Available online at www.sciencedirect.com
ScienceDirect
Optics & Laser Technology 39 (2007) 669–680
Optics & Laser Technology
www.elsevier.com/locate/optlastec

Numerical characterizations of unstable optical resonators and evaluation of the geometry effects

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Received 8 August 2005; received in revised form 15 March 2006; accepted 12 April 2006
Available online 21 June 2006

Abstract

Unstable resonators have been widely used in high-power gas lasers as well as solid-state lasers. The phase and the spatial distribution of intensity of these lasers are very important in some applications such as material processing. In this paper, unstable resonators with three different geometries have been characterized numerically and the results have been compared and evaluated. Based on the Fresnel–Kirchhoff integral, the two-dimensional phase and intensity have been calculated for three different positive branch unstable resonators. The results show that the resonators with rectangular geometry have the best performance for near-field as well as far-field intensity, which is more suitable for material processing. The calculations also show that the maximum output power can be extracted from the rectangular resonator with spherical surface, while the circular resonator with spherical surface has minimum output power. The results also show that the laser has a higher divergence for the cylindrical resonator in compare with those for the circular and rectangular resonators.

Keywords: Unstable resonator; High-power laser; Optical resonator

1. Introduction

High-energy lasers have been the most preferred devices for many applications for many years [1]. The laser resonator geometry is one of the main topics to achieve high-brightness operation. Fox and Li [2] were the first who studied the optical resonators and since then many types of the optical resonators have been proposed and used. Optical resonators are classified mostly into two types: the stable and unstable resonators.

The stable resonator has been used in most industrial lasers because of several advantages. For instance, in the stable resonator, the coupling ratio can be easily adjusted by choosing the reflection ratio of the front mirror. The fundamental mode of stable resonators is also Gaussian. Such mode is magnificent for many kinds of applications. However, since the spot size of the lowest order transverse mode is small, high power cannot be obtained from the large-bore stable resonator. Using some obstacles in stable resonators, the large-bore laser can be oscillated only in the fundamental mode, but both the power and the efficiency decreases drastically. Thus it is very difficult to obtain high power from a large-bore laser medium in the single fundamental mode. However, in CO_2 or YAG lasers the diameters of the laser medium are large, and therefore suitable to oscillate in higher-order modes. In multi-mode lasers, the size of the focused spot is large. Then the multi-mode operation is not suitable for the industrial applications. In addition the partial transparent dielectric mirrors can be unstable or damaged at high-brightness transmission.

The unstable resonator has several advantages compared with the stable resonator, such as large and controllable mode volume, and good transverse mode discrimination. The major advantage of unstable resonators is to produce laser beam of large mode volumes even in a short cavity [3]. However, a laser medium with high gain is necessary for

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0030-3992/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.optlastec.2006.04.008

the use of the unstable resonator, because the resonator does not oscillate by a low-gain laser medium. Since unstable resonators are usually composed of total reflectors, they are strong against high-power laser beam and are widely used in high-power gas lasers [4] as well as solid-state lasers [5]. In addition, all reflective optics in such resonators can be easily cooled. However, the near-field output beam of an unstable resonator usually has an annular pattern and the far-field output beam has several rings, which causes lower focusing ability, due to the diffraction effect. This makes the beam quality of unstable resonators lower than that of stable resonators operating in the TEM_{00} mode. In addition to the geometrical effects in output beam, there are also some other sources that affect the beam quality in unstable resonators from which thermal induced distortion [6–8] and distortion due to mounting of the mirrors [9,10] are more important.

However, the geometrical effects in passive and active resonators have not been comparatively investigated, as we are aware, although a few assessments have been reported for some resonators individually. In this paper we have presented the results of two-dimensional numerical calculations in order to investigate the performance of unstable resonators with three different geometries. Based on the *Fresnel–Kirchhoff* integral [11], the phase and the intensity of the far field as well as near field are calculated for the cylindrical, circular and rectangular resonators with spherical surface. The divergence was also estimated for the three types of resonators and the results were compared. The calculations conducted using a wide range of Fresnel number and magnification and the behaviors for the operation of the resonators were obtained.

The spatial phase and intensity in near and far field for passive resonators were assessed. The code can also be used for investigating active resonator by applying finite uniform or non-uniform gain. However, the main goal of this paper is to show the geometrical effects in the resonator performance.

2. Theory

Since the invention of the unstable resonators by Siegman [3] the confocal unstable resonator shown in Fig. 1(a) has been used in high-power lasers, in which the laser beam diffracted from the convex mirror is used as

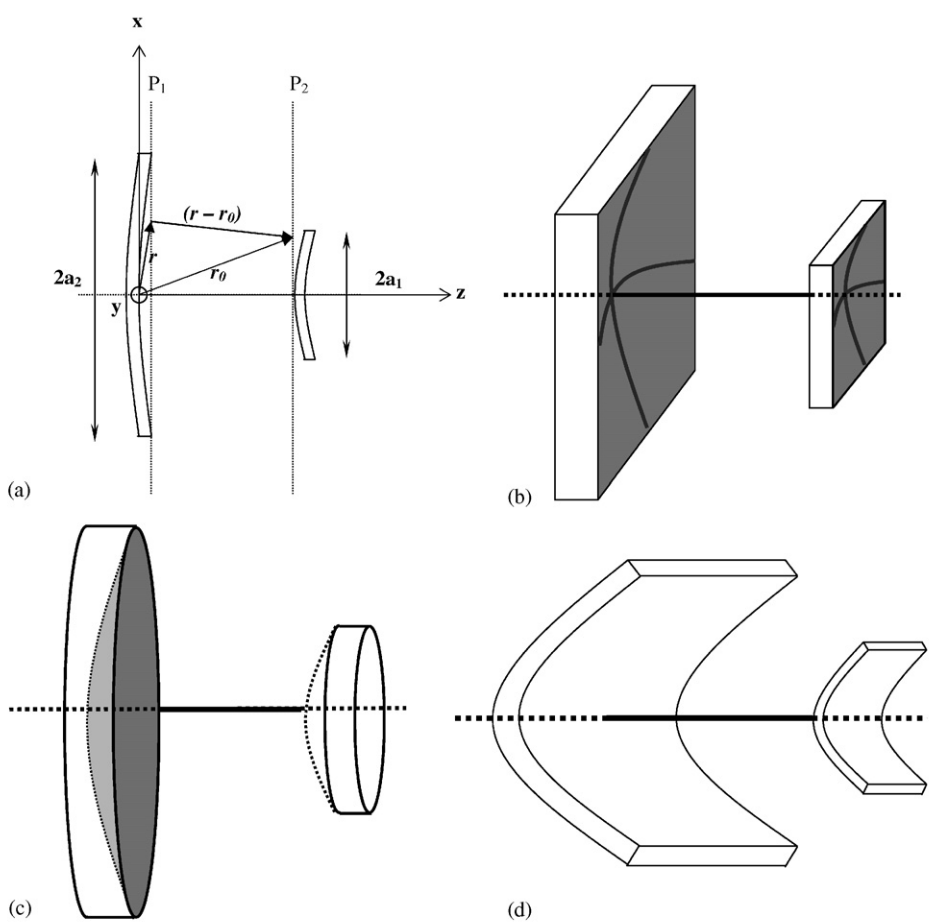

Fig. 1. Schematic diagram of positive- branch confocal passive unstable resonator. (a) one dimensional strip resonator, (b) two-dimensional rectangular resonator, (c) two-dimensional circular resonator, and (d) two-dimensional cylindrical resonator.