

# 高斯光束通过复杂光学系统的变换

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## 提 要

使用矩阵光学技巧和方法详细研究了高斯光束通过复杂光学系统的传播问题。将结果推广于: (1) 物像空间折射率不相等 ( $n_1 \neq n_2$ ); (2) 光学系统矩阵元为复数或  $C$  元素为零的情况。就高斯限模光阑对光束传输的影响作了讨论。经典光学和高斯激光束光学 ( $n_1 \neq n_2, n_1 = n_2$ ) 的比较, 清楚地说明了它们的区别和联系。

关键词: 光束变换; 矩阵光学; ABCD 定律。

光束变换是激光光学中一个重要的研究课题。已发展了多种研究方法<sup>[1,2]</sup>, 其中简明而又规范的首推基于 ABCD 定律的矩阵光学方法。文献 [3] 对高斯光束在入射空间和出射空间折射率  $n_1 = n_2$  情况下通过复杂光学系统的变换作了研究, 并给出了与经典光学的类比结果。本文将此结果推广到更为一般的  $n_1 \neq n_2$  情况 (例如激光束通过大气和海水的传输等), 并讨论了光束的反向传输、光阑的孔径效应和远焦系统等激光光学设计中常遇到的。

## 一、变换公式

### 1. 一般公式

如图 1 所示在折射率  $n_1$  的物空间  $l_1$  处入射复参数  $q_1$  的高斯光束通过交换矩阵  $\begin{pmatrix} a & b \\ c & d \end{pmatrix}$  的复杂光学系统后, 在折射率  $n_2$  的像空间  $l_2$  处变为复参数  $q_2$  的高斯光束

$$q_i^{-1} = \frac{1}{R_i} - i \frac{\lambda_i}{\pi w_i^2} = a_i - ib_i, \quad (i=1, 2) \quad (1)$$

式中  $R_i, w_i$  分别为高斯光束的等相面曲率半径和光斑尺寸,  $\lambda_i$  为  $w_i$  所在空间激光波长。图 1 中  $l_1, l_2$  分别以过光学系统顶点、垂直于光轴的平面  $RP_1, RP_2$  为参考计算,  $l_1$  在  $RP_1$  之左为正,  $l_2$  在  $RP_2$  之右为正, 相反为负。如所周知, 由  $q_1 \rightarrow q_2$  的交换遵从 ABCD 定律

$$q_2^{-1} = \frac{c + Dq_1^{-1}}{A + Bq_1^{-1}}, \quad (2)$$

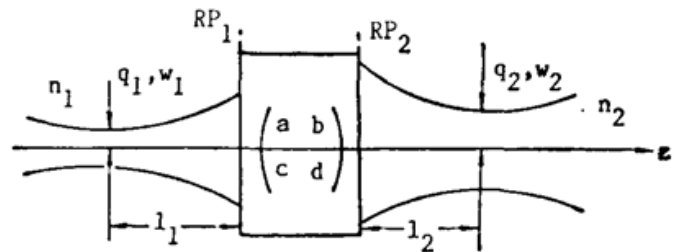


Fig. 1 Schematic illustration of Gaussian beam propagation through an optical system with ray transfer matrix  $\begin{pmatrix} a & b \\ c & d \end{pmatrix}$

$$M = \begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & l_2 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} 1 & l_1 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} a+cl_2 & b+al_1+dl_2+cl_1l_2 \\ c & d+cl_1 \end{pmatrix}, \quad (3)$$

$$\det M = AD - BC = (n_1/n_2), \quad (4)$$

将(1)、(3)式代入(2)式, 并利用(4)式得

$$\left. \begin{aligned} a_2 &= \frac{(a_1^2 + b_1^2)BD + a_1(AD + BC) + AC}{A^2 + 2a_1AB + (a_1^2 + b_1^2)B^2}, \\ b_2 &= \frac{(n_1/n_2)b_1}{A^2 + 2a_1AB + (a_1^2 + b_1^2)B^2}. \end{aligned} \right\} \quad (5)$$

(5)式为高斯光束通过复杂光学系统的一般变换公式, 使用条件为公式中诸量为实数。

(1) 作为特例, 入射光束取在束腰  $w_{01}$  处

$$a_1 = 0, \quad b_1 = b_{01} = (\lambda_1/\pi w_{01}^2) = z_{01}^{-1}, \quad (6)$$

式中  $z_{01}$  为物方瑞利尺寸, (5)式成为

$$\left. \begin{aligned} a_2 &= \frac{BD + ACz_{01}^2}{B^2 + A^2z_{01}^2}, \\ b_2 &= \frac{(n_1/n_2)z_{01}}{B^2 + A^2z_{01}^2}. \end{aligned} \right\} \quad (7)$$

(2) 实际工作中最感兴趣的是  $a_1 = a_2 = 0$ , 即研究入射与出射高斯光束束腰间的交换,

(5)式简化为

$$\left. \begin{aligned} BD + ACz_{01}^2 &= 0, \\ z_{02} &= \frac{B^2 + A^2z_{01}^2}{(n_1/n_2)z_{01}}. \end{aligned} \right\} \quad (8)$$

利用(3)、(4)式, 当  $c \neq 0$  时, 可将(8)式写成

$$\left. \begin{aligned} l_2 &= -\frac{a}{c} + \frac{(n_1/n_2)[l_1 + (d/c)]}{(d+cl_1)^2 + c^2z_{01}^2}, \\ w_{02} &= \frac{(n_1/n_2)w_{01}}{[(d+cl_1)^2 + c^2z_{01}^2]^{1/2}}. \end{aligned} \right\} \quad (9)$$

(9)式决定了象方束腰位置  $l_2$  和大小  $w_{02}$ , 文献中常称为成像公式和物像比例公式。

## 2. 三个放大率

可仿照经典几何光学, 定义高斯光束放大率<sup>[4]</sup>

(1) 横向放大率  $\beta$

$$\beta = (w_{02}/w_{01}), \quad (10)$$

(2) 角放大率  $\gamma$

$$\gamma = (\theta_{02}/\theta_{01}), \quad (11)$$

$$\theta_{0i} = (\lambda_i/\pi w_{0i}), \quad (i=1, 2) \quad (12)$$

$\theta_{0i}$  为物、像方高斯光束远场发散角。

(3) 轴向放大率  $\alpha$

$$\alpha = z_{02}/z_{01}, \quad (13)$$

式中  $z_{02}$  为像方瑞利尺寸。易证  $\alpha, \beta, \gamma$  间有重要关系

$$\beta = \alpha\gamma, \quad (14)$$

$$\beta\gamma = (n_1/n_2). \quad (15)$$

由(10)、(11)、(15)式得

$$n_2 \theta_{02} w_{02} = n_1 \theta_{01} w_{01} \quad (16)$$

此即对应于经典光学的杜格朗日-赫姆霍兹不变式。

### 3. 高斯光束的主面和节面

在光束交换理论中,基面的概念对不变性参数研究是十分重要的<sup>[3]</sup>。对高斯光束,有意义的是主面和节面。仿照经典光学,由主面定义  $\beta=1$  和(9)式,求得以  $RP_i$  为参考,主面位置

$$\left. \begin{aligned} l_{1P}^{\pm} &= -\frac{d}{c} \pm \frac{1}{c} \sqrt{\left(\frac{n_1}{n_2}\right)^2 - (cz_{01})^2}, \\ l_{2P}^{\pm} &= -\frac{a}{c} \pm \frac{1}{c} \sqrt{1 - \left(\frac{n_1}{n_2} cz_{01}\right)^2}. \end{aligned} \right\} (|c|z_{01} \leq n_1/n_2) \quad (17)$$

由节面定义  $\gamma=1$  和(9)式,求得节面位置

$$\left. \begin{aligned} l_{1N}^{\pm} &= -\frac{d}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2} \\ l_{2N}^{\pm} &= -\frac{a}{c} \pm \frac{n_1}{n_2 c} \sqrt{1 - (cz_{01})^2} \end{aligned} \right\} (|c|z_{01} \leq 1) \quad (18)$$

利用(17)、(18)式和矩阵光学技巧<sup>[5]</sup>,不难求出高斯光束主面间、节面间的变换矩阵以及高斯光束主、节面与经典主、节面间的变换矩阵。显然,在高斯光束公式中,令  $z_{01}|c| \rightarrow 0$  就过渡到经典光学的相应公式。现将所得结果和与经典光学的比较总结于表1、表2。由表1、表2可知:

(1) 当  $n_1 \neq n_2$  时,主面和节面分开,即  $\beta=1$  和  $\gamma=1$  两者面不可同时兼得,像方高斯光束参数  $l_2, w_{02}$  都依赖于  $n_1/n_2$  的取值。

(2) 高斯光束主面和节面位置  $G_P^{\pm}, G_N^{\pm}, G'_P^{\pm}, G'_N^{\pm}$  分别相对于经典焦面  $F(-d/c), F'(-a/c)$  为对称,但主、节面间的相对位置则与  $n_1, n_2, c$  和  $z_{01}$  等参数选取有关。

(3) 高斯光束在二主面或二节面间传输时光束参数的不变性可直接由 ABCD 定律验证,而不需象文献[3]那样讨论本征值问题。以二节面间的变换为例,由表1知,由  $G_N^{\pm} \rightarrow G'_N^{\pm}$  的变换矩阵为

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} \pm \frac{n_1}{n_2} \sqrt{1 - (cz_{01})^2} & -\frac{n_2 cz_{01}^2}{n_1} \\ 0 & \pm \sqrt{1 - (cz_{01})^2} \end{pmatrix}, \quad (19)$$

设入射高斯光束参数  $q_{01}^{-1} = (-i\lambda_1/\pi w_{01}^2) = -iz_{01}^{-1}$ , 代入(2)式得到

$$n_2 w_{02} = n_1 w_{01} \quad (20)$$

这正是预期的结果。

(4) 与经典光学显著不同的是: (i)  $l_{iP}^{\pm}, l_{iN}^{\pm} (i=1, 2)$  都分别对应于  $\beta=1, \gamma=1$ , 而无反主面 ( $\beta=-1$ ), 反节面 ( $\gamma=-1$ ); (ii) 高斯光束成像位置、大小、主节面位置等都与入射光束瑞利尺寸  $z_{01}$  有关。

例如,高斯光束通过薄透镜的变换。

在图1中,设光学系统为一薄透镜

Table 1 The matrices and positions of the principal and nodal planes for the classical and Gaussian beam Optics

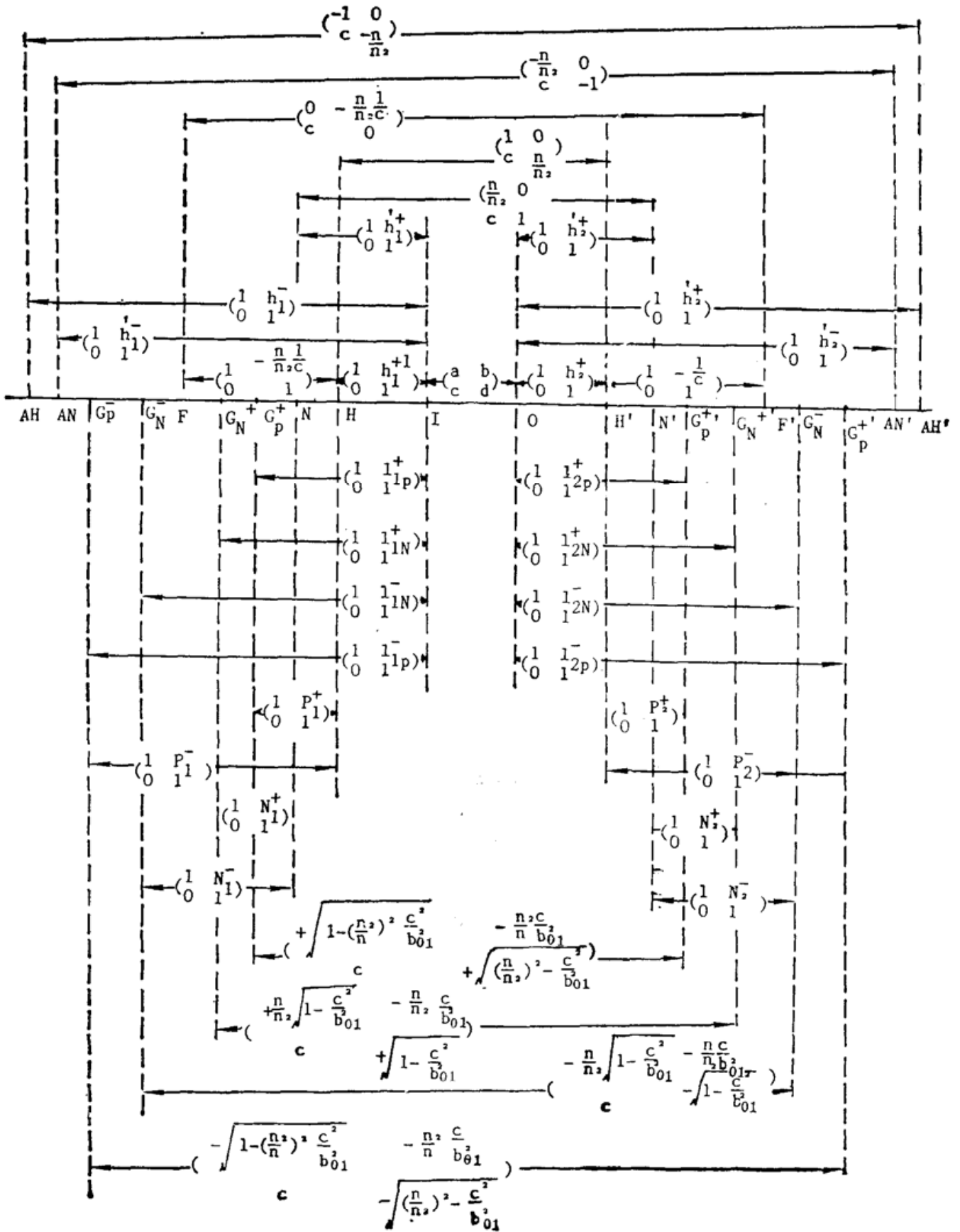


Table 2 A comparison between the classical and Gaussian beam Optics

	Gaussian beam Optics		Classical Optics	
	$n_1 \neq n_2$	$n_1 = n_2$	$n_1 \neq n_2$	$n_1 = n_2$
magnification	$\beta = \frac{w_{02}}{w_{01}}$ $\gamma = \frac{\theta_{02}}{\theta_{01}}$ $\alpha = \frac{z_{02}}{z_{01}}$ $\beta = \alpha\gamma$ $\beta\gamma = n_1/n_2$	$\beta = \frac{w_{02}}{w_{01}}$ $\gamma = \frac{\theta_{02}}{\theta_{01}}$ $\alpha = \frac{z_{02}}{z_{01}}$ $\beta = \alpha\gamma$ $\gamma\beta = 1$	$\beta = r_2/r_1$ $\gamma = \theta_2/\theta_1$ $\alpha = dv/du$ $\beta = \alpha\gamma$ $\beta\gamma = n_1/n_2$	$\beta = r_2/r_1$ $\gamma = \theta_2/\theta_1$ $\alpha = dv/du$ $\beta = \alpha\gamma$ $\beta\gamma = 1$
Principal planes	$l_{1P}^\pm = -\frac{d}{c} \pm \frac{1}{c} \sqrt{\left(\frac{n_1}{n_2}\right)^2 - (cz_{01})^2}$ $l_{2P}^\pm = -\frac{a}{c} \pm \frac{1}{c} \sqrt{-1\left(\frac{n_2}{n_1}(z_{01})\right)^2}$ $\beta = 1$	$l_{1P}^\pm = -\frac{d}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2}$ $l_{2P}^\pm = -\frac{a}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2}$ $\beta = 1$	$h_1^\pm = -\frac{d}{c} \pm \frac{n_1/n_2}{c}$ $h_2^\pm = -\frac{a}{c} \pm \frac{1}{c}$ $\beta = \pm 1$	$h_1^\pm = -\frac{d}{c} \pm \frac{1}{c}$ $h_2^\pm = -\frac{a}{c} \pm \frac{1}{c}$ $\beta = \pm 1$
nodal planes	$l_{1N}^\pm = -\frac{d}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2}$ $l_{2N}^\pm = -\frac{a}{c} \pm \frac{n_1}{n_2c} \sqrt{1 - (cz_{01})^2}$ $\gamma = 1$	$l_{1N}^\pm = -\frac{d}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2}$ $l_{2N}^\pm = -\frac{a}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2}$ $\gamma = 1$	$h_1^\pm = -\frac{d}{c} \pm \frac{1}{c}$ $h_2^\pm = -\frac{a}{c} \pm \frac{n_1/n_2}{c}$ $\gamma = \pm 1$	$h_1^\pm = -\frac{d}{c} \pm \frac{1}{c}$ $h_2^\pm = -\frac{a}{c} \pm \frac{1}{c}$ $\gamma = \pm 1$
imaging eq.	$l_2 = -\frac{a}{c} \pm \frac{\frac{n_1}{n_2} \left( l_1 + \frac{d}{c} \right)}{(a+cl_1)^2 + c^2 z_{01}^2}$	$l_2 = -\frac{a}{c} \pm \frac{l_1 + \frac{d}{c}}{(d+cl_1)^2 + c^2 z_{01}^2}$	$\frac{(-1/c)}{u}$ $+\frac{(-\frac{n_1}{n_2}/c)}{v} = 1$	$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ $f = -1/c$
object-image relation	$w_{02} = \frac{\frac{n_1}{n_2} w_{01}}{[(d+cl_1)^2 + c^2 z_{01}^2]^{\frac{1}{2}}}$	$w_{02} = \frac{w_{01}}{[(d+cl_1)^2 + c^2 z_{01}^2]^{\frac{1}{2}}}$	$r_2 = \frac{\frac{n_1}{n_2} r_1}{d+cl_1}$	$r_2 = \frac{r_1}{d+cl_1}$

planes  $H, H'$ , respectively. The approximation towards the classical Optics is  $z_{01}/c \rightarrow 0$  spaces, respectively.  $u$  and  $v$  are the object and image distances re-referred to the principal In classical Optics.  $r_1, \theta_1$  are the ray positions and slopes in the object ( $s=1$ ) and image ( $s=2$ )

表说明:  $P_1^\pm = -\frac{n_1}{n_2c} \pm \frac{1}{c} \sqrt{\left(\frac{n_1}{n_2}\right)^2 - (cz_{01})^2}$ ,  $P_2^\pm = -\frac{1}{c} \pm \frac{1}{c} \sqrt{1 - \left(\frac{n_2}{n_1} cz_{01}\right)^2}$

$N_1^\pm = -\frac{1}{c} \pm \frac{1}{c} \sqrt{1 - (cz_{01})^2}$ ,  $N_2^\pm = -\frac{n_1}{n_2c} \pm \frac{n_1}{n_2c} \sqrt{1 - (cz_{01})^2}$

$l_{1P}^\pm, l_{2P}^\pm, l_{1N}^\pm, l_{2N}^\pm$  are (1-17), (1-18), respectively.

$$\left. \begin{aligned} \begin{pmatrix} a & b \\ c & d \end{pmatrix} &= \begin{pmatrix} 1 & 0 \\ -\frac{1}{f} & \frac{n_1}{n_2} \end{pmatrix}, \\ \frac{1}{f} &= \frac{1}{n_2 R_1 R_2} [(n_0 - n_2) R_1 + (n_1 - n_0) R_2], \end{aligned} \right\} \quad (21)$$

式中  $f$  为  $n_1 \neq n_2$  时薄透镜的象方焦距  $n_0, R_1, R_2$  分别为薄透镜介质折射率、入射和出射介面曲率半径。将(20)式代入(9)式得

$$\left. \begin{aligned} \frac{l_2}{f} &= 1 + \frac{(n_1/n_2) [(l_1/f) - (n_1/n_2)]}{[(l_1/f) - (n_1/n_2)]^2 + (z_{01}/f)^2}, \\ w_{02} &= \frac{(n_1/n_2) w_{01}}{\{[(l_1/f) - (n_1/n_2)]^2 + (z_{01}/f)^2\}^{1/2}} \end{aligned} \right\} \quad (22)$$

数值计算例如图 2(a)、(b)。由图可见,随着 $(n_2/n_1)$ 的增加,  $[(l_2/f) - (l_1/f)]$ 、 $[\beta - (l_1/f)]$  曲线都向左移,  $l_2$ 、 $\beta$  的值发生变化。

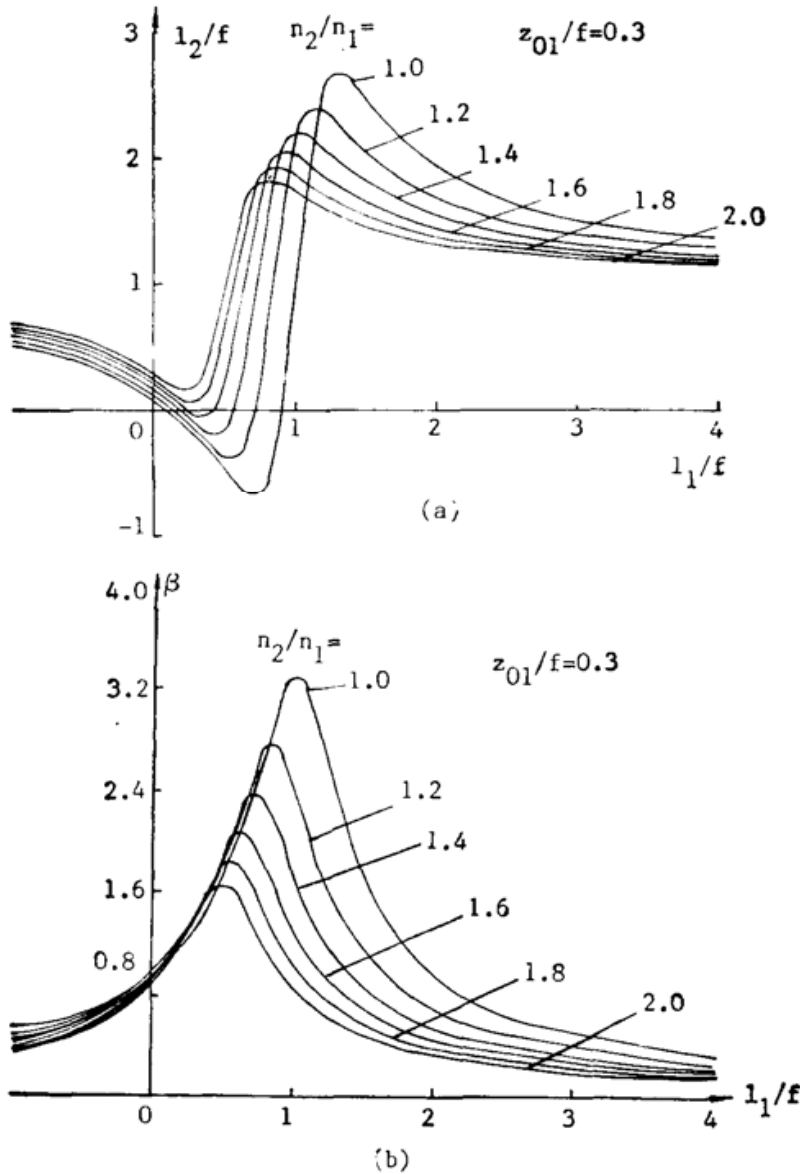


Fig. 2 Gaussian beam transformation through a thin lens

(a)  $l_2/f$  as a function of  $l_1/f$ ;

(b) lateral magnification  $\beta$  versus  $l_1/f$

(parameters:  $n_2/n_1=1, 1.2, 1.4, 1.6, 1.8, 2$ ;  $z_{01}/f=0.3$ )

## 二、高斯光束通过复元素光学系统的变换

一个实际的光学系统,因光学元件横向有限的几何尺寸而存在孔径效应,这对激光束的传输必然产生影响。对硬边光阑,迄今仅有数值计算结果。对软边光阑,例如高斯光阑可用矩阵光学方法作解析讨论<sup>[6]</sup>,其变换矩阵为

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -i\lambda/\pi\sigma^2 & 1 \end{pmatrix}, \quad (23)$$

式中  $\lambda$  为激光在光阑所在空间的波长,  $\sigma$  为高斯光阑的宽度。这时, 因矩阵元  $c$  为虚数, 前二节推导的公式失效, 但 ABCD 定律仍成立<sup>[7]</sup>。为具体起见, 可以设例 1 中的薄透镜有一前孔径高斯光阑 GA(图 3), 光学系统的变换矩阵为

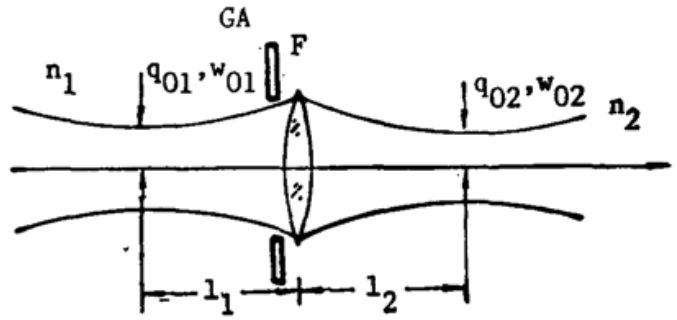
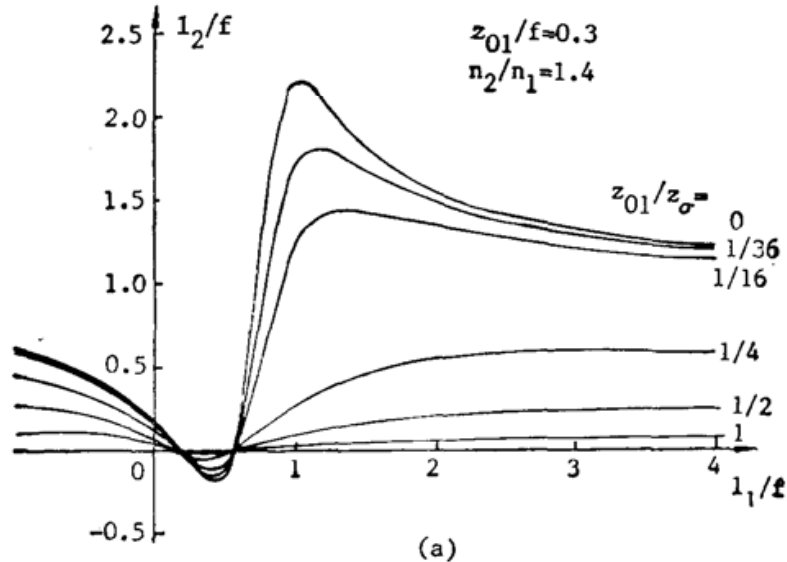


Fig. 3 Schematic diagram of Gaussian beam transformation through a thin lens and a forward Gaussian aperture

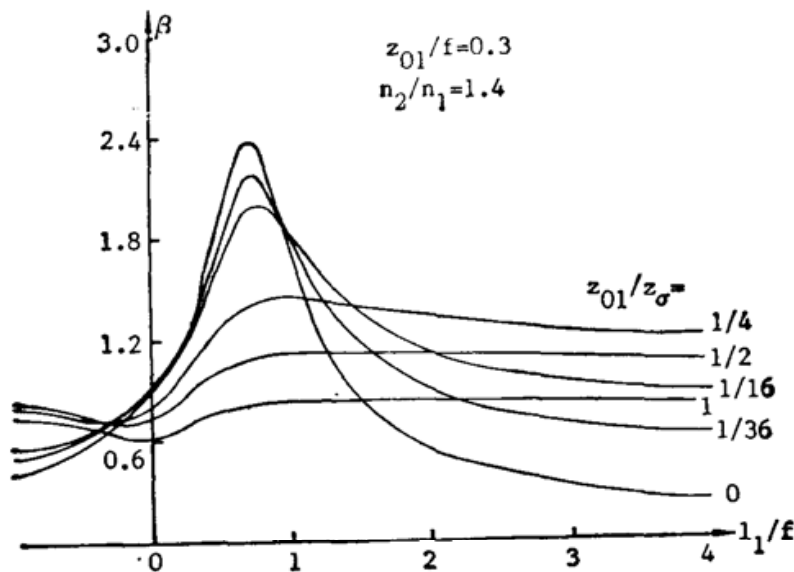
$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -[(1/f) + (i/z_\sigma)] & n_1/n_2 \end{pmatrix}, \quad (24)$$

$z_\sigma^{-1} = (\lambda/\pi\sigma^2)$

由  $q_{01} \rightarrow q_{02}$  的变换矩阵



(a)



(b)

Fig. 4 Gaussian beam transformation through a thin lens and a forward Gaussian aperture

(a)  $l_2/f$  as a function of  $l_1/f$ ; (b) lateral magnification  $\beta$  versus  $l_1/f$   
 (Parameters:  $z_{01}/z_\sigma = 0, 1/36, 1/16, 1/4, 1/2, 1$ ;  $z_{01}/f = 0.3$ ;  $n_2/n_1 = 1.4$ )

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} [1 - (l_2/f) - i(l_2/z_\sigma)] & [l_1 + (n_1/n_2)l_2 - (l_1l_2/f) - i(l_1l_2/z_\sigma)] \\ [-(1/f) - i(1/z_\sigma)] & [(n_1/n_2) - (l_1/f) - i(l_1/z_\sigma)] \end{pmatrix}, \quad (25)$$

将(30)代入(2)式,分离实、虚部得到

$$\left. \begin{aligned} l_2 &= \frac{(z_{01}/f)^2 - [(n_1/n_2) - (l_1/f)]l_1}{(z_{01}/z_\sigma) + (n_1/n_2) - (l_1/f)]^2 + [(z_{01}/f) + (l_1/z_\sigma)]^2}, \\ \beta &= \frac{w_{02}}{w_{01}} = \frac{n_1}{n_2} \left\{ \frac{1 + (n_2 z_{01}/n_1 z_\sigma) [1 + (l_1^2/z_{01}^2)]}{[(z_{01}/z_\sigma) + (n_1/n_2) - (l_1/f)]^2 + [(z_{01}/f) + (l_1/z_\sigma)]^2} \right\}^{1/2}. \end{aligned} \right\} \quad (26)$$

(1)  $n_1 = n_2$

$$\left. \begin{aligned} l_2 &= \frac{(z_{01}^2/f) - [1 - (l_1/f)]l_1}{[(z_{01}/z_\sigma) + 1 - (l_1/f)]^2 + [(z_{01}/f) + (l_1/z_\sigma)]^2}, \\ \beta &= \left\{ \frac{1 + (z_{01}/z_\sigma) [1 + (l_1^2/z_{01}^2)]}{[(z_{01}/z_\sigma) + 1 - (l_1/f)]^2 + [(z_{01}/f) + (l_1/z_\sigma)]^2} \right\}^{1/2}. \end{aligned} \right\} \quad (27)$$

(2)  $z_\sigma \rightarrow \infty$ , 即无光阑时, (26)式就回到(22)式。高斯光阑对  $l_2, \beta$  影响的数值计算例如图 4(a)、图 4(b)所示。由图 4 知: 随  $(z_{01}/z_\sigma)$  的增加,  $l_2$  和  $\beta$  都偏离无光阑  $(z_{01}/z_\sigma) = 0$  的值。

### 三、高斯光束通过 $c=0$ 光学系统的变换

在激光束传输中常用的准直望远镜, 空间滤波器等远焦系统, 其变换矩阵元  $c=0$ , (9)

式中第一式失效, 但(8)式仍成立。现以图 5 所示带高斯光阑的空间滤波器为例进行分析。为一般起见, 设焦距为  $f_1, f_2$  的薄透镜构成的滤波系统浸于折射率为  $n$  的介质中, 其间距

$$l_T = f_1 + \frac{n}{n_2} f_2, \quad (28)$$

Fig. 5 Schematic illustration of Gaussian beam propagation through an afocal optical system ( $c=a$ )

在距薄透镜  $F$  右  $f_1$  处置有一高斯光阑  $GA$ , 于是

$$\left. \begin{aligned} \begin{pmatrix} a & b \\ c & d \end{pmatrix} &= \begin{pmatrix} (nM_T/n_2) & [(n_1/n)l_T - i(n_1f_1f_2/n_2z_\sigma)] \\ 0 & (n_1/nM_T) \end{pmatrix}, \\ M_T &= -f_2/f_1. \end{aligned} \right\} \quad (29)$$

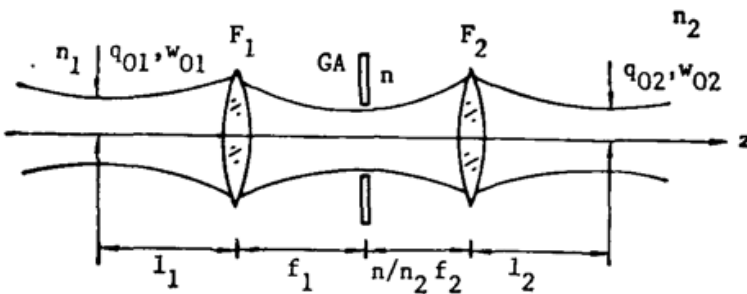
由  $q_{01} \rightarrow q_{02}$  的变换矩阵

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} (nM_T/n_2) & [(n_1l_T/n) + (nM_T/n_2)l_1 + (n_1l_2/nM_T) - i(n_1f_1f_2/n_2z_\sigma)] \\ 0 & (n_1/nM_T) \end{pmatrix}. \quad (30)$$

将(30)代入(8)式, 得到

$$\left. \begin{aligned} l_2 &= - (n^2/n_1n_2) M_T^2 l_1 - M_T l_T, \\ \beta &= (n/n_2) |M_T| \left[ 1 + \frac{(n_2/n) f_1^2}{z_{01} z_\sigma} \right]^{1/2}. \end{aligned} \right\} \quad (31)$$

(1)  $n_1 = n_2 = n$  时,





$$\left. \begin{aligned} l_2 &= -M_T^2 l_1 - M_T l_T, \\ \beta &= |M_T| \left(1 + \frac{f_1^2}{z_{01} z_\sigma}\right)^{1/2}. \end{aligned} \right\} \quad (32)$$

若取  $l_1 = f_1$ , 则

$$l_2 = f_2. \quad (33)$$

(2)  $z_\sigma \rightarrow \infty$  时

$$\left. \begin{aligned} l_2 &= -\frac{n^2}{n_1 n_2} M_T^2 l_1 - M_T l_T, \\ \beta &= \frac{n_1}{n_2} |M_T|. \end{aligned} \right\} \quad (34)$$

比较(31)~(34)式知: (1) 折射率  $n_1, n_2, n$  对像距  $l_2$  和横向放大率  $\beta$  都有影响; (2)  $l_2$  与  $l_1$  有关, 但  $\beta$  与  $l_1$  无关; (3) 光阑的存在使  $\beta$  增大。

#### 四、小 结

本文在较为普遍的情况下研究了高斯光束, 通过复杂光学系统的变换规律得到了一些新的结果。除硬边光阑外, 一般轴对称光学元件和系统均可纳入已研究范围, 使用矩阵 ABCD 定律<sup>[5, 8]</sup>, 本文结果还可直接推广用于研究椭圆高斯光束通过任意非轴对称光学系统的变换。限于篇幅, 对此将另文讨论。

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## Gaussian beam transformation through complicated optical systems

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### Abstract

Gaussian beam propagation through complicated optical systems is studied in detail by using matrix optics method. The results are generalized to the cases including (1) refractive indices of the object and image spaces are not the same ( $n_1 \neq n_2$ ); (2) the transfer matrix elements of optical systems are complex or the element  $C$  is equal to zero. The effects of Gaussian limiting aperture on the beam transmission are discussed. A comparison between the classical and Gaussian beam optics ( $n_1 \neq n_2$ ,  $n_1 = n_2$ ) clearly illustrates their differences and relations.

**Key words:** beam transformation; matrix optics; ABCD law.

更正

《光学学报》第 10 卷第 11 期 1040 页“熔锥直线型 3×3 单模光纤定向耦合器的光功率耦合分析”一文中作者中文名字正确排列应为：姚寿铨、黄勇、刘慧珍。