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Propagation properties of Gaussian beam through a asymmetric negative index slab system by transfer matrix

Jianhua Zhou [a,*], Yangsu Zeng [a], Yonghua Hu [b], Tongcheng Huang [a]

[a] Institute of Laser Technology, and Department of Information Engineering, Shaoyang University, Shaoyang, Hunan 422000, China
[b] School of Computer Science and Engineering, Hunan University of Science and Technology, Xiangtan 411201, China

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ABSTRACT

Propagation properties of Gaussian beam through a asymmetric negative index slab system are investigated by transfer matrix. Firstly, transfer matrix related to negative index slab is derived; then the electric field distribution of each region in the system is obtained by ABCD law and the beam focusing both inside and outside the negative index slab is researched. On the paraxial approximation, the propagation properties of Gauss beam through a asymmetric negative index slab system are clearly revealed. When the positive index materials on both sides of the slab are the same, our conclusion can be evolved into the conclusion of a special case, the evolution of conclusion is the same as that of a symmetric negative index slab system.

1. Introduction

Since Pendry inferred from the theory that negative refractive index material can be artificially structured and perfect lens can be made use this material [1], negative refractive index materials [2] has become a research hotspot [3–7]. Many researchers have done a lot of research on negative index materials from theory and experiment, the progress is very rapid [7,8]. In many of the negative index literature, the plane electromagnetic wave is the object of study, however, the plane electromagnetic wave is just an ideal situation, in actual application systems, they are based on paraxial beams. Therefore, the transmission research of a light beam in asymmetric negative index media slab system, is a very important practical significance.

Negative refraction index slab system is a new optical system [1], a lot of scholars researched on this system [9–13], but their models are symmetrical, that is, in the negative index slab sides, either free space or the same positive refractive index material. In our system, both the negative index slab sides are two different positive refractive index materials, which we call asymmetric negative index slab system. Thus our model is universal and general; their model should be a special case of our model. If the refractive index is equal on both sides, our conclusions can be evolved into the conclusions of the specific model.

In this paper, we use the transfer matrix to study the propagation properties of light beam. In the research of the propagation of light beam, most literature is based on the angular spectrum theory, which has a complicated mathematical integral operation. Transfer matrix method is a simple and efficient research tool for beam propagation, and each matrix element has a clear physical meaning. We know that the characteristic matrix is used to calculate the transmittance and reflectivity of a

* Corresponding author.
E-mail address: zjh598@126.com (J. Zhou).

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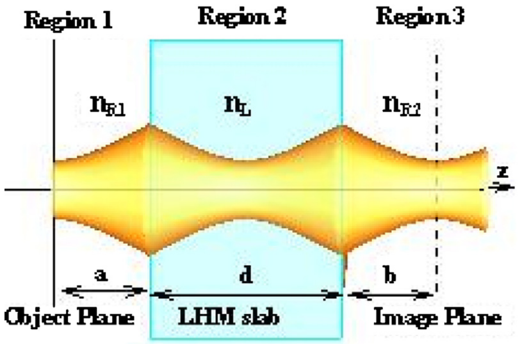

Fig. 1. Gaussian beam through a asymmetric negative index slab system.

ray through a stratified medium [14]. So in this paper, we use the transfer matrix to research the propagation properties of Gauss beam in the asymmetric negative index slab system. Compared with the angular spectrum theory, we avoid complicated integral operation and obtain definite conclusion. Negative index slab system can also be used as an imaging system [15,16], an invisibility cloak [17], a waveguide [18], and others. We hope our investigation will be helpful to the research on such slab systems.

2. Gauss beams propagation through a asymmetric negative index slab system

For a asymmetric negative index slab system, as shown in Fig. 1, the region 2 is a isotropic negative index slab, there are usually isotropic positive index materials around it, in which n_{R1}, n_L and n_{R2} are the indices of the material in region 1, region 2 and region 3, respectively, d is the thickness of the negative index slab. Without any loss of generality, assuming the waist of input Gaussian beam locates at the object plane $z = 0$, and a is the distance from the object plane to the left boundary of the negative index slab. If the beam can be focused in the third region, the distance from the image plane to

the right boundary of the negative index slab is assumed to be b. Next, we will discuss the field distribution in region 1 and region 2 when the Gauss beam passes through the asymmetric negative index slab, and the change of field distribution in region 3.

2.1. Field distribution when Gaussian beam through region 1

According to previous assumptions, the propagation direction of the beam is the positive direction of the z-axis, the position of the focal plane of the incident light beam is $z = 0$, where the complex parameter of beam is

$$q_0 = iz_0 = i\frac{1}{2}k_0 n_{R1} w_0^2 \tag{1}$$

In region 1, when the beam propagates a distance z from the focal plane where$0 < z \leq a$, the complex parameter of the beam abiding by ABCD law becomes

$$q_1 = z + i\frac{1}{2}k_0 n_{R1} w_0^2 \tag{2}$$

And the field distribution of the beam with complex q_1 is

$$\boldsymbol{E_1}(r, z) = \frac{w_0}{w_1}\exp\left[-\frac{r^2}{w_1^2} - i(\frac{k_0 n_{R1} r^2}{2R_1} - \arctan\frac{z}{z_0} + k_0 n_{R1} z)\right] \tag{3}$$

where$R_1 = z + (z_0)^2/z$, it is the Gaussian beam wave front curvature radius, $w_1 = w_0[1 + z^2/(z_0)^2]^{1/2}$, it is the Gaussian beam width, $\arctan\frac{z}{z_0}$is the Gouy shift, $k_0 n_{R1} z$ is the linear phase, and $z_0 = k_0 n_{R1} w_0^2/2$ the Rayleigh length in the region 1. when$z = a$, substituting it into Eq. (3), the field distribution at the interface of region 1 and region 2 can be obtained.

2.2. Field distribution of beam in the region 2(negative index slab)

When beam propagates from region 1 into region 2, at the interface, the beams in both sides satisfy a linear relation, then, the ABCD law can be calculated use the transfer matrix of the media index mutation [10]. We assume that the Gaussian