

Description

The invention relates to a method for the fabrication of lenses with a refractive index varying in three dimensions.

5 Lenses with a variable refraction index, such as a Luneburg lens or a Eaton-Lippmann lens, are well known. It is also known, e.g. from US 4 288 337, that lenses with variable refraction indexes can be used as radar reflectors or, as is known from E. F. Buckley; "Stepped-Index Luneburg Lenses"; Electronic Design, April, 13, 1960, as part of an antenna system.

10 As Buckley has described in said article, it is a known method for the fabrication of Luneburg lenses to use a hemispherical-shell construction with a given number of layers.

According to said US patent the Layers for the fabrication of Luneburg and Eaton-Lippmann Lenses can be produced by mixed dielectrics. Such a mixed dielectric can be obtained by mixing expanded particles selected from the group consisting of expanded polystyrols, expanded polyethylenes, expanded polyurethanes, glass balloons and silica balloons, with metal-coated particles consisting of said expanded particles, surfaces
15 of which have been coated with a thin film selected from the group of chromium, aluminium, copper, nickel, gold, silver, and magnesium in proper proportions to obtain a desired dielectric constant then forming the same to the desired shape by the use of a binder.

From the article "A multiple-beam multiple-frequency spherical Lens Antenna System providing hemispherical Coverage" of M. A. Mitchel et al.; 6. International Conference on Antennas and Propagation (ICAP) 1989, Part 1, pp. 394 - 398 it is known that the relative dielectric constant, and by this the refraction index, of a dielectric material, such as polysterene, can be modified by a variation of density of said material. Thereby hemispherical shells with given refraction indexes may be produced.

From US 3 307 196 a method is known, which allows the production of a two-dimensional dielectric lens, such as a disk, by winding a ribbon, shut or strip type of module.

25 In the US patent 3 307 196 it is proposed to fabricate a three-dimensional dielectric lens by the individual preparation of wound disks, which are superposed upon one another. The superposed disks are of successively different diameters and dielectric profile and could be formed, starting with individual substantially strip or ribbon modules, by cutting successively different Lengths away from the high dielectric constant ends of said different strips, and then rewinding the resultant successively different length strips.

30 There are two disadvantages in the known methods for the fabrication of three-dimensional lenses. It is either possible just to approximate the variation of the refractive index required, which is dependent on the dielectric constant. Or it is necessary to carry out a large number of steps. That means no easy and practical method for smoothly varying the refractive index has been achieved.

By using shells with different dielectric constants and there-by with different refraction indexes, reflection losses occur by which power is reflected from the dielectric boundaries.

35 It is an object of the invention, to present an easy method for the fabrication of lenses with a variable refraction index, which overcomes the deficiencies of the prior art.

This can be realized by a method according to claim 1.

40 The method according to the invention allows to produce three-dimensional lenses with a variable refraction index n by wrapping a material with a given refraction index, e.g. such as the known materials from US 4 288 337, into the final shape of the lens to be produced.

It is an advantage of the invention to present a method for the fabrication with a reduced number of steps.

45 It is a further advantage of the invention to produce lenses with a better aperture efficiency by avoiding surface waves, which are set up at the spherical boundaries, and by achieving a more exact phase of the collimated rays at the feed points, which makes the lens less frequency dependent.

If the material with the given refraction index is shaped as a thread, the method for the fabrication can be executed more easily.

The present invention will be better understood with the aid of the following description and accompanying drawings, wherein

- 50 Fig 1 shows a known Luneburg lens radar reflector,
- Fig 2 shows a known Luneburg lens antenna,
- Fig 3, shows a preferred embodiment,
- Fig 4a, b show possible shapes of thread used.

55 Prior to the detailed description it should be mentioned, that in the preferred embodiment the lenses to be produced are able to refract electromagnetic waves, preferably microwaves.

In this case the material with a given refraction index n is a dielectric material and the refraction index n is given by the expression

$$E = n^2,$$

where E is the relative dielectric constant.

Though the preferred embodiment is shown with lenses for electromagnetic waves, it should be kept in mind, that the invention is not limited to such lenses. By using a material with an appropriate refraction index even lenses, which are able to refract any other waves, e.g. sound waves, may be produced.

Fig. 1 shows a three-dimensional Luneburg lens 10, which works as radar reflector and as is state of the art. An incoming wave 11 is focussed by the lens 10 in such a way that the wave is focussed on a focus point 12. The wave is reflected by a reflector 13, whereby the reflected wave 14 is generated, which is led by the lens 10 in such a way, that it leaves the lens 10 in the same direction as the incoming wave 11 came from.

For leading the incoming wave 11 and the reflected wave 14 in the desired manner, it is necessary, that the relationship between the relative dielectric constant $E(r)$ and the normalized radius r/a is given by

$$E(r) = 2 - (r/a)^2, \quad (1)$$

where

r is the distance from the center point,

a is the radius of the lens 10, and

$r/a = 1.0$ at the outer surface of the lens.

Fig. 2 shows another application of the Luneburg lens 10. The difference between this embodiment and the embodiment of fig. 1 is, that here an incoming wave, such as 11a is led to a first focus point 12a and received by a first feeder horn 20a. In the same manner incoming waves 11b and 11c are led to focus points 12b, 12c and received by feeder horns 20b, 20c respectively. The signals received by the feeder horns 20a, 20b, 20c are led to not shown receivers.

Of course the system according to fig. 2 can also work as transmitter antenna, if transmitters are connected to the feeder horns 20a, 20b, 20c.

According to the invention the three-dimensional lens 10 is produced by wrapping a dielectric material, preferably shaped as a thread. This is in principle shown in fig. 3.

Starting at the center point of a Lens 10' to be produced, a dielectric thread 21 is wrapped around the center point. Said thread has at least initially a relative dielectric constant $E = 2.0$. With an increasing distance from the center point the effective relative dielectric constant $E(r)$ of the lens 10' to be produced decreases according to the formula (1).

The effective relative dielectric constant may be varied by a variation of the relative dielectric constant E of the thread. This could be achieved e.g. by a variation of the chemical composition or by a variation of the density of said thread with length. A variation of density with length could be achieved e.g. by a variation of pressure, proceeded by a press arranged before the lens 10' to be produced.

Another possibility of variation of the relative dielectric constant E may be achieved by a thread, created by several strands, whereby the number and/or the relative dielectric constant E of said strands may vary with length.

It is still another possibility to vary the effective dielectric constant E by a variation of the amount of trapped air ($E = 1$).

This might be realized e.g. by a variation of the thickness of the thread, whereby the amount of trapped air is increased and thereby the effective relative dielectric constant is decreased.

It is another possibility to use a crimped thread, e.g. like it is shown in fig. 4a or 4b, which might be stretched by a variation of a stretching force used.

The dielectric constant of the thread may also be varied along the length with the aid of a metallic paint. In this case a low density dielectric thread of constant dielectric constant is used and as it is wrapped into the shape of the lens to be produced small areas of the thread are painted at a separation necessary to give the correct dielectric constant profile. That means for a desired value of the effective refraction index the thread used is painted with a paint, which may be metallic. Thickness, density or/and intensity of this paint may be varied. This is a simple method and will result in a relatively light lens.

It is to be said, that electromagnetic scattering by individual strands of the thread can be made negligible by keeping the radial dimensions of the thread 21 small.

Versions of the preferred embodiment may contain at least one of the following variations:

- instead of a thread, the material with the given refraction index may have any other appropriate shape, e.g. like a strip, ribbon, or the like
- by using an appropriate dielectric material, the lens to be produced may be able to refract other electromagnetic waves, such as visible or infrared light,
- by an appropriate wrapping process, lenses with non-spherical shapes may be produced,
- the lens to be produced may have any desired relation ship between the effective dielectric constant $E(r)$ or the refraction index respectively and the normalized radius r/a , e.g. in that way, that the focus

- point 12 is inside or outside of the surface of the lens,
- the wrapping process may start at the surface of a core, which itself might have a variation of the refraction index and might be located around the center point,
 - several threads may be used, one after the other and/or at the same time,
 - by using a material with an appropriate refraction index even lenses, which are able to refract any other waves, e.g. acoustic waves, may be produced,
 - a bonding agent may be used, which e.g. might be wrapped with the dielectric thread and when cured at an elevated temperature forms a more solid lens. Of course, it might also be possible to dip the lens to be produced into an appropriate bonding agent during or/and after the wrapping process.

The invention presents a method for the fabrication or production of three-dimensional lenses with a variable effective refraction index by wrapping a material with a given refraction index, which may be constant or may vary with length. It is preferred, that said material has the shape of a thread, which might be cylindrical.

The preferred shapes of the lens to be produced are spherical or semi-spherical. The latter one can be achieved by an appropriate wrapping process or by cutting the spherical shape.

By the inventive method it is possible to produce the said lenses with a smooth varying of the refraction index.

Claims

1. Method for the fabrication of lenses (10) with a refractive index varying in three dimensions, characterized in that a material (21) with a given refractive index is wrapped into the final shape of the lens (10) to be produced.
2. Method according to claim 1, characterized in that the material (21) with the given refractive index is shaped as a thread.
3. Method according to claim 1 or 2, characterized in that the final shape of the lens (10) is spherical.
4. Method according to one of the claims 1 to 3, characterized in that the lens (10) to be produced is a Luneburg-type or Eaton-Lippmann-type lens.
5. Method according to one of the claims 1 to 4, characterized in that the material (21) with the given refractive index used has an actual change in the refractive index.
6. Method according to claim 5 characterized in that said thread (21) itself is created by several strands and the actual change in the refractive index is achieved by a variation of the refractive index and/or the number of said strands.
7. Method according to one of the claims 2 to 6, characterized in that the thread (21) used has a changing diameter with length.
8. Method according to one of the claims 1 to 7, characterized in that the material (21) with the given refractive index is a dielectric material.
9. Method according to one of the claims 1 to 8, characterized in that the material (21) to be wrapped is crimped.
10. Method according to claim 9, characterized in that a variation of the refractive index is achieved by stretching the crimped material with a given variable force.
11. Method according to one of the claims 1 to 10, characterized in that a bonding agent is used, which is wrapped with the material (21) with a given refractive index.
12. Method according to one of the claims 1 to 11, characterized in that a bonding agent is used, in which the lens (10) to be produced is dipped in during or/and after wrapping.
13. Method according to one of the claims 1 to 12, characterized in that small areas of the material (21) to be wrapped are painted at a separation necessary to give the correct dielectric constant profile.



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- several threads may be used, one after the other and/or at the same time,
- by using a material with an appropriate refraction index even lenses, which are able to refract any other waves, e.g. acoustic waves, may be produced,
- a bonding agent may be used, which e.g. might be wrapped with the dielectric thread and when cured at an elevated temperature forms a more solid lens. Of course, it might also be possible to dip the lens to be produced into an appropriate bonding agent during or/and after the wrapping process.

The invention presents a method for the fabrication or production of three-dimensional lenses with a variable effective refraction index by wrapping a material with a given refraction index, which may be constant or may vary with length. It is preferred, that said material has the shape of a thread, which might be cylindrical.

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Patentansprüche

1. Verfahren zur Fertigung von Linsen (10) mit einem in drei Dimensionen variierenden Brechungsindex, dadurch gekennzeichnet, daß ein Material (21) mit einem bestimmten Brechungsindex in die endgültige Form der herzustellenden Linse (10) gewickelt wird.
2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das Material (21) mit dem bestimmten Brechungsindex die Form eines Fadens aufweist.
3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die endgültige Form der Linse (10) sphärisch ist.
4. Verfahren nach einem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß die herzustellende Linse (10) eine Linse des Typs Luneburg oder des Typs Eaton-Lippmann ist.
5. Verfahren nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß das verwendete Material (21) mit dem bestimmten Brechungsindex eine tatsächliche Änderung im Brechungsindex aufweist.
6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß der Faden (21) selbst aus mehreren Litzen geschaffen ist und die tatsächliche Änderung im Brechungsindex durch eine Variation des Brechungsindex und/oder der Anzahl der Litzen erreicht wird.
7. Verfahren nach einem der Ansprüche 2 bis 6, dadurch gekennzeichnet, daß der verwendete Faden (21) einen sich mit der Länge ändernden Durchmesser aufweist.
8. Verfahren nach einem der Ansprüche 1 bis 7, dadurch gekennzeichnet, daß das Material (21) mit dem bestimmten Brechungsindex ein dielektrisches Material ist.
9. Verfahren nach einem der Ansprüche 1 bis 8, dadurch gekennzeichnet, daß das zu wickelnde Material (21) gefaltet (gecrimpt) ist.
10. Verfahren nach Anspruch 9, dadurch gekennzeichnet, daß eine Variation des Brechungsindex dadurch erreicht wird, daß das gecrimpte Material mit einer bestimmten variablen Kraft auseinandergezogen wird.
11. Verfahren nach einem der Ansprüche 1 bis 10, dadurch gekennzeichnet, daß ein Haftmittel verwendet wird, welches mit dem Material (21) mit einem bestimmten Brechungsindex gewickelt wird.
12. Verfahren nach einem der Ansprüche 1 bis 11, dadurch gekennzeichnet, daß ein Haftmittel verwendet wird, in welches die herzustellende Linse (10) während des Wickelns oder/und nach dem Wickeln eingetaucht wird.
13. Verfahren nach einem der Ansprüche 1 bis 12, dadurch gekennzeichnet, daß kleine Bereiche des zu wickelnden Materials (21) mit einem für das Erreichen des korrekten dielektrischen Konstanten-Profiles notwendigen Abstand gefärbt sind.

Revendications

1. Procédé pour la fabrication de lentilles (10) avec un indice de réfraction qui varie en trois dimensions, caractérisé en ce qu'un matériau (21) avec un indice de réfraction donné est enroulé pour former la forme finale de la lentille (10) à produire.
2. Procédé selon la revendication 1, caractérisé en ce que le matériau (21) avec l'indice de réfraction donné est formé comme un fil.
3. Procédé selon la revendication 1 ou 2, caractérisé en ce que la forme finale de la lentille (10) est sphérique.
4. Procédé selon l'une des revendications 1 à 3, caractérisé en ce que la lentille (10) à produire est une



lentille, de type Luneburg ou de type Eaton-Lippmann.

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5. Procédé selon l'une des revendications 1 à 4, caractérisé en ce que le matériau (21) avec l'indice de réfraction donné utilisé a un changement effectif dans l'indice de réfraction.
 6. Procédé selon la revendication 5, caractérisé en ce que ledit fil (21) lui-même est créé par plusieurs torons et le changement effectif dans l'indice de réfraction est obtenu par une variation de l'indice de réfraction et/ou du nombre des torons.
 7. Procédé selon l'une des revendications 2 à 6, caractérisé en ce que le fil (21) utilisé a un diamètre changeant avec la longueur.
 8. Procédé selon l'une des revendications 1 à 7, caractérisé en ce que le matériau (21) avec l'indice de réfraction donné est un matériau diélectrique.
 9. Procédé selon l'une des revendications 1 à 8, caractérisé en ce que le matériau (21) à enrouler est ondulé.
 10. Procédé selon la revendication 9, caractérisé en ce qu'une variation de l'indice de réfraction est obtenue en étirant le matériau ondulé avec une force variable donnée.
 11. Procédé selon l'une des revendications 1 à 10, caractérisé en ce qu'un agent adhésif est utilisé qui est enroulé avec le matériau (21) avec un indice de réfraction donné.
 12. Procédé selon l'une des revendications 1 à 11, caractérisé en ce qu'un agent adhésif est utilisé dans lequel la lentille (10) à produire est trempée pendant ou/et après l'enroulement.
 13. Procédé selon l'une des revendications 1 à 12, caractérisé en ce que de petites zones du matériau (21) à enrouler sont peintes à une séparation nécessaire pour donner le profil à constante diélectrique correct.