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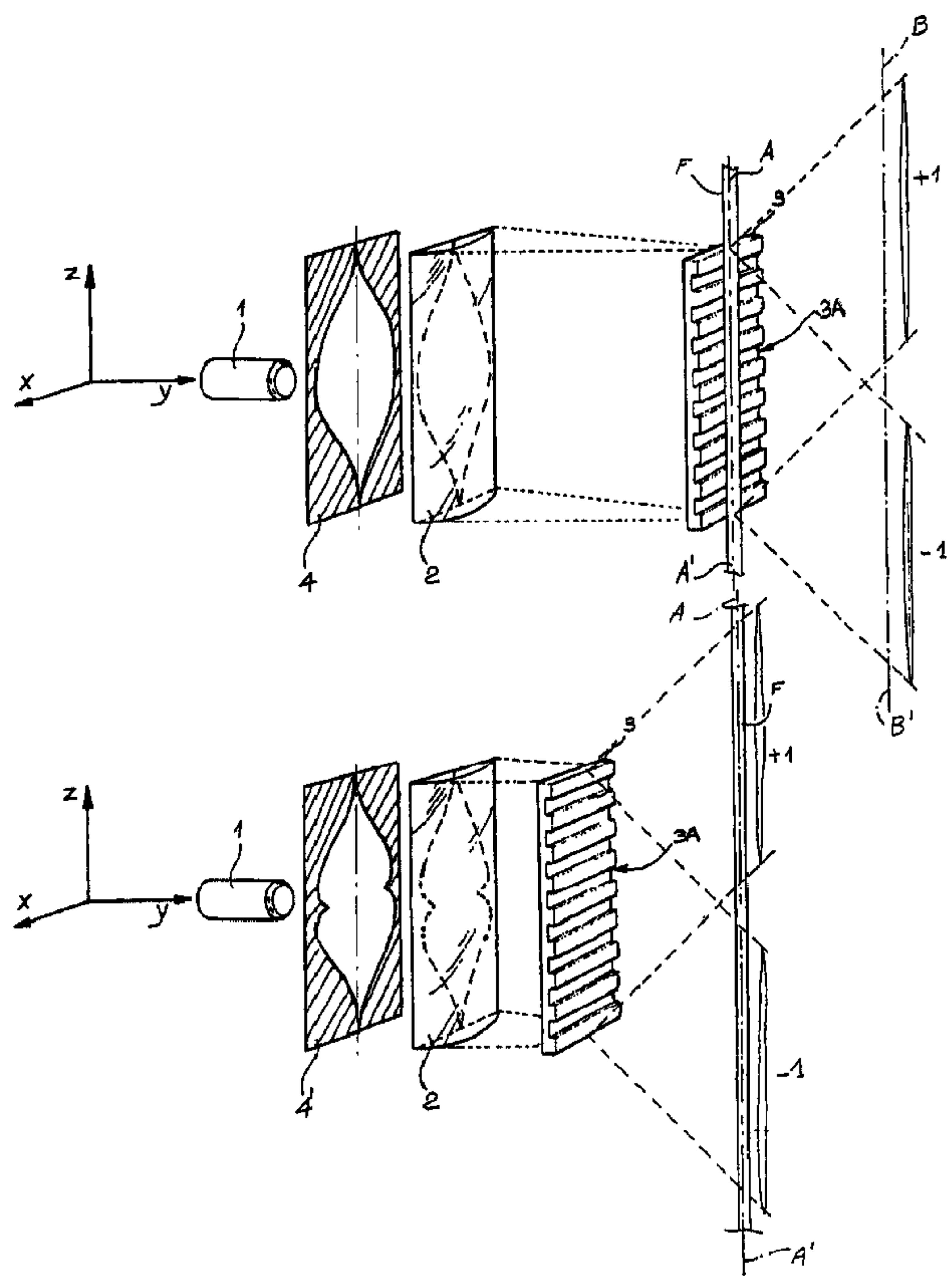
(54) Titre : METHODE ET DISPOSITIF DE REALISATION DE GRILLE DE DIFFRACTION DANS LES FIBRES OPTIQUES
(54) Title: METHOD OF AND DEVICE FOR OPTICAL FIBRE GRATING FABRICATION



(57) Abrégé/Abstract:
An optical fibre is sequentially submitted to a first and a second exposure to the grating writing radiation. The first exposure is performed by positioning the fibre in proximity of a phase mask, so as to expose the same fibre to a radiation of which the intensity is spatially modulated by the interference fringes generated by the phase mask itself. The second exposure is

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(57) **Abrégé(suite)/Abstract(continued)**:
performed with the fibre spaced apart from the phase mask in the propagation direction of the writing radiation by a sufficient distance in order the radiation incident on the fibre is substantially defined by the first diffraction orders generated by the phase mask in a situation in which there is basically no reciprocal interference among said first orders.

ABSTRACT

An optical fibre is sequentially submitted to a first and a second exposure to the grating writing radiation. The first exposure is performed by positioning the fibre in proximity of a phase mask, so as to expose the same fibre to a radiation of which the intensity is spatially modulated by the interference fringes generated by the phase mask itself. The second exposure is performed with the fibre spaced apart from the phase mask in the propagation direction of the writing radiation by a sufficient distance in order the radiation incident on the fibre is substantially defined by the first diffraction orders generated by the phase mask in a situation in which there is basically no reciprocal interference among said first orders.

METHOD OF AND DEVICE FOR OPTICAL FIBRE GRATING FABRICATION

This invention relates to the techniques of fabricating optical fibre gratings, such as optical fibre Bragg gratings.

For an general overview of such techniques reference can be made to the work by T. Erdogan, entitled “Fiber Grating Spectra”, published on Journal of Lightwave Technology, Vol. 15, No. 8, August 1997, pages 1277 to 1294.

In particular the invention relates to the technique known as apodisation, also mentioned in the previous work and consisting in the essence in inducing along the fibre axis a refractive index increase whose envelope exhibits a particular spatial distribution such that a constant average refractive index is obtained. The envelope has a lenticular or eye behaviour (for instance with a distribution of the type termed as “raised Gaussian”).

Different apodisation techniques are described, for example, in the article by R. Kashyap, A. Swanton and P. J. Armes: "Simple technique for apodising chirped and unchirped fibre Bragg gratings", Electronics Letters, June 10 1996, Vol. 32, No 13, pages 1226-1227; in the paper by M. Guy, J. Lauzon, M. Palletier, P. Ehbets and D. Asselin: "Simple and flexible technique for spectrally designing all-fibre filter and apodizing fibre gratings", presented at the ECOC’97 conference, September 22 to 25, 1997, Conference Publication No 448, IEE 1997, pages 195 to 198; in the paper by J.J. Pan, F.Q. Zhou, Y. She, S.X. Li: “Effective apodized Phase Mask For Optimum FBGs”, presented at the Cleo Europe ’98 conference, September 14 to 18, 1998, Glasgow, Scotland, as well as in the paper by H. Singh and M. Zippin: "Apodized fiber Bragg gratings for DWDM applications using uniform phase masks", presented at the

ECOC '98 conference, September 20 to 24, 1998, Madrid, Spain.

All the apodisation techniques described in the above-cited works involve, to a greater or lesser extent, some drawbacks owing to factors such as the complexity/high costs of implementing the apodisation process and/or inaccuracies mainly due to the need of removing the mask and/or longitudinally displacing the fibre or in any case of acting on the fibre itself: said inaccuracies have corresponding negative effects on the characteristics of the grating fabricated in the fibre.

One of the techniques to which reference has been made requires moreover the illumination of the fibre on both sides, what causes important limitations to the structure of the photo-induction optical bench.

This invention aims at providing a technique for the fabrication of apodised gratings in an optical fibre that is not affected by the above drawbacks and can be implemented in a simple, accurate and economical way.

According to this invention, such aim is achieved by virtue of a method having the characteristics described herein. The invention also concerns the related device.

The invention will now be described purely by way of a non-limiting example with reference to the accompanying drawings, wherein:

- Fig. 1 and Fig. 2 schematically show two subsequent phases of implementation of the method according to the invention,
- Fig. 3 shows a variation of Fig. 2,
- Figs. 4 to 10 show typical behaviours of the intensity of the writing radiation and/or of the refractive index of the fibre obtained in the subsequent phases of the method, and
- Fig. 11 schematically illustrates a possible embodiment of a device for implementing the method.

To fabricate a grating such as a Bragg grating in an optical fibre F, the embodiment of the invention being preferred at present require the use of the following elements:

- a source 1 for the generation of the electromagnetic radiation used for writing the grating in the fibre: it is a monochromatic ultraviolet source (for example an Argon laser, with frequency doubling, so as to have an emission wavelength in the range of about 244 nanometers) having a bi-dimensional profile of the beam intensity that can be for instance, of approximately Gaussian type,
- a lens 2, typically a cylindrical lens, that allows focussing the writing beam outgoing from the source 1 and concentrating it on a focussing axis A-A' which extends in the

direction of the z-axis of a Cartesian reference system, shown in Figs. 1, 2 and 3,

- a phase mask 3, to be located between the lens 2 and the fibre F, and
- a first and a second interchangeable diaphragms 4, 4', destined to be located between the source 1 and the cylindrical lens 2, according to the criteria that will be further illustrated hereinafter.

The elements 1, 2, 3, 4 (and 4') previously described are mutually aligned along the general direction of propagation of the radiation generated by the source 1. Such propagation direction corresponds to the y-axis of the reference system shown in Figs. 1, 2 and 3. Diaphragm 4 may also be dispensed with, as will be seen later.

The criteria governing the choice of source 1, lens 2 and phase mask 3 are commonly known in the art and therefore do not require to be illustrated here in more detail, also because they are not significant for understanding the invention. This applies also in particular as far as the characteristics of the phase mask 3 are concerned. Said phase mask is provided, on its surface 3a which is destined to face the fibre F, with an array of rectilinear surface etchings, usually arranged in an orthogonal direction to the axis A-A' and therefore, as will be better seen hereinafter, to the axis of the fibre F.

The method according to the invention envisages in the essence a double exposure of the fibre F to the radiation generated by the source 1, without the removal of mask in both phases.

The first exposure is performed according to the criteria illustrated in Fig. 1: the fibre F is arranged along the focal axis A-A' of the lens 2 and the phase mask 3 is located in proximity – usually in direct contact – of the fibre F and lies in a plane orthogonal to the y-axis (i. e. the direction of propagation of the writing radiation arriving from the source 1 and concentrated by the lens 2.

Still in Fig. 1, references "+1" and "-1" schematically show the corresponding first orders of diffraction of the phase mask, that present an interference region in which the fibre F must be located so as to originate the desired effect of intensity modulation of the writing radiation incident on the fibre, with the consequent corresponding modulation of the refractive index of the same fibre.

As already mentioned, the beam of the ultraviolet radiation outgoing from the source 1 usually has an approximately Gaussian bi-dimensional intensity profile. Before being concentrated, through the lens 2, on the core of the fibre F, the beam is shaped by the diaphragm 4 that has the most appropriate form for the specific case. The diaphragm 4 is so designed (in a known way) that it allows the radiation beam to have, in the focus of the cylindrical lens 2 and in the direction parallel to the focal axis A-A' (hence along the axis of the fibre core) an intensity profile that can be represented by the desired mathematical function.

Fig. 1 shows, by way of example, a diaphragm with an opening defined by two Gaussian curves, symmetrical with respect to an axis oriented according the z-axis, so as to ideally obtain a Gaussian profile of the light intensity along the optical axis A-A' in the absence of the phase mask 3. This profile can be seen in Fig. 4. Fig. 5 shows instead the effect of the phase mask 3, positioned in contact with or in proximity of the fibre F. In practice the mask produces a modulation of the intensity of the writing radiation incident on the fibre core, causing in such core a modulation of the refractive index with a behaviour of the type represented in Fig. 7, where the envelope and the average value have a substantially Gaussian behaviour.

In Figs. 4 and 5, as well as in all the subsequent Figures, the abscissa axis of the diagrams actually corresponds to z-axis of the Cartesian reference system of Figs. 1 to 3. In particular, Fig. 6 shows the behaviour of the radiation intensity, as it may be detected in the configuration of Fig. 1 along a straight line B-B' parallel to the axis A-A' and aligned or substantially aligned with the same axis A-A' in the direction y of propagation of the writing radiation. The distance between the straight lines B-B' and A-A' is bound to the length of the grating. For instance, the straight line B-B' may be located at a distance of about 10-20 mm from the axis A-A' for a grating 5-10 mm long, respectively. It is in practice a sufficient distance to allow that, in coincidence with the straight line B-B', there are no longer the effects of reciprocal interference between the diffraction orders +1 and -1 induced by the presence of the phase mask. It will be appreciated that along this straight line the intensity profile of the radiation that can be detected corresponds in practice to two bells, each of them with a Gaussian profile (in the example shown) with at the most a slight additive effect, which is practically negligible, in coincidence with the overlapping of the reciprocally internal tails of both bells.

It will be further appreciated that the use of the diaphragm 4, albeit preferred in the exemplary embodiment illustrated here, is in no way mandatory. This applies at least in the event in which the spatial distribution of intensity of the radiation generated by the source 1 exhibits a profile regarded as satisfactory in itself (whether Gaussian or not). Obviously, if use of an intensity profile different from that of the source is desired for fibre writing, a diaphragm 4 will be adopted such as to originate such a different profile.

In the second phase of the method, represented - according to two possible embodiments - in Figs. 2 and 3, a relative displacement is performed between the fibre F and the phase mask 3 so that the fibre F lies in a region in which the diffraction orders +1 and -1 of phase mask 3 no longer interfere. Fig. 6 refers to those conditions.

This result can be achieved by keeping the mask 3 in the focus of lens 2 and displacing the fibre F so that its axis coincides with straight line B-B', as shown in Fig. 3. An equivalent and presently preferred solution is shown in Fig. 2: the fibre F is kept in the focus of the cylindrical lens 2 whilst the mask 3 is positioned in such a way that the axis B-B' of Fig. 1 coincide with A-A'. Regardless of the solution being adopted, the above relative displacement is usually performed with the source 1 switched off, so that during the above displacement the fibre F is not exposed to the writing radiation.

In any case, the above displacement is a relative one, in the sense that the same may be performed by keeping stationary the set-up formed by lens 2 and phase mask 3 (and usually by source 1) and moving the fibre F (as in Fig 3); or by keeping stationary the fibre F and lens 2 and displacing the mask (as in Fig. 2); or yet by displacing both sets of parts involved. The displacements of the fibre and/or of the mask may be performed by means of translation devices of known type, such as micrometric-screw devices, piezoelectric translators, etc. The choice also depends on the extent of the displacement.

The above relative displacement corresponds in practice to a relative spacing apart of fibre F with regard to phase mask 3 in orthogonal direction to the plane of the same mask. It is therefore a displacement that may be performed with accuracy much higher than any longitudinal translation of the fibre F with respect to the phase mask. As already set forth in the introductory part of this description, just the inaccuracies bound to such longitudinal displacement are the reason of the inaccuracies present in some apodisation methods according the known technique.

As far as the practical implementation of such relative displacement is concerned, different solutions are available.

For instance, Fig. 11 shows a positioning device 10 in which the phase mask 3 is mounted on a frame made in the vertical arm of an L-shaped element 101, whereas the fibre F is mounted on a second L-shaped element 102. The horizontal arms of the above elements 101, 102 are then mounted on respective slides 103, 104, sliding on a same horizontal guide 105. It is also possible to remove the slide 103 carrying the mask 3 from the guide 105 or in any case to move it away from the fibre holder 102 to the extent required to allow replacing the phase mask. The actuation elements (typically micrometric screws) of the slides 103, 104 are denoted by 106. The displacement devices mentioned here are quite conventional and do not require to be here described in detail.

Concurrently with the relative displacement of the fibre F and the phase mask 3, in order to proceed to the second phase of exposure of the fibre F to the source 1, the previously used diaphragm 4 (if any) is replaced by a diaphragm 4', so designed as to give rise along the focussing axis A-A' of the lens 2, in the absence of phase mask 3, to a light intensity profile which - if the first exposure has been performed with a Gaussian intensity profile - is of the type illustrated in Fig. 8 and can be defined as complementary-Gaussian. This term indicates a bell-shaped profile whose flanks have a behaviour substantially similar to that of the flank of a Gaussian curve with its vertex coincident with the abscissa axis.

Fig. 9 shows the behaviour of the radiation intensity as it may be detected, during the second exposure phase, along the axis of the fibre F in the presence of the phase mask 3. The effect of presence of the mask is just that of originating, through the diffraction orders +1 and -1, no longer reciprocally interfering, an intensity profile formed by two curves that have an "additively complementary-Gaussian" behaviour.

The term "additively complementary-Gaussian" indicates the fact that, as may be better noted in Fig. 9, the intensity profiles corresponding to the two diffraction orders +1 and -1 (each substantially corresponding to a profile of the type illustrated in Fig. 8) define, in the region S comprised between the two respective maximum values, profiles of which the sum is exactly complementary to a Gaussian profile.

As already said, Fig. 7 represents the behaviour of the refractive index obtained in the core of the fibre F through the first exposure, that has been performed according to the modalities shown in Fig.1.

The effect of the second exposure phase, performed acting with the set-up shown in Fig. 2 or Fig. 3 is therefore that of "adding", to the behaviour of the refractive index shown in Fig. 7, a complementary-Gaussian behaviour of the type obtained in the region S of the intensity diagram of Fig. 9.

The overall result is then the overlapping, in an additive sense, of a complementary-Gaussian to the behaviour of the refractive index represented in Fig. 7, in order to achieve as a final result a behaviour of the type represented in Fig. 10. Here the refractive index of the fibre core has an oscillating behaviour around a given average value (with frequencies defined by the characteristics of the phase mask 3 during the first exposure) and an overall envelope having an eye behaviour of the type commonly called "raised Gaussian". Such a behaviour of the refractive index corresponds, as is known in the art and illustrated in the various prior-art documents mentioned in the introductory part of this description, to the attainment of the desired apodisation effect. It is however evident that the achievement of such a result takes for granted that the "raising" of the refractive index obtained during the second exposure has a sufficient value (in terms of index variation). This requires the corresponding tuning of the intensity of the writing radiation and/or of the exposure time. This operation takes place in any case according to well-known criteria, the description of which is not required here.

It is evident that, while the principle of the invention remains unchanged, the construction details and the embodiments may be considerably varied with respect to what is described and depicted herein, without thereby departing from the scope of the invention itself, as defined in the claims.

In particular the detailed description given above refers to the attainment of refractive index behaviours with a Gaussian envelope: it however wholly evident that the same solution may be adopted by intervening – in a known manner - on the various elements of the system which have been illustrated, so as to achieve the desired apodisation effect also with behaviours of a different type. It follows that what has been previously said regarding the optional and non-mandatory character of the use of the first diaphragm 4 applies - mutatis mutandis - to the second diaphragm 4'.

Furthermore, the method and the devices described here may be applied also to the simultaneous apodisation of gratings which are photo-induced simultaneously on more fibres parallel aligned around the axis A-A', according to the criteria described in EP-A 0 880 042.

CLAIMS

1. A method of fabricating apodised gratings in optical fibres, in which at least one fibre is submitted to a double exposure to a focussed writing radiation through a phase mask comprising the steps of:

a first exposure performed with the phase mask being located in proximity of the fibre and producing interference fringes spatially modulating the intensity of the writing radiation; and

a second exposure performed after the fibre has been spaced apart from the phase mask in the direction of propagation of the writing radiation by such a distance that the fibre lies in a region where the radiation incident on the fibre is substantially defined by the first diffraction orders generated by the phase mask in the practical absence of reciprocal interference among said first orders, the first and second exposure of the fibre to the writing radiation through the phase mask being sequentially performed;

wherein said exposures comprise the operation of focussing said writing radiation by means of a lens along a focussing axis, and wherein, during said first exposure, the fibre is substantially placed in correspondence with said focussing axis within an interference region of the +1st order and the -1st order diffraction beam directly adjacent the phase mask, and wherein for the second exposure, the relative spacing of the phase mask and the fibre is increased in an orthogonal direction to the plane of the phase mask while keeping the fibre longitudinally stationary.

2. The method according to claim 1, further comprising the operation of shaping the intensity profile of said writing radiation, at least during said second exposure, by a diaphragm.

3. The method according to claim 2, characterised in that for said second exposure, said diaphragm is chosen in such a way as to give a profile to the radiation intensity defined by said first orders such that the intensity profiles corresponding to the two diffraction orders +1 and -1 in a region comprised between the two respective maximum values define profiles of which the sum is complementary to a Gaussian

profile.

4. The method according to any of claims 1 to 3, wherein during said second exposure the fibre is substantially located in correspondence with said focussing axis and the displacement between the fibre and the phase mask is obtained by translation of said phase mask.

5. The method according to any of claims 1 to 3, wherein during said second exposure, the fibre is placed along a straight line that is parallel to and spaced apart from said focussing axis.

6. The method according to any of claims 1 to 5, wherein during said first exposure the fibre is positioned in contact with the phase mask.

7. The method according to any of claims 1 to 6, further comprising the operation of inhibiting the action of said writing radiation on the fibre between said first and said second exposure.

8. The method according to any of claims 1 to 7, wherein said writing radiation exhibits a bi-dimensional intensity profile that is approximately Gaussian.

9. The method according to any of claims 1 to 8, wherein one of said first and second exposures is performed simultaneously on a plurality of fibres, arranged side by side on the same plane.

10. The method according to any of claims 1 to 9, wherein said writing radiation is focussed along said focussing axis by means of a cylindrical lens.

11. A device for fabricating apodised gratings in optical fibres by means of a double exposure of the optical fibre with a focussed writing radiation, comprising, aligned along the general direction of propagation of the writing radiation,

a source of the writing radiation, emitting the writing radiation in a propagation direction;

a phase mask exposed to the writing radiation generated by said source;

a space for positioning the optical fibre in an orientation transversal to the writing radiation propagation direction;

means for the relative positioning of said phase mask and of the optical fibre in which the apodised grating is to be fabricated, said positioning means being arranged to take a first position in which the fibre is positioned in proximity of said phase mask, and a second position in which the fibre is located at a sufficient distance from said phase mask in order the radiation incident on the fibre is substantially defined by the first diffraction orders generated by the phase mask in the substantial absence of reciprocal interference among said first orders; and

a lens adapted to concentrate the radiation generated by said source along a focusing axis;

and wherein in said first position of the positioning means said phase mask is arranged in such proximity of the focussing axis as to be within an interference region of the +1st order and the -1st order diffraction beam directly adjacent the phase mask.

12. The device according to claim 11, wherein the second position of the positioning means is at a distance from said focussing axis, with said fibre kept in correspondence with the focussing axis.

13. The device according to claim 11, wherein the focussing axis is located in said proximity of said phase mask, said first position of the positioning means being such that the fibre is arranged in correspondence with the focussing axis and said second position of the positioning means being such that the fibre is arranged along a straight line that is parallel to and spaced apart said the focussing axis.

14. The device according to any of the claims from 11 to 13, further comprising at least one diaphragm for shaping the bi-dimensional intensity distribution of the writing radiation generated by said source, which diaphragm can be placed between said

source and said phase mask.

15. The device according to claim 14, characterised in that it comprises a first and a second diaphragm for shaping the intensity distribution of the radiation generated by said source, said first and said second diaphragm being reciprocally interchangeable and usable in said first position and in said second position of said positioning means, respectively.

16. The device according to any of claims 11 to 15, characterizd in that the lens is a cylindrical lens.

fig.1

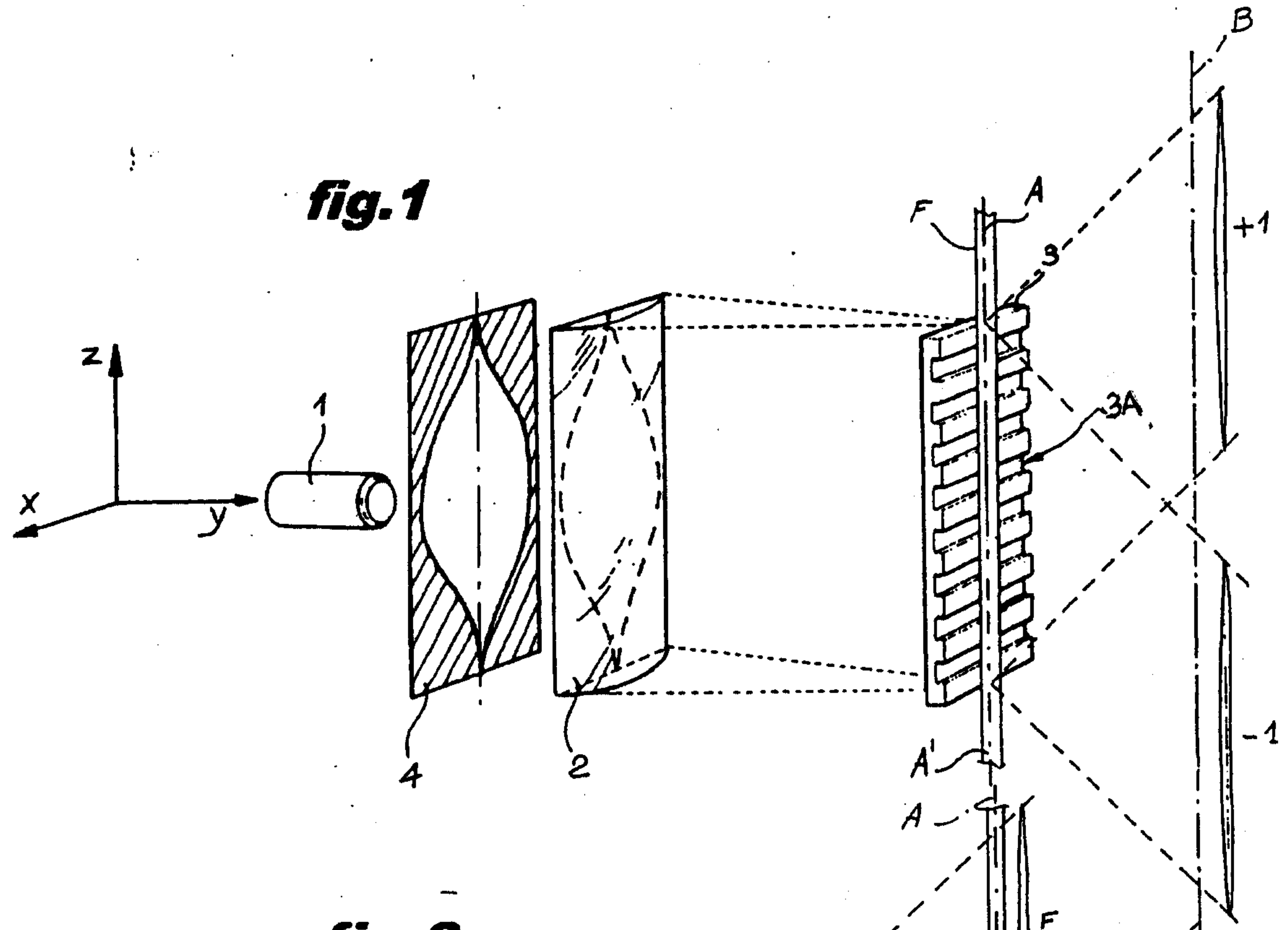


fig.2

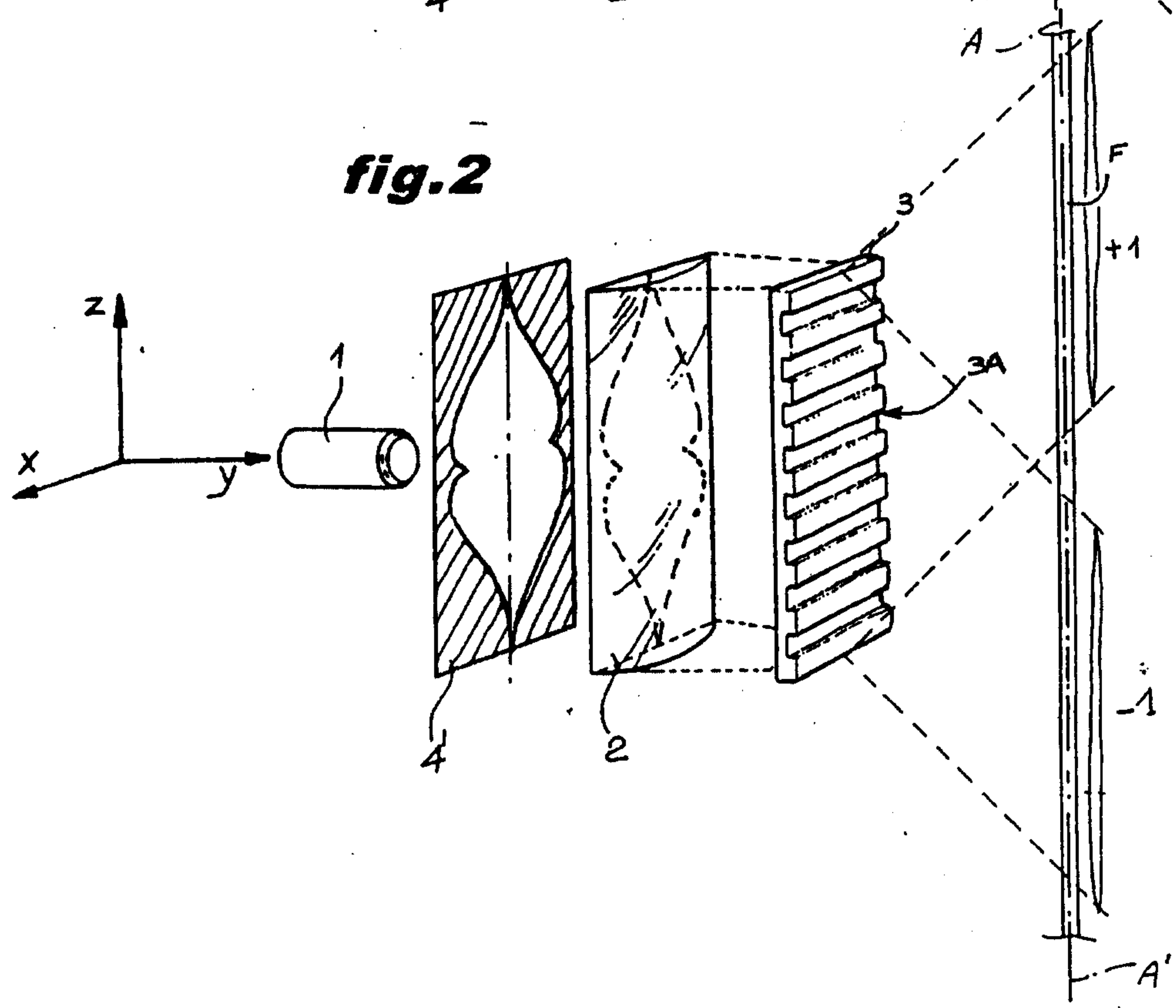


fig.3

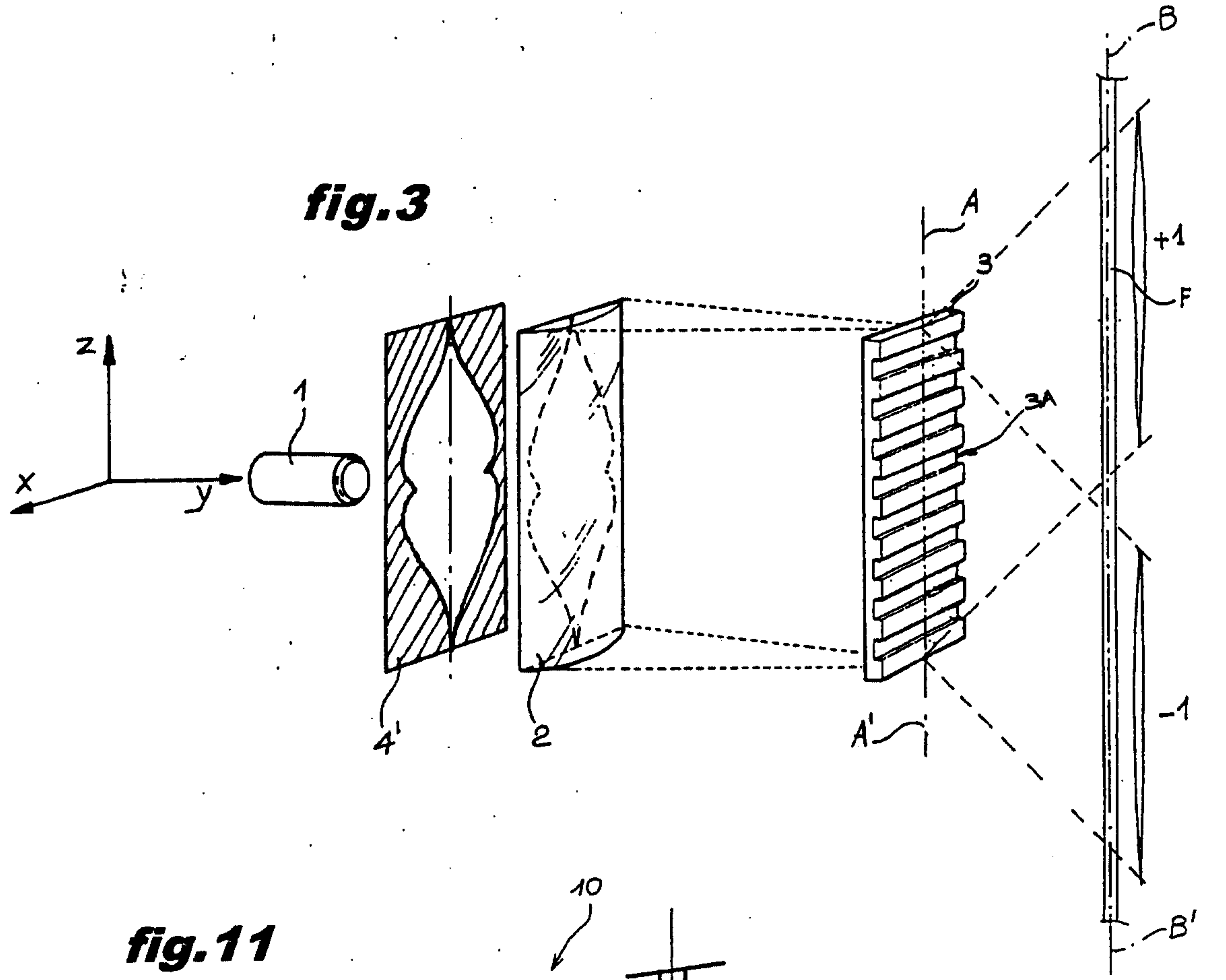


fig.11

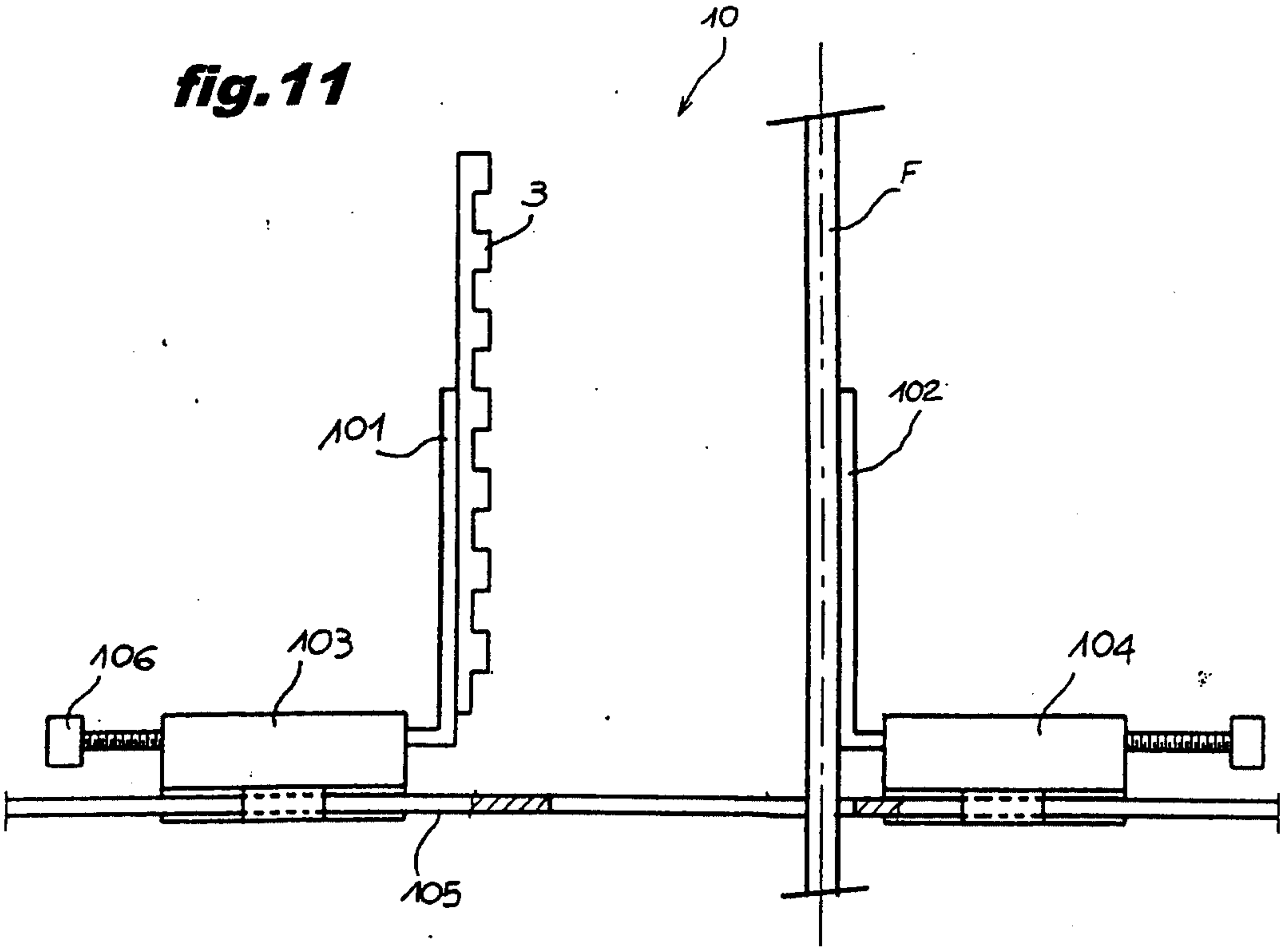


fig.4

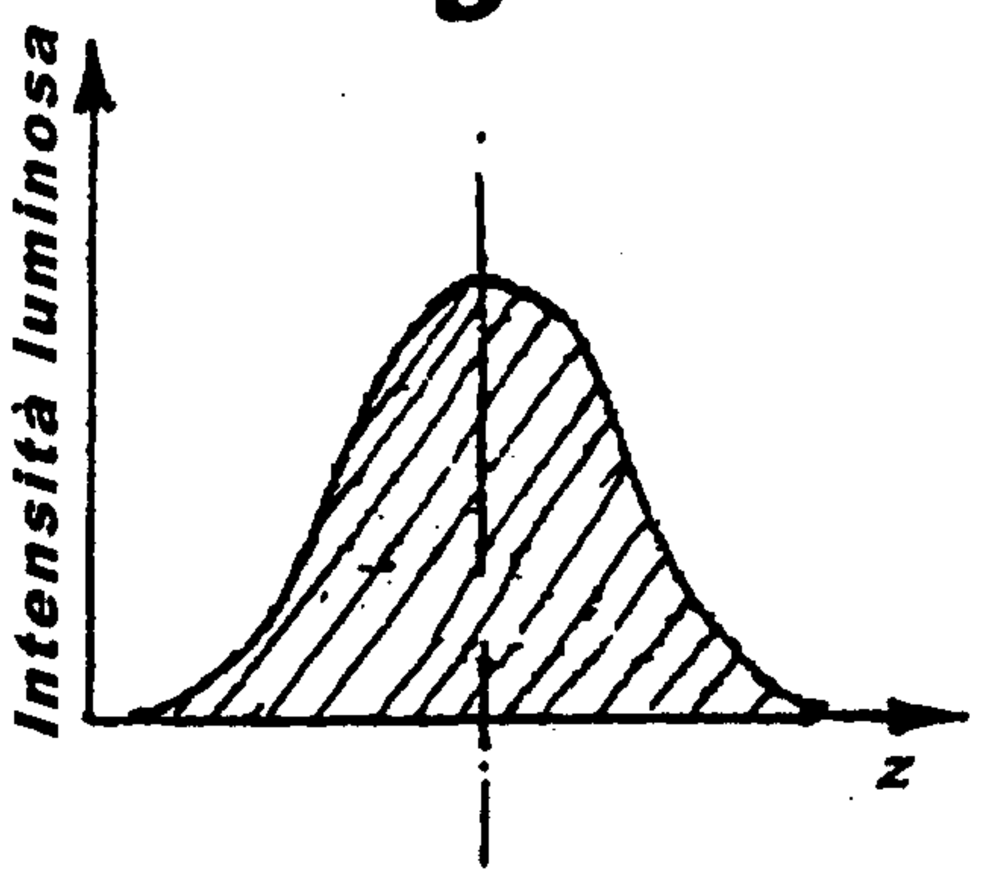


fig.5

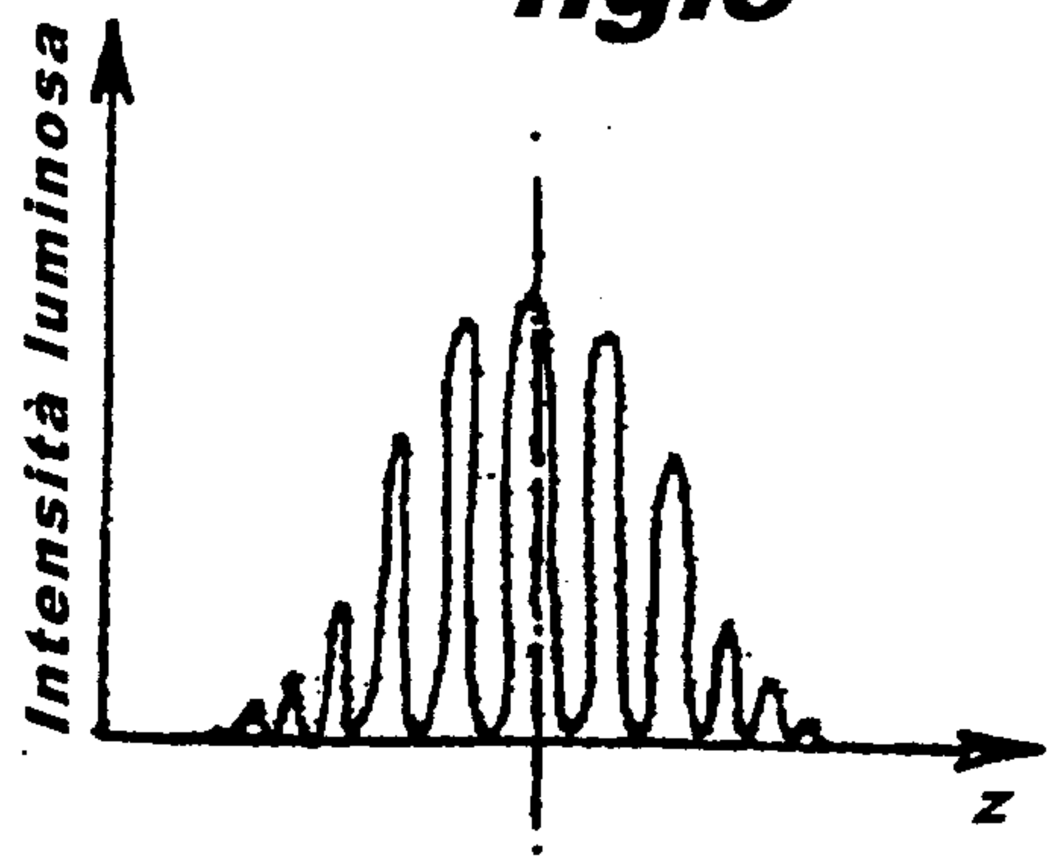


fig.6

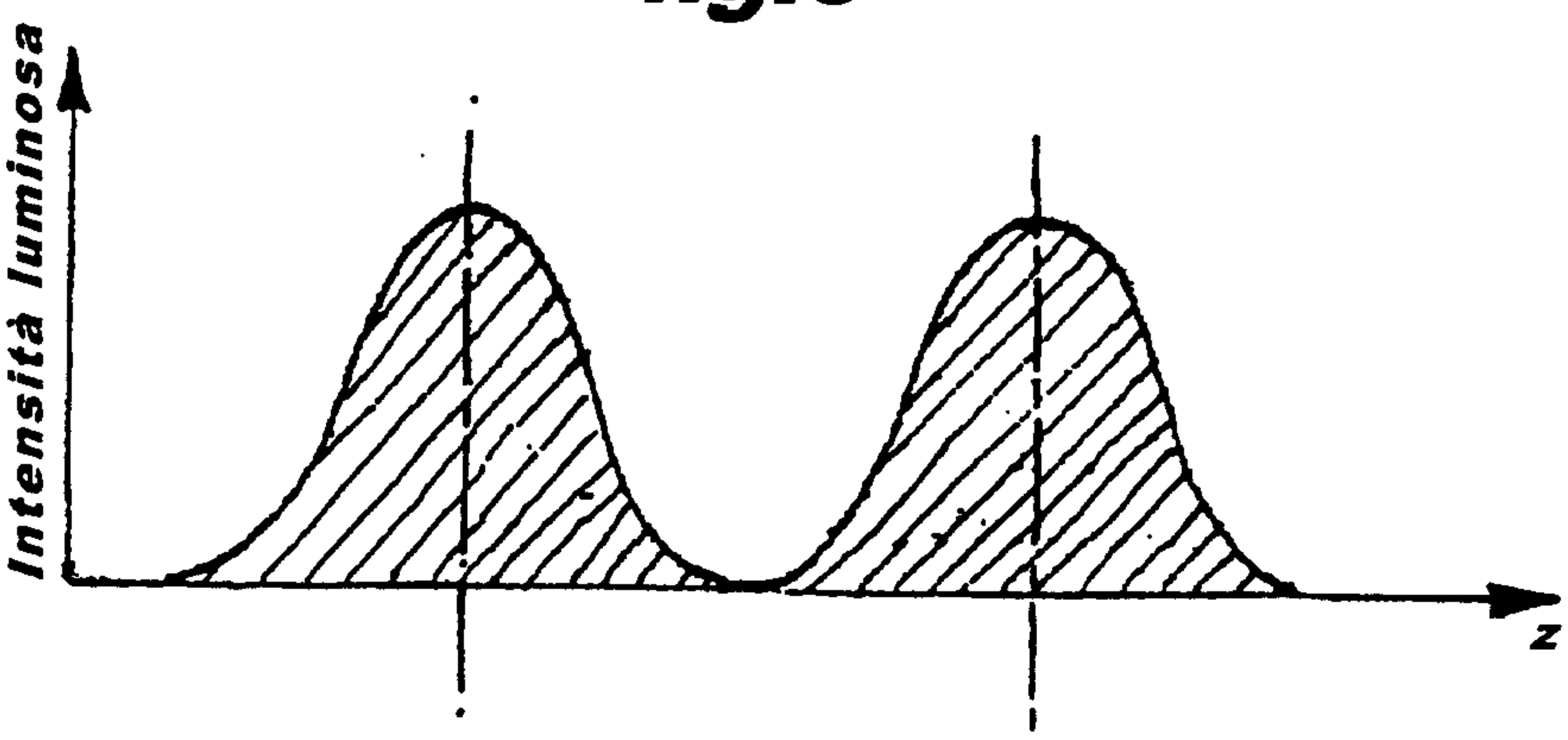


fig.7

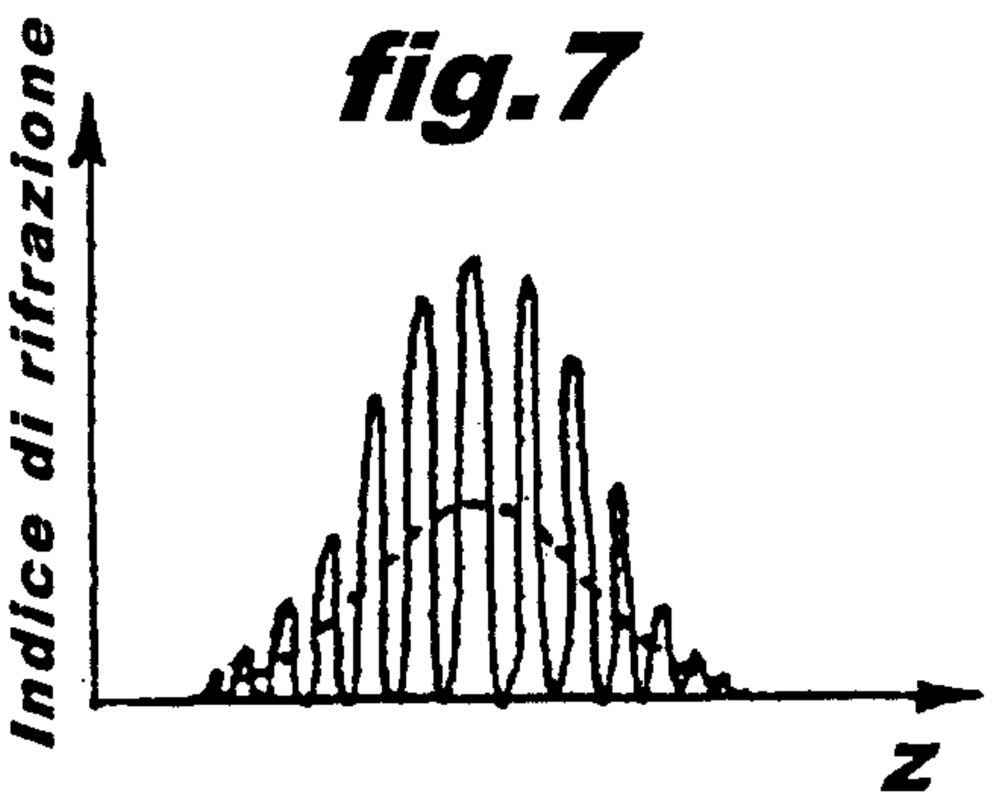


fig.8

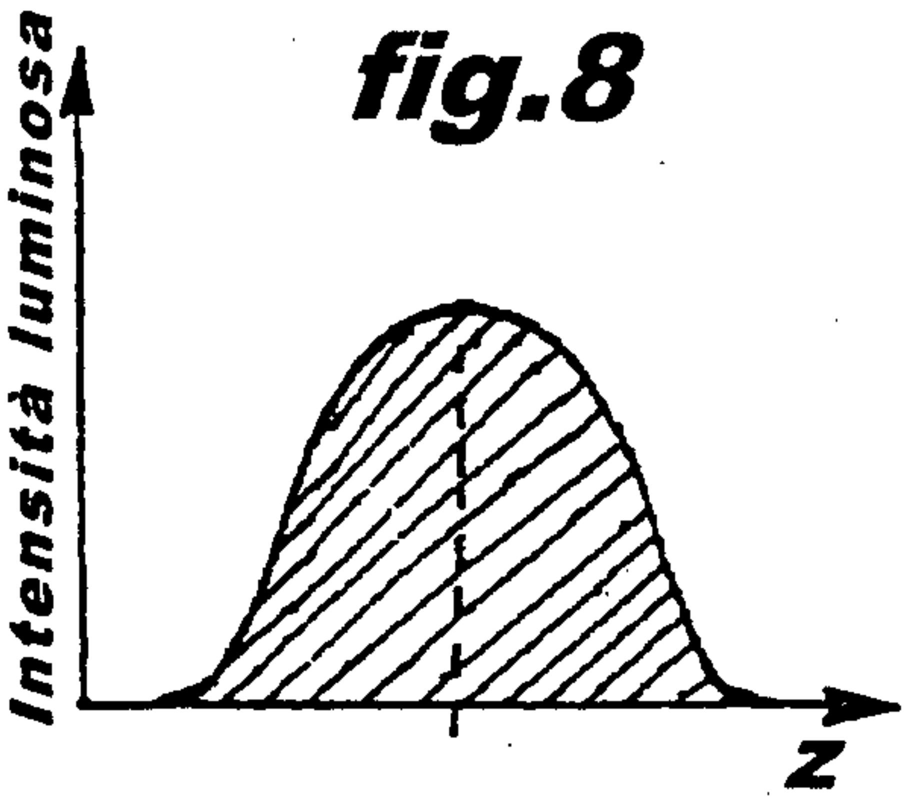


fig.9

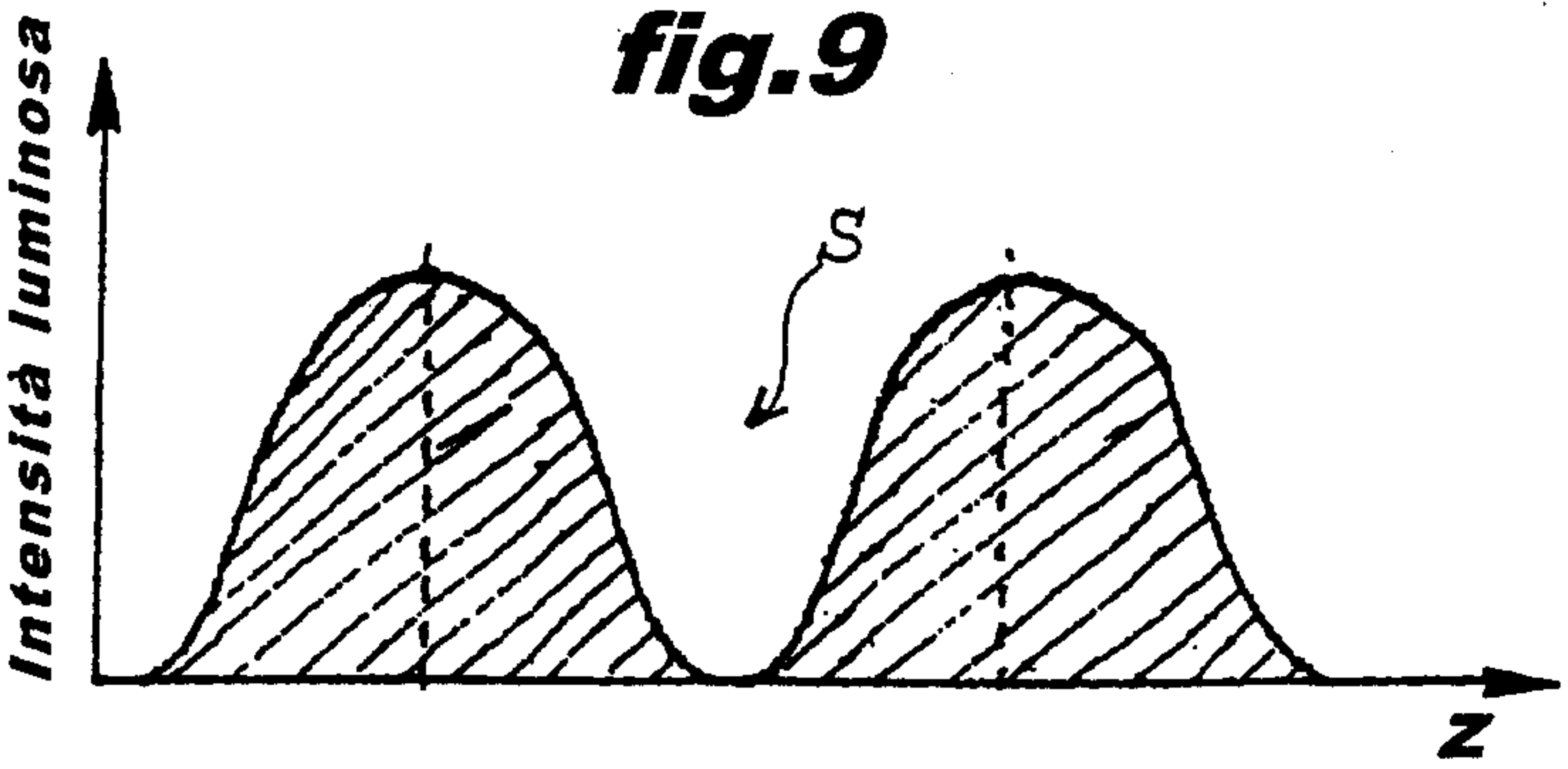
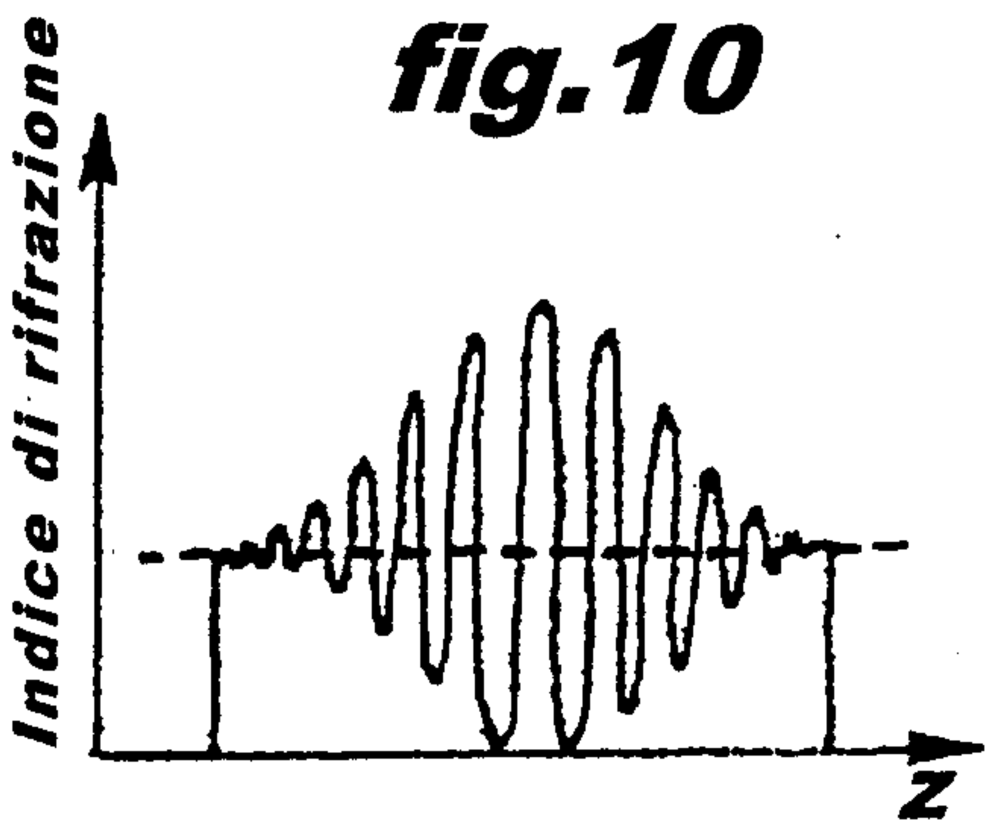
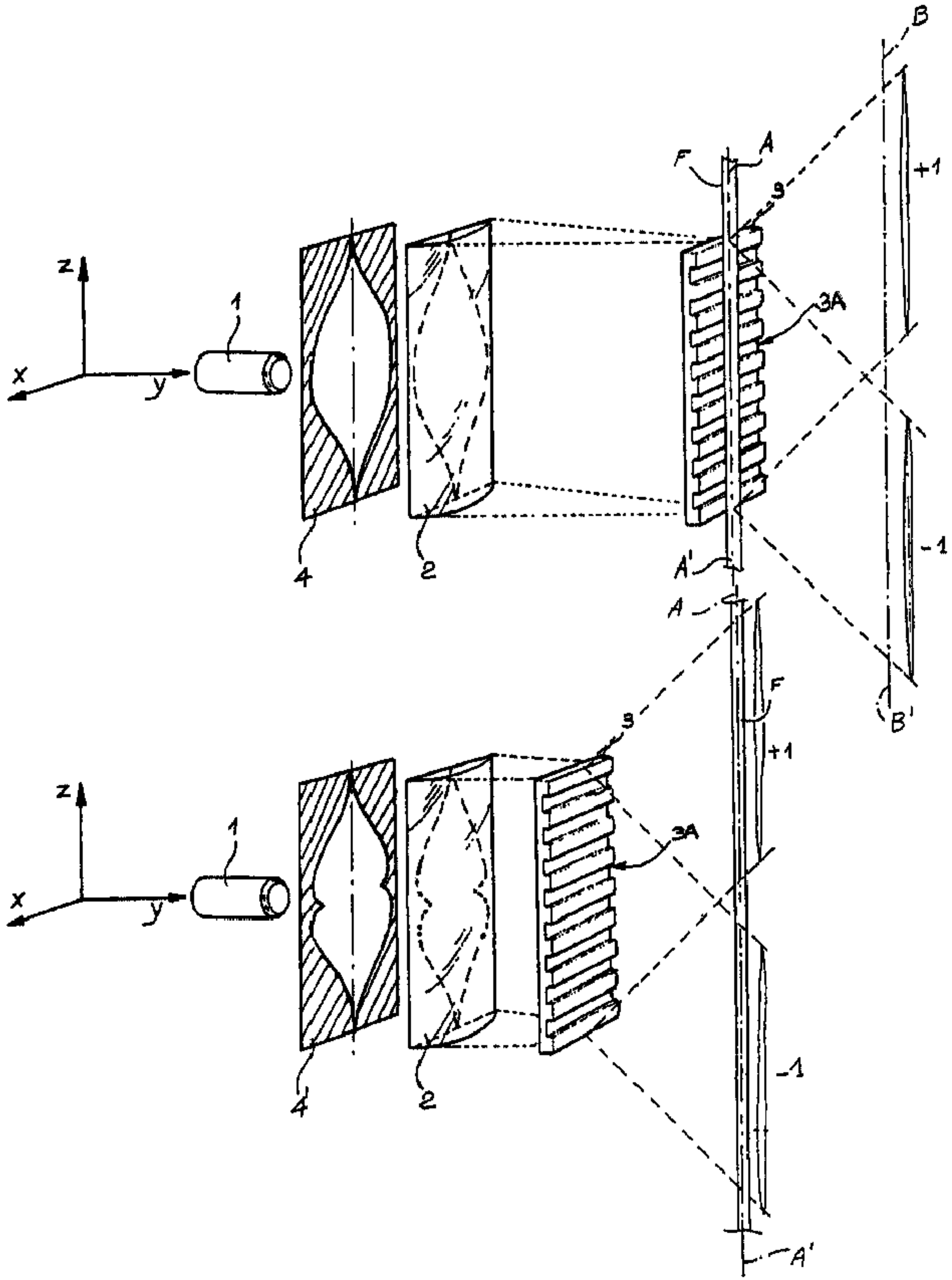


fig.10

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