}U(x)\,\exp(-i\,kXx/r)\,dx \qquad (2)$$

$$N_{eq}=\frac{M-1}{2M^2}N_o\ ,\qquad N_o=(Ma)^2/\lambda L$$

where, L is the resonator length, r is the distance between points x and x' on the mirrors, X is the variable in the far field plane, R is the distance between points on the output mirror and far field plane, N_o is the outer fresnel number and N_{eq} is equivalent number.

The unstable-direction intensity and phase distributions at the output mirror plane and their correspondent far-field distributions and encircled energy versus far-field half-angle obtained with our numerical simulations for the two positive-branch resonators with magnifications M=1.25 and M=1.14 are shown in figures 1 to 3.

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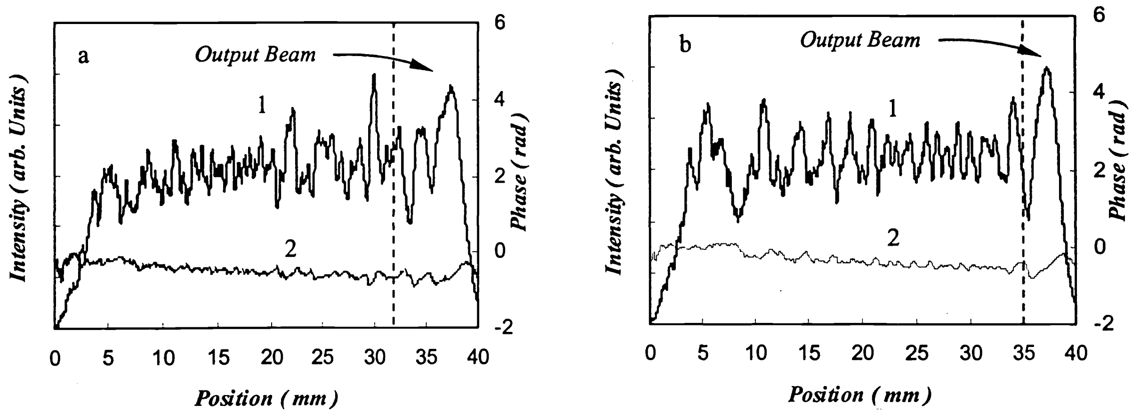


Fig.1. Unstable-direction intensity profiles (1) and field phases (2) on output mirrors of the positive-branch resonators with a) M=1.25 and N_{eq}= 22.4 , b) M=1.14 and N_{eq}=15.1 generated by numerical simulation. The vertical lines indicate the locations of the coupling edges. The optical axis is at x=1.5 mm.

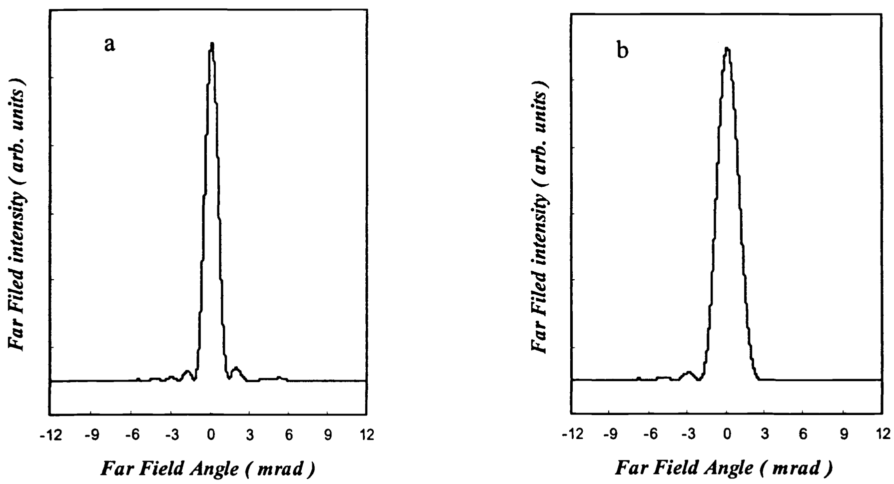


Fig.2. Numerical far field distribution of the beam emerging from the positive-branch resonators with a) M=1.25 and N_{eq}= 22.4 , b) M=1.14 and N_{eq}=15.1.

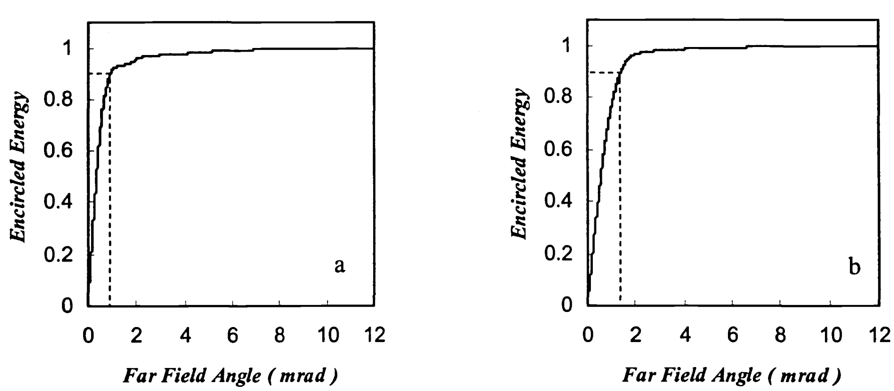


Fig.3. Encircled energy versus far-field half-angle calculated for the distributions in fig.1. a) M=1.25 and N_{eq}= 22.4, b) M=1.14 and N_{eq}=15.1.

The intensity profiles in fig.1 show that the resonators with M=1.25 and M=1.14 has a three-lobed and one-lobed output patterns respectively. Also the far-field distributions in Fig.2 show that the energy is concentrated in smaller far-field angel for the resonator with higher magnification. From encircled energy curves in Fig.3 it can be seen that 90% of encircled energy is concentrated in 1.8 mrad far field angle for the resonator with higher magnification and 2.8 mrad far field angle for the other one.
In Fig.4 the results of different calculations performed for different mirror misalignments reveals that growing misalignments correspond to the alternation of a two and three-lobed output pattern.

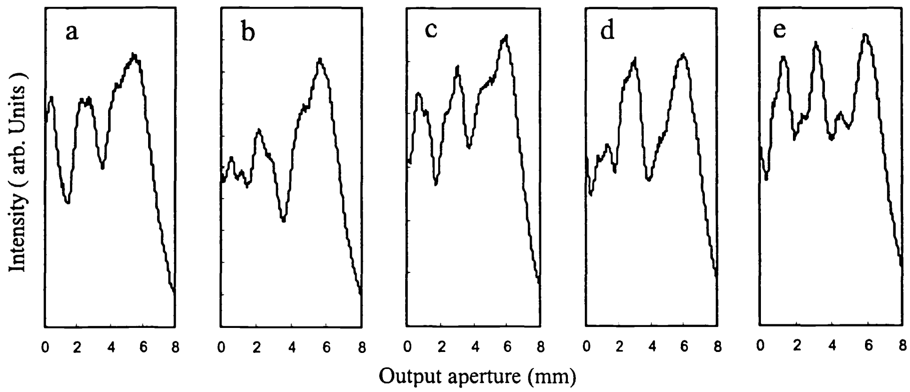
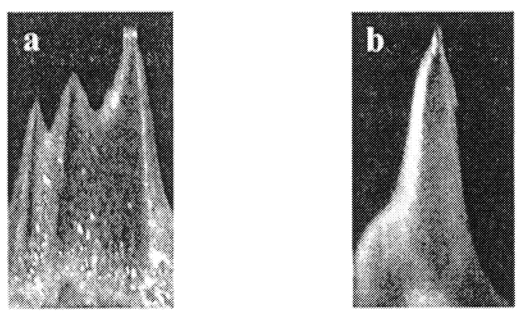


Fig.4. Numerical unstable-direction intensity profiles of the beam emerging from the positive-branch resonator with M=1.25 and N_{eq}= 22.4, for different output mirror misalignments: a)0 μrad;b)30 μrad; c)50 μrad; d)70 μrad; e)90 μrad.

3. EXPRIMENTAL RESULTS

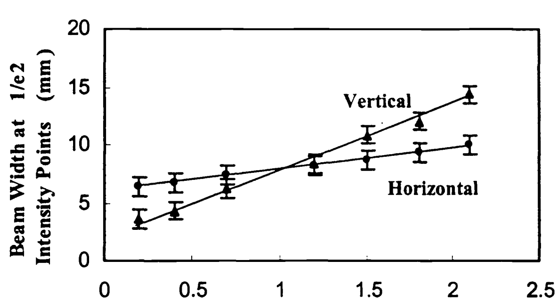
In Fig.5 the experimental profiles of the output laser beam obtained in acrylic block for the two resonators with a) M=1.25 and b) M=1.14 are shown which are in agreement with numerical results in Fig.1.

Fig.5



The results of experiments for measurement of far field divergences in unstable directions for the two resonators, using a focusing mirror with focal length f=50 cm and measurement of beam diameter by knife-edge method showed nearly $\pm$ 10% deviation from numerical results (Fig.2 and 3). The far-field divergence in stable direction was also measured to be equal to 6.5 ± 0.6mrad, which is nearly 1.2 times the divergence of a Gaussian beam with the same waist at the output plane.
Fig.6 shows the results of the measurements of beam-widths in the vertical and horizontal directions versus distance of propagation for the resonator with M=1.25.

Fig.6



Experimental results in Fig.7 for the resonator with M=1.25 show the variations of output power (measured by Gentec power meter, model PS-300), for a) different misalignments of front mirror in a direction that increases the distance between output edge of the mirror and the electrodes and for b) different resonator lengths. Fig.7(a) shows that for mirror tilts bigger than 200 μrad , there is some kind of output power oscillation and from Fig.7(b) it can be seen that there is not a considerable output power sensitivity to the resonator length variations for this kind of resonators. For the resonator with M=1.14, the results are similar except that in this case there is a higher sensitivity to misalignment .

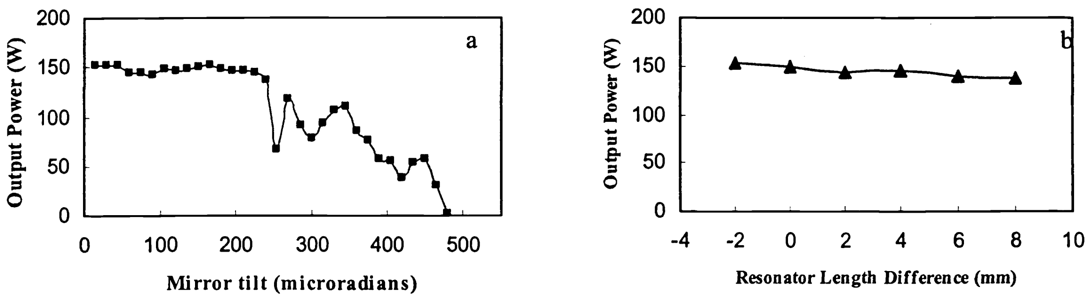


Fig.7

Fig.8 shows the experimental unstable-distribution profiles of the output laser beam obtained in acrylic block for the resonator with M=1.25, for different output mirror misalignments: a)0 μrad; b)30 μrad; c)50 μrad; d)70 μrad; e)90 μrad, which is in acceptable agreement with numerical results of Fig.4.

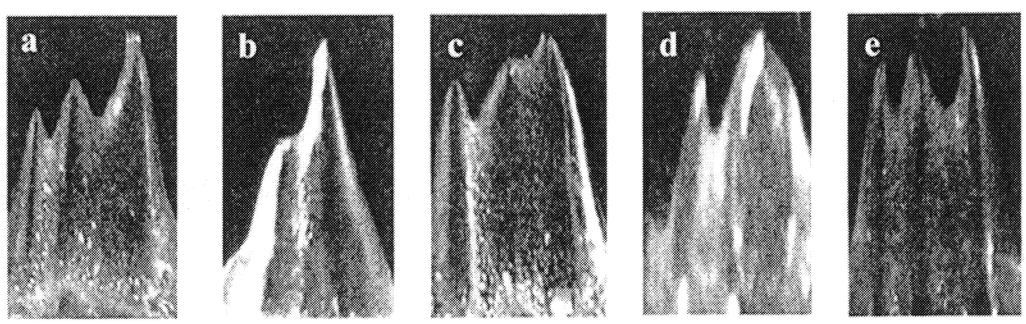


Fig.8

4. CONCLUSION

We have investigated the output characteristics of two hybrid stable-unstable resonators with different magnifications and the results show acceptable consistency between numerical calculations and experiments. The output intensity profile of the resonator with smaller magnification has lower spatial frequency but bigger divergence. The output power of these kind of resonators have a low sensitivity to small resonator length variations but very high sensitivity to misalignment. Our simulation and experiments confirm the oscillation of output power and alternation of transverse modes when the front mirror is tilted.

5. REFERENCES :

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