Tuneable Gaussian to flat-top resonator by amplitude beam shaping using a digital laser

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ABSTRACT

In this paper we experimentally demonstrate a simple laser cavity that produces spatial tuneable laser modes from a Gaussian beam to a Flat-top beam and a Donut-beam. The laser cavity contains an opaque ring and an adjustable circular aperture that could be varied and thus allows for tuneability of the cavity without it being realigned. A digital laser with an intra-cavity spatial light modulator is used to demonstrate and confirm the predicated properties of the resonator.

Keywords: laser beam shaping, laser resonators, spatial light modulators, invariant optical fields,

1. INTRODUCTION

Flat-top laser beams are very important in many various industrial applications since they provide uniform intensity distribution which enables even laser treatment of working surfaces[1]. There exist many extra-cavity techniques[2-4] that can generate Flat-top beams with very little power loss, except that they require a fixed input Gaussian beam parameter. Intra-cavity generating the Flat-top beam provides a greater advantage of maximizing the power extraction from the laser and this has been shown by different techniques which used customised optical elements[5-15] such as diffractive optical elements and deformable mirrors.

In this work we propose an alternative technique for obtaining a Flat-top (FT) beam as the fundamental output of a laser cavity. Our technique requires only an intra-cavity opaque ring as an amplitude filter in combination with a standard circular aperture, in a conventional laser cavity. We show that choosing certain parameters the cavity can be made to generate a FT beam or a Gaussian beam or a Donut beam, by merely adjusting the circular aperture. The mode tuneability of the cavity is shown to be easy to implement and requires no re-alignment of the laser cavity, no new specialised optical elements. The generated modes are observed both in the near and far field which makes this technique very attractive for many applications since it would simplify the delivery of the modes on the working surfaces. We verify our concept and theoretical predictions using a "digital laser"[16], comprising an intra-cavity spatial light modulator as a rewritable holographic mirror.

2. CONCEPT AND SIMUTLATION

It was shown theoretically in[17,18] that a combination of two intra-cavity optical elements namely an opaque ring and circular aperture could be used to increase the discrimination of the fundamental TEM_{00} mode and the first competing mode. In this paper we will show the combination of the two optical elements is able to transform the fundamental TEM_{00} mode to be a Flat-top beam or a quasi-Gaussian beam. We will show the transformed beams could be obtained by simultaneously varying the normalized radius $Y_a = \frac{\rho a}{W}$ of the opaque ring with

Laser Resonators, Microresonators, and Beam Control XVI, edited by Alexis V. Kudryashov,
Alan H. Paxton, Vladimir S. Ilchenko, Lutz Aschke, Kunihiko Washio, Proc. of SPIE
Vol. 8960, 89601L · © 2014 SPIE · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2038960

annular ring width $\Delta = \frac{h}{\lambda}$ and the normalised radius $Y_c = \frac{\rho_c}{w}$ of the circular aperture; where w and w_c are the beam radius of the Gaussian beam of a bare cavity (without the ring and aperture) (see fig. 1) at the flat and curved mirror respectively.

We consider a stable plano–concave resonator shown in Fig. 1(a) where the opaque ring is set against the flat mirror which is programmed on a digital hologram inside an Spatial Light Modulator (SLM)(1). The output is from the concave mirror (3) with a radius of curvature *R* which is placed closer to circular aperture having a radius ρ_c. We will consider the effects of intra-cavity varying parameters Y_a and Y_c on the laser output beam both in the near-field and far-field intensity profiles where λ=1.06 μm is the laser wavelength.

Fig. 1. A schematic representation of the concept. An absorbing ring (2) is placed at the plano (1) end of a plano-concave cavity. A standard circular aperture (3) is placed at the opposite end, and the mode is transmitted through the output coupler (4).

Our simulation results, shown in Fig. 2, suggest that at $Y_a = 1.5$ the cavity eigenmode is a FT beam, the purity of which can be adjusted by varying Y_c. We find optimal settings of $Y_c = 2.5$ for a high quality FT beam, which can be approximated in shape by a super-Gaussian beam of order ~5. Furthermore we predict that the FT beam can be transformed into a quasi-Gaussian beam by simply adjusting the circular aperture to $Y_c = 2.0$, while keeping Y_a constant at 1.5. The results are shown in the far field. If the circular aperture is opened further more exotic modes are found, for example, a donut mode at $Y_c = 2.6$.

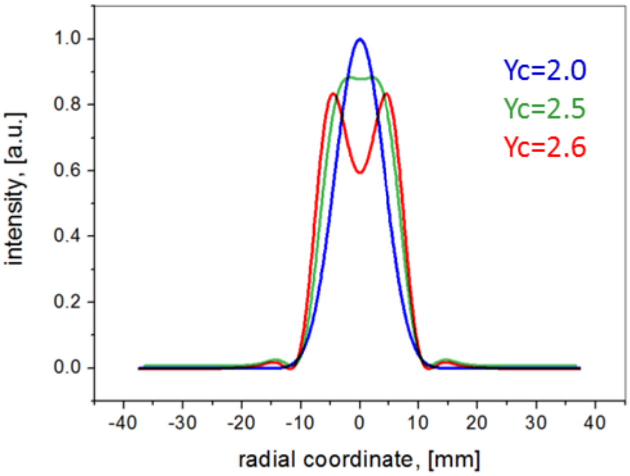

Fig. 2. Fox-Li simulation of the far-field intensity profiles of the quasi-Gaussian ($Y_c = 2$), flat-top ($Y_c = 2.5$) and donut beam ($Y_c = 2.6$). The simulations were performed with a normalised ring radius of $Y_a = 1.5$ and a ring width of 100 μm. The parameters of the cavity were selected to match the experiment, namely, $R = 500$ mm and $L = 252$ mm for $g \sim 0.5$ at a wavelength of $\lambda = 1064$ nm.

From the simulations we also notice that the eigenvalue of the desired FT mode depends on the ring radius, its thickness, and also the circular aperture radius. For our simulated parameters the desired mode did not always have the smallest eigenvalue: for Y_c setting of 2.0 (quasi-Gaussian), 2.5 (FT) and 2.6 (donut) the eigenvalue of the desired mode suggested that it was in fact the first, second, and third order mode, respectively.

3. EXPERIMENTAL SETUP

In order to test the simulated results we used the laser set–up shown in Fig. 3(a). The cavity was arranged in a Z-shape to allow the high power pump (808 nm) to pass through the gain medium (Nd:YAG) without interference from the aperture and ring mask. The stable plano-concave cavity had an effective length of 252 mm, with the circular aperture placed directly in front of the curved (R = 500 mm) output coupler of reflectivity 80%. The output mode could be measured in both the near field and far field with imaging or Fourier transforming optics. Care was taken to separate the lasing wavelength (1064 nm) from the pump light (808 nm) with suitable filters.

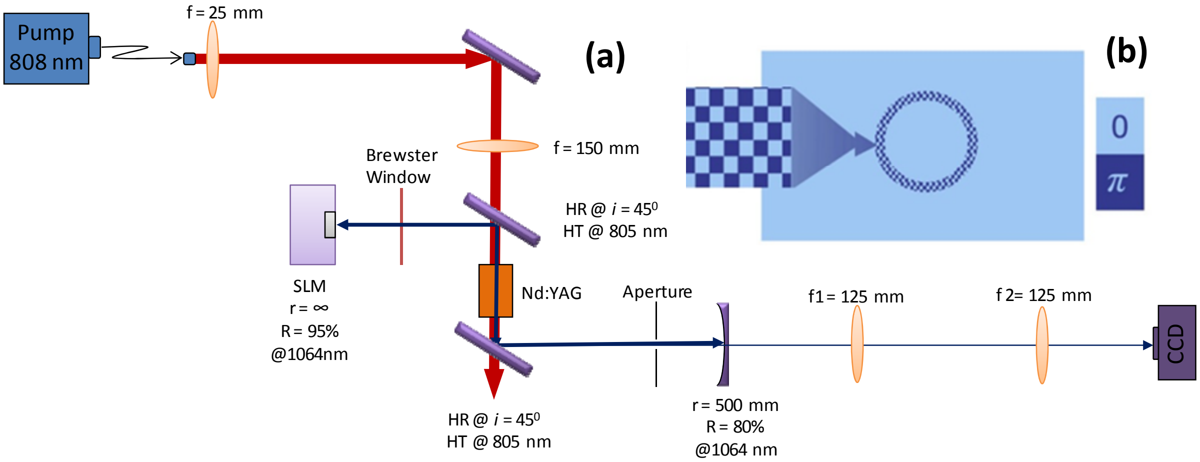

Fig. 3. (a) Schematic setup of an intra-cavity SLM with diagnostic and control equipment. The High Reflectors (HR) were used to reflect the 808 nm or 1064 nm wavelengths. (b) SLM phase screen acted as a flat-end mirror containing an opaque ring of 100 μm width.

An additional novel aspect of this experiment was the use of a "digital laser"[16]. One of the cavity mirrors in the digital laser setup is a rewritable phase-only spatial light modulator (SLM), forming a holographic end-mirror. The SLM was programmed with a digital hologram representing both the flat mirror and the opaque ring, as shown in Fig.3 (b). The digital laser allowed for easy optimisation of the ring radius as well as the ring thickness. To vary these parameters with lithographically produced rings of varying thickness and radius would be time consuming and costly, and would require a realignment of the cavity for each setting. In the digital laser, a new ring could be created by merely changing an image on the control PC representing the desired digital hologram, without any realignment. The amplitude modulation employed to realise the ring was achieved by complex amplitude modulation[19,20] using high spatial frequency gratings in the form of so-called "checker boxes". On the other side of the cavity we had a variable circular aperture which was controlled manually in order to get desirable parameter of Y_c. This (standard) aperture provided the tuneability of the mode.

4. RESULTS

The output from the digital laser is shown in Fig. 4, where the near field and the far field intensity profiles of the quasi-Gaussian (a), Flat-top (b) and (c) Donut beams are shown. In the first six panels (a-c) we have the results for a 20 μm width ring, while in the last six panels (e-f) we have the results for a 100 μm width ring. We note that the spatial intensity distributions are in good agreement with the simulated Fox-Li results in Fig. 2. Moreover, as predicted by theory, the desired shapes are found in the far field too. The field patterns are also found at values of Y_a and Y_c close to those predicted by theory, differing by less than 10%. The small deviation can be attributed to minor mode size errors, e.g., due to small thermal lensing or refractive index errors.

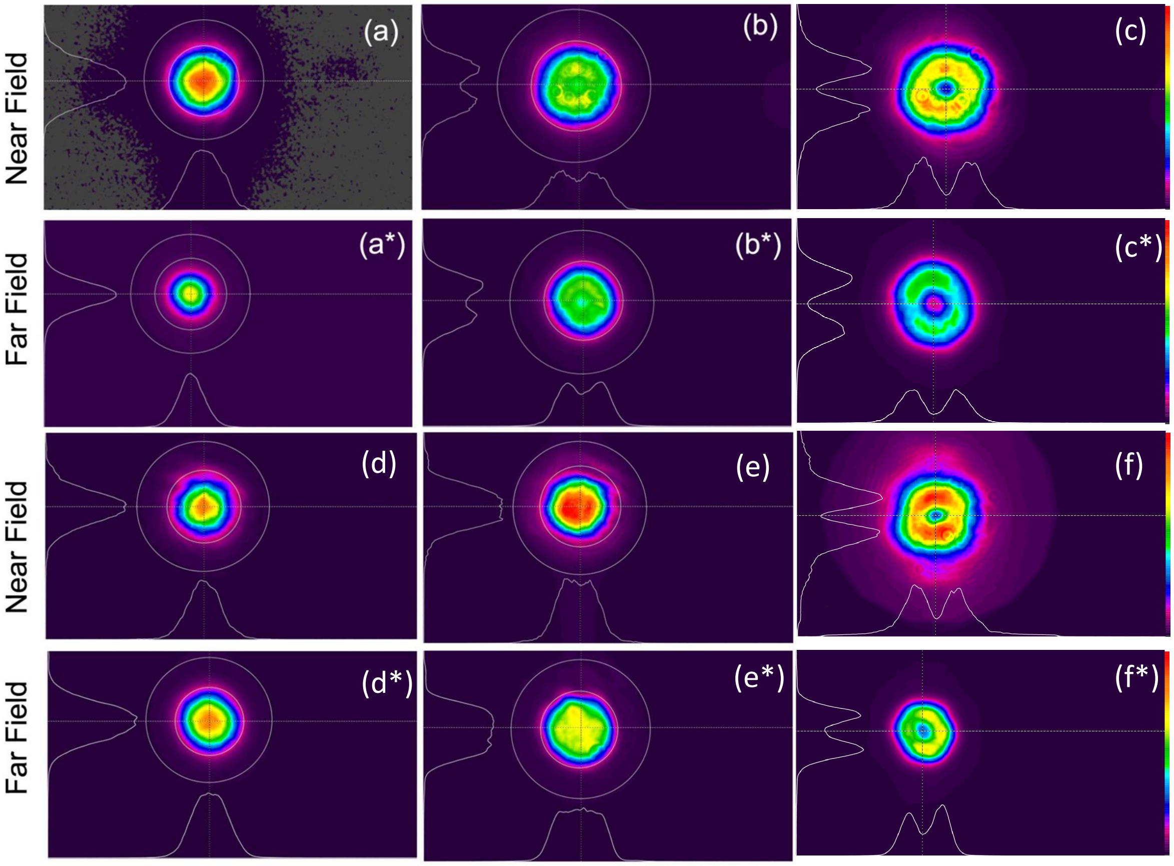

Fig. 4. Experimentally obtained near field and far field images of the Gaussian beam, Flat-top beam and Donut beam for ring width settings of (a-c): 20 μm and (d-f): 100 μm. Gaussian beam (a and a*), Flat-top beam (b and b*) and Donut beam (c and c*) for $Y_a = 1.4$, a ring width of 20 μm, and $Y_c = 2.0$ (Gaussian), $Y_c = 2.3$ (FT) and $Y_c = 2.6$ (Donut). Gaussian beam (d and d*), Flat-top beam (e and e*) and Donut beam (f and f*) for $Y_a = 1.4$, a ring width of 100 μm, and $Y_c = 2.0$ (Gaussian), 2.3 (FT) and 2.6 (Donut). These values are in agreement with theory.

5. CONCULSION

In conclusion, we have conceived of and then demonstrated a novel laser cavity that is mode tuneable. We have shown that by simply adjusting the diameter of a standard circular aperture in the cavity, the mode can be selected from the ubiquitous Gaussian to a Flat-top and a Donut beam. The ring mask was implemented with an intra-cavity holographic mirror for the convenience that this allows in testing the design parameters, but a high power version, optimised for power extract, would necessarily be made with standard optics and lithographic processing techniques to eliminate the SLM losses.

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