Optics Communications 351 (2015) 128–134

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Non-tradition-employed lenses

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ARTICLE INFO

Article history:
Received 12 January 2015
Accepted 16 April 2015
Available online 20 April 2015

Keywords:
Lenses
Combination of beams or laser beams
Phase locking of a laser array

ABSTRACT

Non-tradition-employed (NTE) lenses are presented. The characters are proved by the experiment. Multilayer reflection coatings on designated zones on the surfaces of the lens are different in reflectivity (R) because of different NTE aims. Incident light beams paraxially bounce back and forth between two surfaces of the lens, then leave from a zone or multiple zones of the lens. The application schemes involve solid-state multiple-pass cell, combination of light beams or laser beams, and phase-locking of a laser array.

1. Introduction

Lenses are basic optical components. Some approaches to expanding their application scope and increasing their application capabilities have been applied to many optical systems, such as uniform films on the spherical surfaces of lenses [1], multiple-beam interference of two parallel planes of the plate, off-axis travel between mirrors [2–5] and non-uniform films [6] on optical surfaces of lenses or mirrors. In fact, non-uniform films are anti-Gauss films. Combination of light beams often appears in optical systems. Combination or coherent combination of laser beams and phase locking of a lase array are interesting problems [7–11].

In the paper, we report NTE lenses and their application schemes, and NTE lenses can be expanded their application ranges. In structure, multilayer reflection coatings on designated ring zones, circle regions and other regions on the spherical surfaces of the employed lens are different in reflectivity or transmitance(T). In the operating mechanism, an incident light beam or beams bounce paraxially back and forth between two surfaces, then the beam or beams leave from a zone, or multiple zones, or total surfaces. NTE lenses can be applied to solid-state multiple-pass cell, combination of light beams or laser beams, and phase locking of a laser array.

2. Theory

2.1. Fundamental formulas

The diagrams of NTE lenses are shown in Fig. 1. (a), (d), (g) and (j) are concave–convex lenses, while (b), (e), (h) and (k) are plane-convex lenses, and (c), (f), (i) and (l) are biconvex lenses. The ring regions on the left surfaces, and the left and right central regions of the lenses are partly or totally transmitted except that the left central regions of (j), (k) and (l) of the lenses are totally reflected. ρ_1 and ρ_2 are the curvature radii of the left and right surfaces, respectively. η_1 and η_2 are the refractive indices of inner and outer media of the lens (see Fig. 1(a)), respectively. d is the thickness of the lens. It is assumed that a ray of light is injected into the ring regions of the lens and bounced back and forth between the surfaces and is emergent in the central region of the lens. Let r_n be the ray displacement from the optic axis in the left plane of NTE lens on the nth round trip and r'_n be the ray slope at the left surface on the nth round trip, x_n and y_n be the coordinates of the ray in the left plane of NTE lens on the nth round trip, x'_n and y'_n be the correspondent ray slopes, r_0, x_0, y_0, r'_0, x'_0 and y'_0 be the initial conditions, respectively. x_n and x'_n are obtained from x_0 and x'_0 by transformation, namely,

$$\begin{pmatrix} x_n \\ x'_n \end{pmatrix} = \begin{pmatrix} A' & B' \\ C' & D' \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} = \frac{1}{\sin\theta} \begin{pmatrix} A\sin n\theta - \sin(n-1)\theta & B\sin n\theta \\ C\sin n\theta & D\sin n\theta - \sin(n-1)\theta \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -2/\rho_1 & 1 \end{pmatrix} \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -2/\rho_2 & 1 \end{pmatrix} \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix} \tag{2}$$

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http://dx.doi.org/10.1016/j.optcom.2015.04.039
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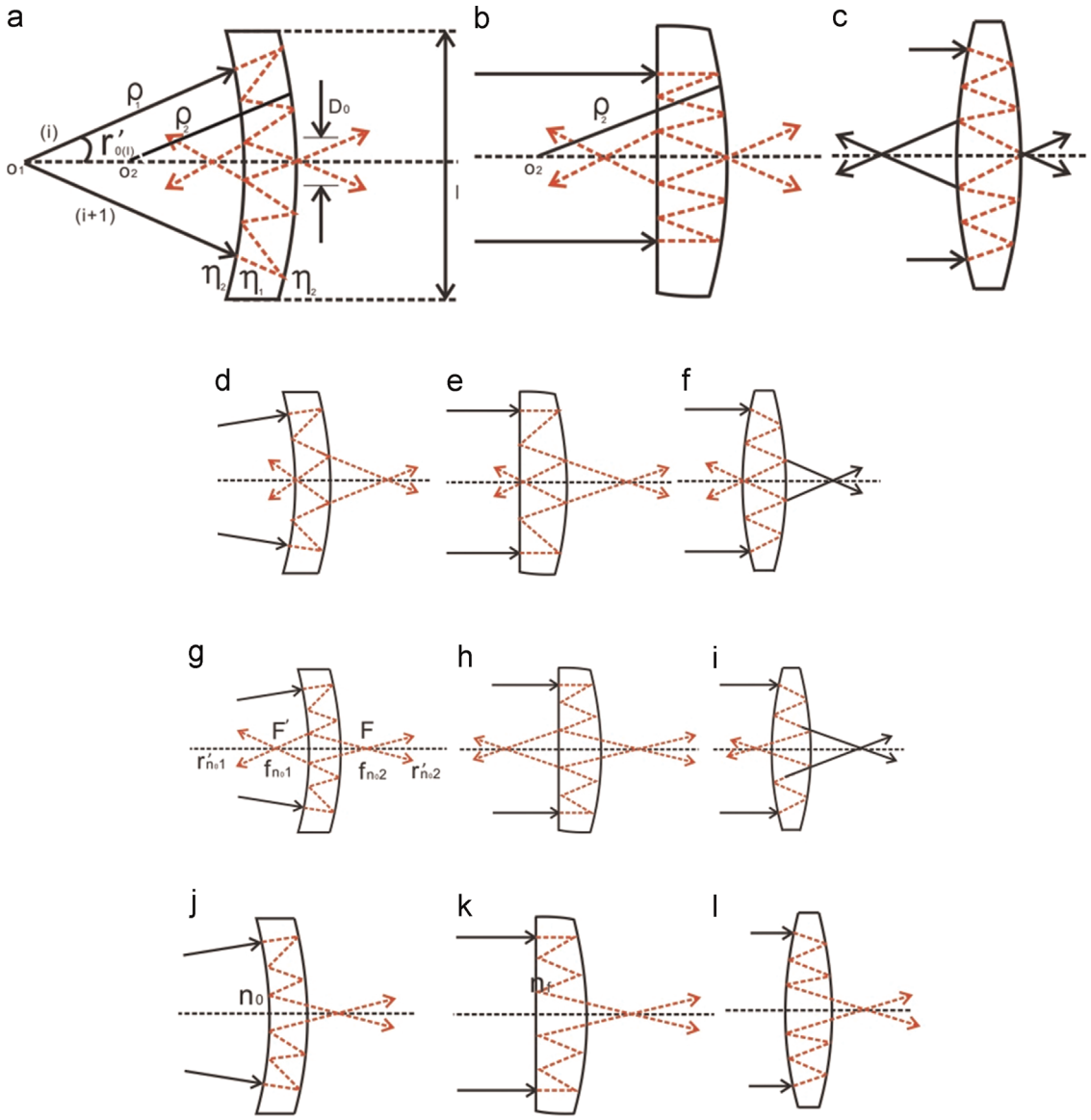

Fig. 1. Characteristic cases of NTE lens: (a)(b)(c): $f_{n0(2)}=0$, $f_{n0(1)}\neq 0$; (d)(e)(f): $f_{n0(2)}\neq 0$, $f_{n0(1)}=0$; (g) (h)(i):$f_{n0(2)}\neq 0$, $f_{n0(1)}\neq 0$; (j)(k)(l): $f_{n0(2)}\neq 0$.

$$A = 1 - 2d/\rho_2,$$
$$B = 2d\left(1 - d/\rho_2\right),$$
$$C = 2\left(-1/\rho_1 - 1/\rho_2 + 2d/\rho_1\rho_2\right),$$
$$D = 1 + 2d\left(-2/\rho_1 - 1/\rho_2 + 2d/\rho_1\rho_2\right);$$

$$\cos\theta = 2g_1g_2 - 1 = \left(A + D\right)/2 \tag{3}$$

$$g_1 = 1 - d/\rho_1,\ g_2 = 1 - d/\rho_2 \tag{4}$$

where $\rho_1 < 0$, $\rho_2 > 0$ for (a), (d), (g) and (j) of Fig. 1; $\rho_1 = \infty$, $\rho_2 > 0$ for (b), (e), (h) and (k); and ρ_1, $\rho_2 > 0$ for (c), (f), (i) and (l). Similarly, y_n, y_n',y_0 and y_0' have the same relationship. Thus we have

$$x_n = x_0\cos n\theta + \frac{dg_2(x'_0 + x_0/\rho_1)\sin n\theta}{\sqrt{g_1g_2(1-g_1g_2)}} \tag{5}$$

$$y_n = y_0\cos n\theta + \frac{dg_2(y'_0 + y_0/\rho_1)\sin n\theta}{\sqrt{g_1g_2(1-g_1g_2)}} \tag{6}$$

The ray follows an elliptical path [2,4,5] on the surface of NTE lens in general. As a special case, let $x_0 = 0$, $x'_0=0$ *or* $y_0 = 0$, $y'_0 = 0$,

Thus $y_0 = r_0, y'_0 = r'_0, y_n = r_n, y'_n = r'_n$ *or* $x_0 = r_0, x'_0 = r'_0, x_n = r_n, x'_n = r'_n$, and

$$r_n = r_0\cos n\theta + \frac{dg_2(r'_0 + r_0/\rho_1)\sin n\theta}{\sqrt{g_1g_2(1-g_1g_2)}} \tag{7}$$

$$r'_n = \frac{1}{\sin\theta}[Cr_0\ \sin\ n\theta + (D\ \sin\ n\theta - \ \sin(n-1)\theta)r'_0] \tag{8}$$

As shown in Fig. 1(g), let the intersection points of the emergence rays with the axis be F and F', the polar coordinates of the emergence points are $r_n(2)$ and $r_n(1)$, the distances from F and F' to the centers of the related surfaces are $f_n(2)$ and $f_n(1)$, the slopes are $r'_n(2)$ and $r'_n(1)$, respectively. The results of the parameters $r_{n(2)}$, $f_{n(2)}$, $r'_{n(2)}$, $r_{n(1)}$, $f_{n(1)}$, *and* $r'_{n(1)}$ are

$$r_{n(2)} = r_n + r'_n\ d \tag{9}$$