CuBr laser beam transformations

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Abstract. CuBr laser beam profile transformations are studied in a beam focusing experiment. A modeling via Fourier transform is also performed with annular beams of simplified flat two-level geometry of near field: bright outer ring with a darker core. The pattern of focal beam profile i.e. far field is calculated and characterized with respect of its intensity structure. As found beam annularity has small effect on far-field intensity pattern.

1. Introduction

In 2000 a comprehensive reference book appeared which reviewed theory and technique, and gave basic information onto research, development and design of beam shaping systems \cite{1}. By beam shaping the raw laser profiles which often are of random shape and not good enough for straight use, can be tailored in due way. Thus many applications of lasers can benefit from the proper redesign of beam profile. Techniques and models are abundant and they make feasible actually any profiles needed for laser applications.

Copper vapor lasers are still the most high-power and high-efficiency lasers which produce visible light ($\lambda = 510$nm and $\lambda = 578$nm) in a straightforward way without any subsequent light conversion. In some cases their profiles need tailoring as well.

To concentrate more power very frequently laser intensity is increased by focusing the radiation. The focusing causes a near-field beam profile to transforms into a far-field beam profile of intensity distribution often quite different from the initial near-field intensity distribution. Relations between near-field and far-field beam profiles are of expanding interest due to the vast employment of laser (and generally, optical) beams in science and technology. In this paper we present results of experiments as well as modeling of beam transformations observed after focusing the CuBr laser emission.

2. Experiment with focusing of MOPA (Master-Oscillator Power-Amplifier) CuBr laser beam

CuBr laser profile varies from annular to top-hat or Gaussian-like. In the case of MOPA CuBr laser profile variations are reported in experiments on timing and buffer gas composition \cite{2}. While annular profiles are typical for non-hydrogen buffer or at MOPA small delays, top-hat profiles are predominant for buffer containing hydrogen or at MOPA long delays \cite{2, 3}. This is illustrated in figures 1 and 2: in figure 1 the MOPA CuBr laser buffer has no hydrogen added and the emission is annular at all delays; in figure 2 (a hydrogen-added buffer) beam is annular at small delays only.
Figure 1. Typical near-field profiles of MOPA CuBr laser as functions of the MOPA time delay. Buffer gas is Ne of 17 torr.

Figure 2. Typical near-field profiles of MOPA CuBr laser as functions of the MOPA time delay. Buffer gas is a mixture of Ne (17 torr) and H₂ (0.3 torr). Profile mutability is seen in two cases.

Detailed experimental pictures of far-field produced from the corresponding near-field are shown in figure 3.

Figure 3. Three sets of near-field profiles (the lower traces) with the subsequent far-field profiles (the upper traces) taken experimentally with MOPA CuBr laser system.
Two-dimensional far-field beam profiles can be calculated by the two-dimensional Fourier transform of the near-field beam profiles. In real physical world, this transform is easily performed by optical lenses [4]. The focal spot profile is the far-field profile of near-field profile in front of the lens (within the accuracy of a phase coefficient). Fourier transform is a very powerful tool for optical signal processing and its most popular and simple form is the Fast Fourier Transform (FFT). Fourier transform is applicable to the complex optical field. The signal that is optically detectable is the intensity of optical field. To find the field intensity, we have to calculate the product of the optical field complex amplitude and its conjugated optical field complex amplitude [5]. It was performed via MATLAB® built-in discrete functions which resulted in discrete shape of output.

3. Near- and far-field parameters of flat two-level annular beam

3.1. Near-field parameters of flat two-level annulus

The simplest type of annulus is the normalized flat two-level annulus. We define it as a circular ring of inside concentric area of intensity, I1 (which varies from 0 to 1) and the annulus itself of intensity, I2≡1 (normalized by definition). If I1=I2, the profile is top-hat; if I1=0, the profile is 'pure' annular. Such an annulus can be described by two parameters. Its axial section is plotted in figure 4. The first parameter (referred as ‘annularity’), k is k=d1/d2, where d1 and d2 are the inside and the outside diameters of annulus. The second parameter, Idip is the intensity dip of the central area: Idip=I2-I1=1-I1.

![Figure 4. Intensity axial section of normalized two-level annulus; d1 and d2 are the inside and the outside diameters of annulus; the circular core area is of intensity, I1 (varying from 0 to 1), and I2≡1.](image)

3.2. Far-field parameters of flat two-level annulus

The type of calculated pattern of far-field beam profile produced from an annular near-field beam is shown in figure 5. The profile can be described as having a prominent central peak and side peaks concentrically surrounding it (better seen in the figure inset). The appearance of side peaks comes from the discrete form of calculations we applied in the model. Actually they should smear into uninterrupted concentric rings. For FFT computations we employed MATLAB® environment.

![Figure 5. Typical calculated pattern of far-field beam profiles of a two-level annulus; the inset is x10-magnified central area.](image)
In figure 6 we give the patterns of far fields calculated from near fields of different values of k. As k goes up so do the side peaks. NB that in physical reality peaks are concentric rings.

![Patterns of far fields](image)

**Figure 6.** Patterns of far fields calculated from near fields of different values of annularity k. Z-axis is 10% of central peak intensity for better view of ‘rings’ structure.

The far-field profile parameters specified here are with regard to laser beam utilization in applications which are not susceptible to phase components of light. We pay attention to the power (energy) component of light. Nevertheless the coherency of light is a requirement for all our simulations. As a major parameter we introduce the fraction of the central peak energy to the whole energy of beam, PF0. This parameter gives a notion about energy spread within the far-field spot. The higher PF0 the lower energy spread is. In practice that means less affected surrounding (the central peak) area by light radiation. The dependence of PF0 on Idip is plotted in figure 7.

As can be seen the increase of Idip leads to the decrease the central peak energy fraction. At higher k the decrease starts at lower Idip. So at k=0.3 and Idip<0.75, the change of PF0 is less than 1.5%. While the maximum of PF0 is 0.778, for Idip=0.75 the fraction of the central peak energy PF0 is 0.767. But at k=0.8 for the same Idip of 0.75, PF0 is 0.7. The central peak energy fraction dominates the far-field energy distribution nearly over the whole range. The exception is for Idip>0.9 (and k>0.65) which occurs seldom in usual practice. Taking into account that the central peak energy is concentrated on a smaller spot area, the net impact of side energy spread diminishes furthermore.
Figure 7. Dependence of the central peak energy fraction (PF0) on Idip (the intensity dip of the central area: Idip=1-I1) for three values of annularity, k = 0.3, 0.5 and 0.8.

For the sake of usability we performed a surface approximation of the dependence PF0 = f (Idip, k) employing a web-based program [6]. The best approximation is given below graphically (figure 8).

Figure 8. Dependence of the central peak energy fraction (PF0) on Idip (the intensity dip of the central area: Idip=1-I1) and annularity k.

Note: x ≡ Idip, y ≡ k and z ≡ PF0.
and in letter form (equation):

\[ z = a \left( \sinh(x) y^{1.5} \right) + b \left( \tan(x) y^{1.5} \right) + c, \]

where \( a = 2.0310451454356748, b = -1.9232938348115700 \) and \( c = 0.78402321357391169; \)

Consider that \( z \equiv PF_0, x \equiv \text{Idip} \) and \( y \equiv k \).

4. Conclusions
Simulations of annular beams through two-dimensional Fast Fourier Transform show that the far-field central peak energy fraction is prevailing in the focal (far-field) energy distribution virtually regardless the (near-field) shape of annular source beam. Beam annularity and beam central area intensity dip have negligible effect on the focal energy distribution. In practice that means less radiation-affected area in the vicinity of beam central peak. Taking into account that the central peak energy is confined within a smaller spot area, the net impact of side energy spread diminishes furthermore.

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References
[1] Dickey F M and Holswade S C 2000 Laser beam shaping: theory and techniques (Opt. Eng. Series, v. 70) (New York: Marcel Dekker)
[2] Astadjov D N, Stoynchev L and Sabotinov N V 2007 Opt. Quant. Electron. 39 603-10
[3] Astadjov D N, Vuchkov N K and Sabotinov N V 1988 IEEE J. Quantum Electronics 24 1927-35
[4] Goodman J W 1996 Introduction to Fourier Optics (New York: McGraw-Hill) pp 101-107
[5] Lee S H, Basic Principles 1981 Optical Information Processing-Fundamentals, Topics in Applied Physics, 48, ed Lee S H (Berlin: Springer-Verlag) pp 2-41
[6] Phillips J R ZunZun.com Online Curve Fitting and Surface Fitting Web Site