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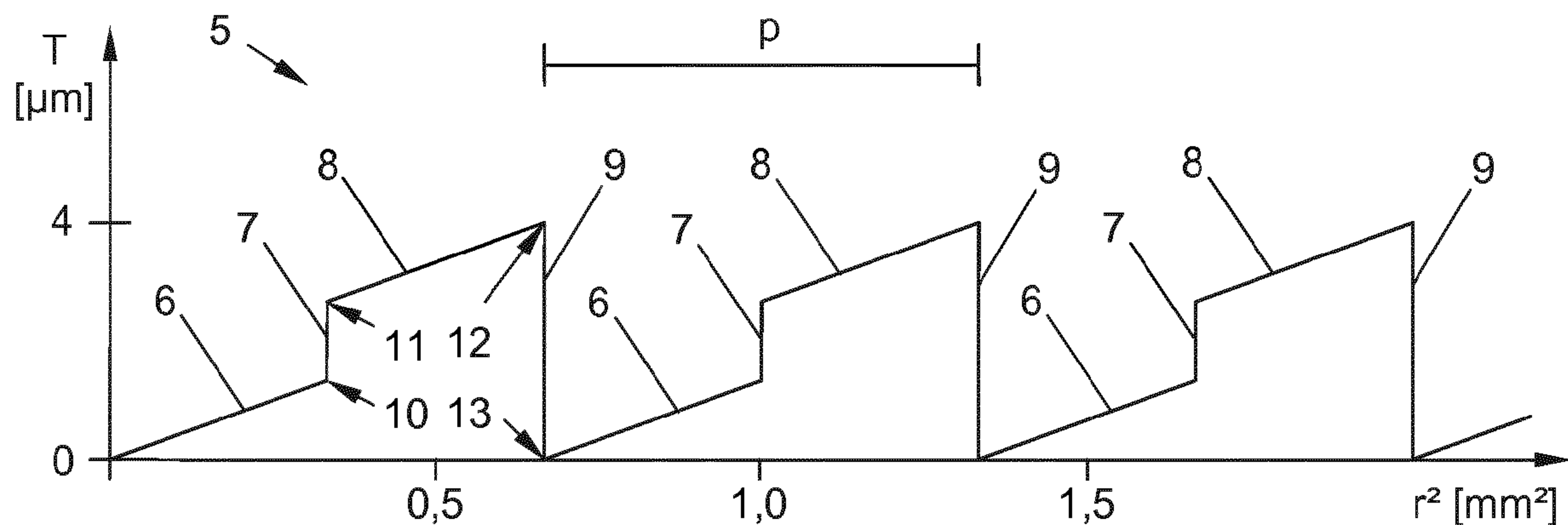


Fig. 4

(57) **Abrégé/Abstract:**

The invention relates to a multifocal lens (1) with a refractive focus (F_r) and with a diffractive structure (5) which, in the radial direction (r) of the lens (1), plotted across the squared radius (r^2), has a periodic profile (6, 7, 8, 9), wherein the profile (6, 7, 8, 9) per period has four adjoining portions (6, 7, 8, 9) which are not differentiable at their connection sites (10, 11, 12, 13), wherein a first portion (9) has a monotonically falling function and the three further portions (6, 7, 8) have a monotonically rising function or vice versa, and wherein the further portion (7), which does not adjoin the first portion (9), has a greater pitch than the other further portions (6, 8).

ABSTRACT

The invention relates to a multifocal lens (1) with a refractive focus (F_r) and with a diffractive structure (5) which, in the radial direction (r) of the lens (1), plotted across the squared radius (r^2), has a periodic profile (6, 7, 8, 9), wherein the profile (6, 7, 8, 9) per period has four adjoining portions (6, 7, 8, 9) which are not differentiable at their connection sites (10, 11, 12, 13), wherein a first portion (9) has a monotonically falling function and the three further portions (6, 7, 8) have a monotonically rising function or vice versa, and wherein the further portion (7), which does not adjoin the first portion (9), has a greater pitch than the other further portions (6, 8).

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MULTIFOCAL LENS

The present invention relates to a multifocal lens with a refractive focal point and a diffractive structure, the structure having a periodic profile in the radial direction of the lens plotted over the squared radius, and the profile having four mutually adjacent portions per period which cannot be differentiated at their junctions.

10 Multifocal intraocular or contact lenses, i.e. lenses with a plurality of focal points, which may for example be used for near and distance vision (bifocal) or near, intermediate and distance vision (trifocal), have been known for several decades and use a very wide range of diffractive structures on
15 a refractive basic lens, in order to provide one or more diffractive focal points in addition to the refractive focal point.

According to documents DE 20 2009 018 881 U1 and EP 2 503 962
20 B1, to produce two diffractive focal points lenses with diffractive structures are used, the profile of which per period has four alternately monotonically rising and monotonically falling portions, i.e. two acute-angled maxima per period. The applicant has recognised that incorporating
25 such structures into the lens not only leads to a plurality of profile peaks which are difficult to manufacture, but also to suboptimal distribution or light yield of the light intensities in the focal points produced.

30 The object of the invention is to provide an improved lens which overcomes the disadvantages of the prior art.

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- According to the invention, the object is achieved with a lens of the above-stated type in which a first portion of the profile falls monotonically and the three further portions
5 rise monotonically, or a first portion rises monotonically and the three further portions fall monotonically, and wherein the further portion which does not adjoin said first portion has a steeper gradient than the other two further portions.
- 10 With the structure according to the invention, a lens is provided whose focal points usable for near, intermediate and distance vision have a higher intensity component than is known in the prior art. For more precise consideration of the problem, "positive" order diffractive focal points will
15 hereinafter be defined as those which are located between the lens and its refractive focal point, and "negative" order diffractive focal points as those which are located on the side of the refractive focal point remote from the lens.
- 20 If the refractive focal point is used for distance vision, for example, the first positive order focal point of the diffractive structure corresponds to a distance for intermediate vision and the second positive order focal point of the diffractive structure to a distance for near vision.
- 25 The respective negative focal points of the diffractive structure will in this case form an image only behind the lens user's retina, for which reason they are not useful to the user and contribute to an impairment of image quality.
- 30 In the case of the lens according to the invention, in contrast, intensity components of the (originally) negative

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orders are imaged onto the positive orders used or onto the zeroth (refractive) order, resulting in a more intensely coloured, higher contrast image compared to the prior art, since the useful focal points comprise higher intensity components.

The same advantages are obtained if, for example in an alternative embodiment, the refractive focal point is used for near vision, and the first negative order focal point of the diffractive structure corresponds to a distance for intermediate vision and the second negative order focal point of the diffractive structure corresponds to a distance for distance vision. In this embodiment, the positive orders of the diffractive structures are of little use, since they are located in front of the near vision focal point, and the third negative order orders are of no use at all, since they are only focused behind the retina. According to the invention, intensity components of the positive orders are here imaged onto the zeroth (refractive) negative first and negative second order, again resulting in a higher light yield in the useful focal points and thus a more intensely coloured, higher contrast image compared to the prior art.

In each embodiment, the lens according to the invention additionally has the significant advantage that the diffractive structure of the lens comprises just one maximum per period and nonetheless produces two diffractive focal points. Production of the diffractive structure on the lens may thus proceed far more simply and with less waste, since the angle of the maximum is larger and moreover only occurs once per period, i.e. only half as often as with the

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diffraction structures according to the prior art, which produce two diffraction focal points. Higher lens accuracy may be achieved in particular at the periphery of the lens, at which the period lengths may be very small, due to the more precise manufacture made possible thereby, leading in turn to more precise, more controlled light distribution.

The refractive focal point of the lens may, as discussed, be used either for near vision or distance vision. If the refractive focal point is used for distance vision, the preferred embodiment is the one in which the first portion falls monotonically and the three further portions rise monotonically. Alternatively, the refractive focal point may be used for near vision, wherein the first portion then preferably rises monotonically and the three further portions fall monotonically.

The portions, plotted over the squared radius, are preferably linear, i.e. they result in quadratically rising or falling flanks on the lens. This allows a simple calculation of the intensity profile of the lens. Alternatively, the portions may also comprise individual profiles, in order to adapt the intensity distribution of the lens.

In one preferred embodiment, the stated first portion is substantially vertical. Irrespective thereof, the further portion which does not adjoin the first portion may also be substantially vertical. These two measures result in an extremely simple profile pattern, since then only the gradient of two portions remains to be determined. This also simplifies manufacture of the lens, because a vertical portion, plotted

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over the squared radius, also results in a vertical flank on the lens.

To simplify calculation of the profile and consequently also manufacture of the lens, the two further portions which each adjoin the first portion, plotted over the squared radius, may have substantially the same gradient.

In one practical embodiment, two further portions which each adjoin the first portion, plotted over the squared radius, have a gradient of $1 \mu\text{m}/\text{mm}^2$ to $10 \mu\text{m}/\text{mm}^2$. Furthermore, the period of the profile, plotted over the squared radius, preferably amounts to 0.5 mm^2 to 1 mm^2 and the profile depth to $2 \mu\text{m}$ to $10 \mu\text{m}$. This yields a lens whose focal points for near and intermediate vision lie at distances desired by users.

The invention is explained in greater detail below on the basis of exemplary embodiments shown in the appended drawings, in which:

20

Fig. 1 is a schematic plan view of the lens according to the invention;

Fig. 2 is a schematic side view of the lens of Fig. 1;

25

Fig. 3 shows an enlarged half section of the lens of Fig. 1;

Fig. 4 shows the profile of the diffractive structure of the lens of Figs. 1 - 3, plotted over the squared radius of the lens; and

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Fig. 5 shows a comparison of the intensity distribution of the lens according to the invention with that of a lens according to the prior art.

5 Figs. 1 and 2 show a lens 1 with a front face 2, a back face 3 and an optical axis 4. The lens 1 has a central zone Z_1 and an annular zone Z_2 , which are explained in further detail below. The described lens 1 is used in particular as an intraocular lens or contact lens, but may also be used in optical
10 equipment.

The lens 1 has a refractive focal point F_r located on the optical axis 4, which focal point may be used, as described below, for distance or near vision and is also described
15 hereinafter as a zeroth order focal point. A diffractive structure 5 is incorporated into the back or front 2, 3 of the lens 1, see Figs. 3 and 4, in order to adapt the lens 1 both to near and to intermediate and distance vision.

20 The diffractive structure 5 generates a plurality of further focal points F_i ($i = \dots, -2, -1, 1, 2$ etc.) located on the optical axis 4 which are distributed symmetrically around the refractive focal point F_r , wherein the refractive focal point F_r is provided by the shape of the lens 1, irrespective of the
25 plotted diffractive structure 5. The diffractive focal points F_1, F_2 are described as positive first or second order focal points respectively of the diffractive structure 5 and lie on the optical axis 4 between the lens 1 and the refractive focal point F_r . The diffractive focal points F_{-1}, F_{-2} are described as
30 negative first or second order focal points respectively of

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the diffractive structure 5 and lie on the side of the refractive focal point F_r remote from the lens 1.

Although the (position) distribution of the focal points F_i is symmetrical around the refractive focal point F_r , the intensity distribution assigned to the respective focal points F_i is not intended to be symmetrical. For instance, in the case of a trifocal lens in particular three maximum intensities are intended to form, namely for distance, intermediate and near vision. This is achieved by forming the diffractive structure 5 according to Fig. 4.

According to Fig. 4 (x-axis: squared radius r^2 [mm]; y-axis: profile depth T [μm]) the diffractive structure 5 comprises a periodic profile in the radial direction r of the lens 1, plotted over the squared radius r^2 , which has four mutually adjacent portions 6, 7, 8, 9 per period p which cannot be differentiated at their junctions 10, 11, 12, 13. The phrase "plotted over the squared radius" means, with regard to periodicity, that the period intervals p diminish on the lens 1.

In an intraocular or contact lens, for example, the period p may lie in the range from 0.5 mm^2 to 1 mm^2 and the profile depth T in the range from $2 \text{ }\mu\text{m}$ to $10 \text{ }\mu\text{m}$.

In the embodiment of Fig. 4, an arbitrary "first" portion of the profile 5, here the portion 9, falls monotonically and the three further portions 6, 7, 8 of the profile rise monotonically. The expression "first" used herein does not relate to the order of the portions 6 - 9, but rather serves

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merely to draw a distinction from three "further" portions.
The order of the portions 6 - 9 within a period p may thus be
freely selected or defined, whereby for example each of the
portions 6, 7, 8, 9 may be selected as the "starting" portion
5 and/or the "first" portion 9 does not necessarily lie at the
start of the period p .

In the embodiment shown in Fig. 4, the refractive focal point
 F_r is designed for distance vision and the three monotonically
10 rising further portions 6, 7, 8 and the monotonically falling
first portion 9 result in two positive order diffractive focal
points F_1 , F_2 for near and intermediate vision (see Fig. 5).
Alternatively, the refractive focal point F_r may for example
also be designed for near vision, to which end three
15 monotonically falling further portions 6, 7, 8 and one
monotonically rising first portion 9 are then used, resulting
in two negative order diffractive focal points F_{-1} , F_{-2} for
intermediate and distance vision (not shown).

20 The further portion which does not adjoin the first portion 9,
i.e. in Fig. 4 the middle further portion 7, has a steeper
gradient than the other two further portions 6, 8. The term
"gradient" is defined herein as the total gradient covered by
a portion 6, 7, 8, 9, i.e. as the gradient between the
25 starting point of a portion 6, 7, 8 or 9 and the end point of
the same portion 6, 7, 8 or 9.

The portions 6 - 9, plotted over the squared radius r^2 , may be
linear, whereby a monotonically rising portion 6, 7, 8 on the
30 lens 1 gives rise to a flank rising quadratically with r .

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According to Fig. 4, moreover, the first portion 9 and the further portion which does not adjoin the first portion 9, i.e. here the middle further portion 7, are substantially vertical, i.e. they have a gradient of $\pm \infty$. Alternatively, these two portions 7, 9 may also each mutually independently have a finite gradient (not shown).

The two further portions 6, 8 which each adjoin the first portion 9 have substantially the same gradient, plotted over the squared radius r^2 . In the case of an intraocular or contact lens, the gradient may for example lie in the range from $1 \mu\text{m}/\text{mm}^2$ to $10 \mu\text{m}/\text{mm}^2$. The two portions 6, 8 may also comprise mutually different gradients (not shown).

The diffractive structure 5 may either be applied to the entire surface of one side 2, 3 of the lens 1 or merely in a central region Z_1 or an annular region Z_2 of the lens 1, as shown in Fig.1. Alternatively or in addition, the structure 5 may be apodised. This means that the profile depth T of the structure 5 decreases as the lens radius r increases.

To produce the lens 1, the diffractive structure 5 may for example be incorporated directly into a lens blank, for example by turning on a lathe. The lens blank could however also merely be a processable starting material for a 3D printer, with incorporation of the structure into the lens blank then proceeding by 3D printing of the starting material to yield the multifocal lens 1.

Alternatively, the diffractive structure 5 could initially also be incorporated as a negative into a moulded blank, for

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example again by means of a lathe or a 3D printer Then, a lens material is brought into contact with the moulded blank in order in this way to produce the multifocal lens 1. The lens material may for example already have been prefabricated into
5 a lens blank, into which the structure 5 is pressed or impressed by means of the moulded blank acting as a "punch". Alternatively, the lens material may be present in a liquid or viscous state and be cast onto the moulded blank, for example in a mould. The lens material is then hardened, for example by
10 the input of light or heat.

Fig. 5 shows a comparison of the intensity profile 14 (shown by a solid line) of the lens 1 presented here with the intensity profile 15 (shown by a broken line) of a lens
15 according to the prior art (x-axis: distance D from the lens [mm]; y-axis: relative intensity I [1]).

The lens 1 used for this comparison with the diffractive structure 5 presented herein had a period p, plotted over the squared radius r^2 , of 0.65 mm^2 , wherein the profile depth T was
20 $4.4 \text{ }\mu\text{m}$. The two further portions 6, 8 which in each case adjoined the first portion 9 had, plotted over the squared radius r^2 , a gradient of $4.3 \text{ }\mu\text{m}/\text{mm}^2$.

25 In contrast, the comparison line relating to the prior art had a periodic profile which within one period had four portions which successively rose, fell, rose and fell monotonically.

As is clear from the diagram of Fig. 5, the result is a
30 similar intensity distribution profile in the region of the refractive focal point F_r . It is however readily apparent from

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Fig. 5 that the lens 1 according to the prior art had greater intensity values in the region of the second negative focal point F_{-2} of the diffractive structure 5. In contrast, in the case of the lens 1 presented here, non-usable, negative order intensities are shifted into usable positive orders, as is apparent from the markedly increased intensities of the profile 10 at the focal points F_1 and F_2 , and the markedly reduced intensity of the profile 14 at the focal point F_{-2} . A more intensely coloured and higher contrast image is thus obtained for the user of the described lens 1 than with lenses according to the prior art

The invention is accordingly not limited to the embodiments shown but rather comprises all variants, modifications and combinations thereof which fall within the scope of the appended claims.

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CLAIMS:

1. A multifocal lens with a refractive focal point (F_r) and a diffractive structure, the structure (5) having a periodic profile (6, 7, 8, 9) in the radial direction (r) of the lens (1) plotted over the squared radius (r^2), and the profile (6, 7, 8, 9) having four mutually adjacent portions (6, 7, 8, 9) per period which cannot be differentiated at their junctions (10, 11, 12, 13), characterised in that a first portion (9) falls monotonically and the three further portions (6, 7, 8) rise monotonically, or a first portion (9) rises monotonically and the three further portions (6, 7, 8) fall monotonically, and wherein the further portion (7) which does not adjoin said first portion (9) has a steeper gradient than the other two further portions (6, 8).
2. The multifocal lens according to claim 1, characterised in that the portions (6, 7, 8, 9) are linear when plotted over the squared radius (r^2).
3. The multifocal lens according to claim 1 or 2, characterised in that the first portion (9) is substantially vertical.
4. The multifocal lens according to any one of claims 1 to 3, characterised in that the further portion (7) which does not adjoin the first portion (9) is substantially vertical.
5. The multifocal lens according to any one of claims 1 to 4, characterised in that the two further portions (6, 8) which

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each adjoin the first portion (9) have substantially the same gradient.

6. The multifocal lens according to any one of claims 1 to 5, characterised in that the two further portions (6, 8) which each adjoin the first portion (9) have, plotted over the squared radius (r^2), a gradient of $1 \mu\text{m}/\text{mm}^2$ to $10 \mu\text{m}/\text{mm}^2$.

7. The multifocal lens according to any one of claims 1 to 10, characterised in that the period (p) of the profile (6, 7, 8, 9), plotted over the squared radius, amounts to 0.5 mm^2 to 1 mm^2 and the profile depth (T) to $2 \mu\text{m}$ to $10 \mu\text{m}$.

8. The multifocal lens according to any one of claims 1 to 15, characterised in that the multifocal lens is an intraocular lens or contact lens.

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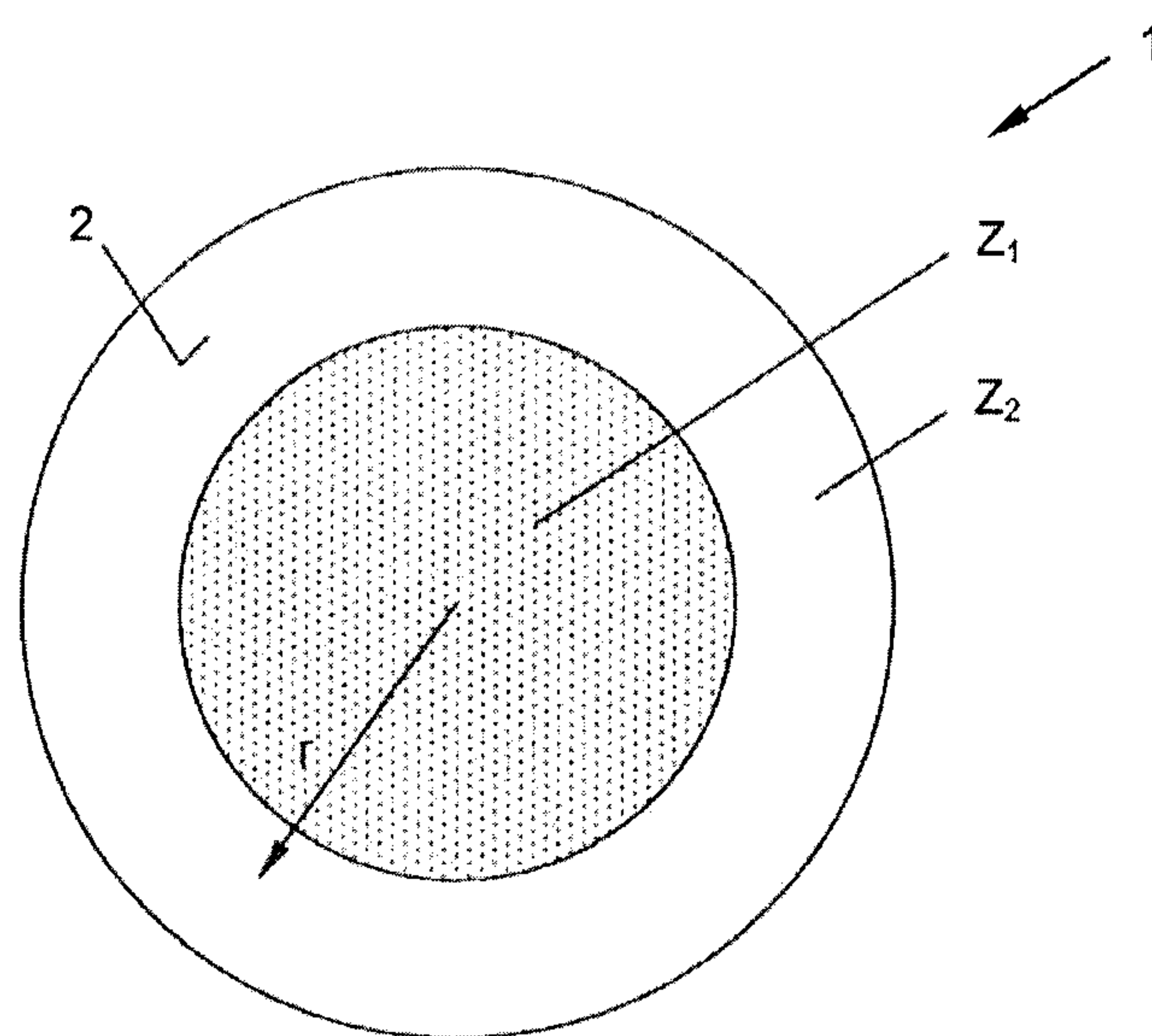


Fig. 1

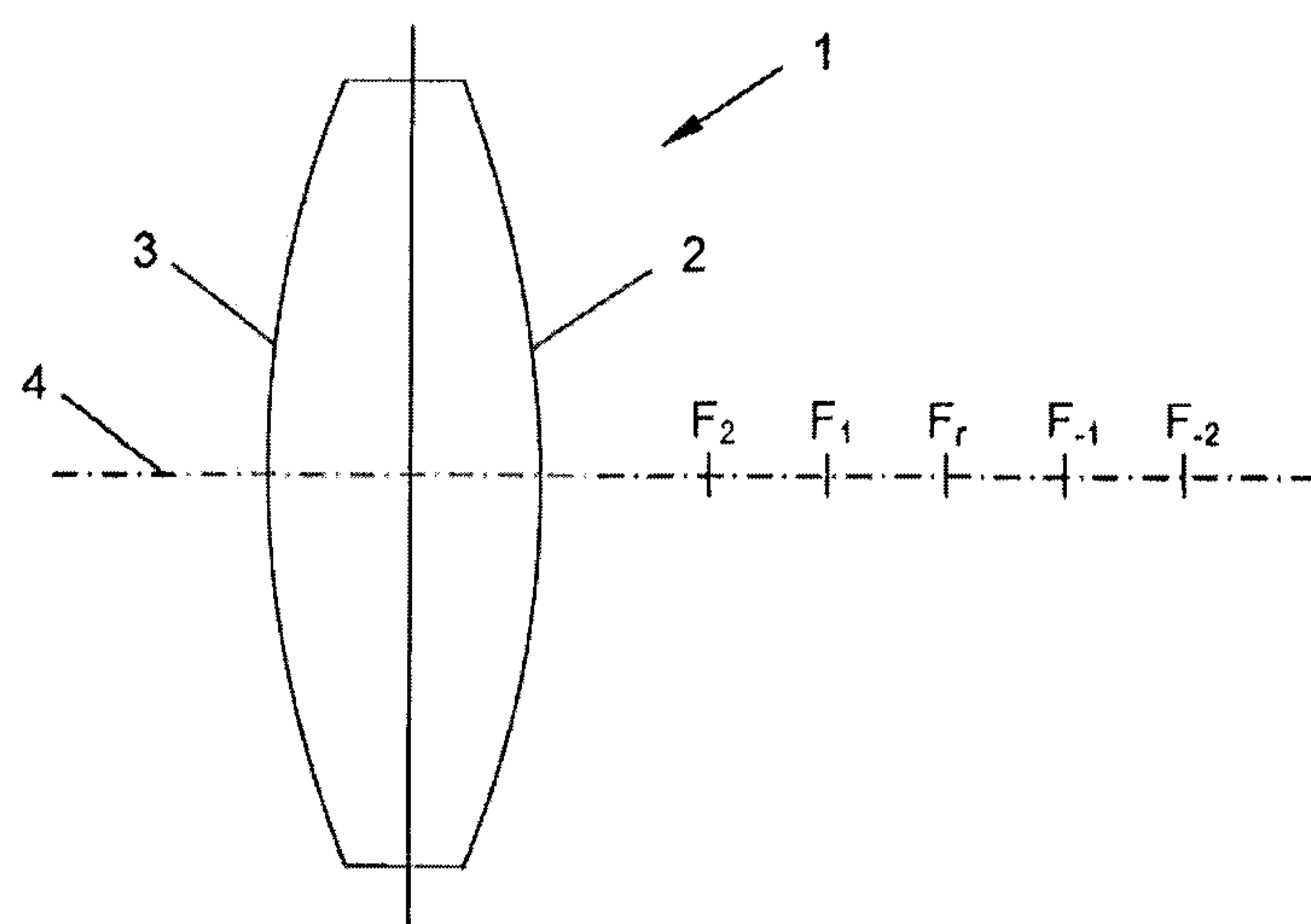


Fig. 2

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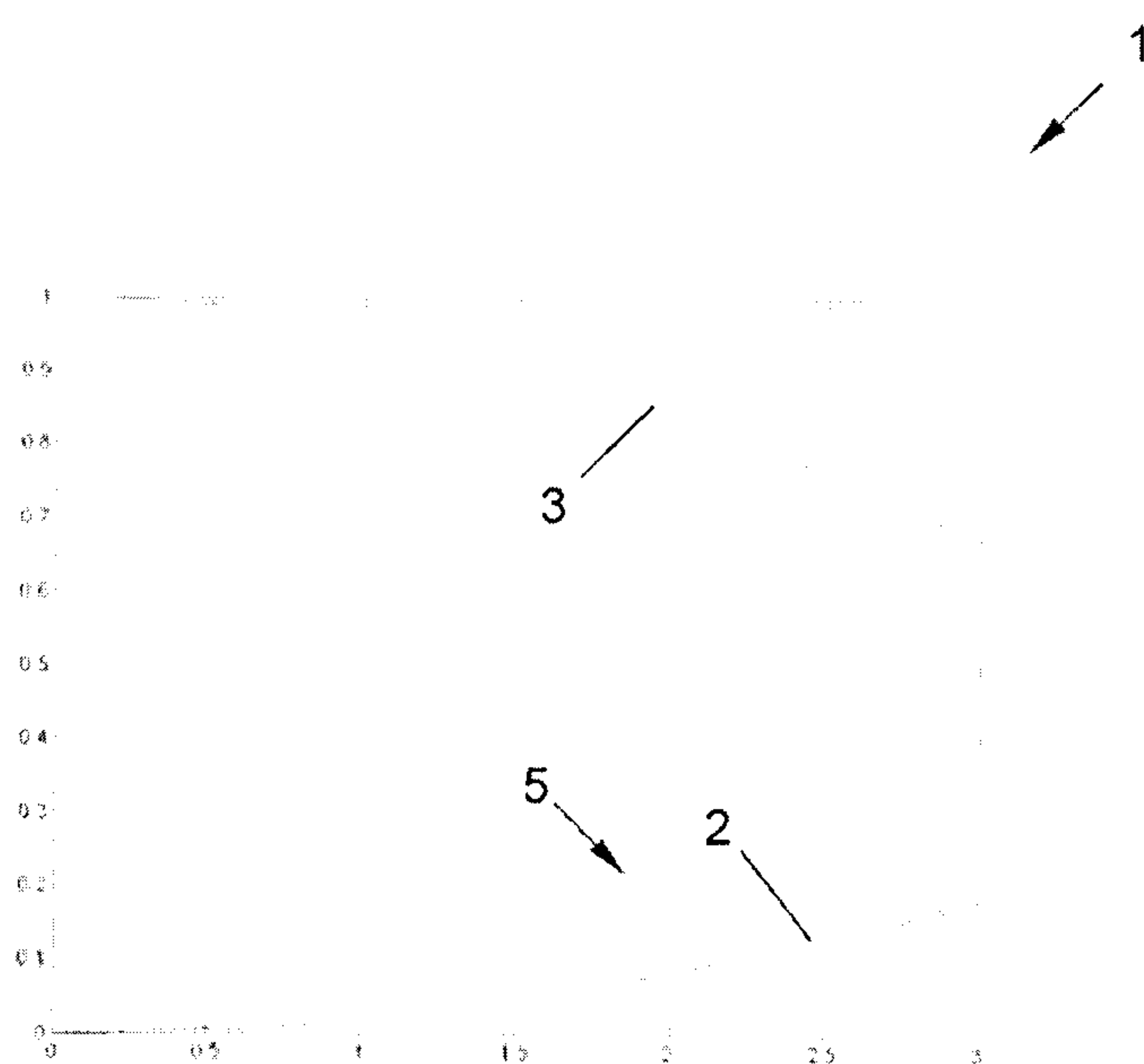


Fig. 3

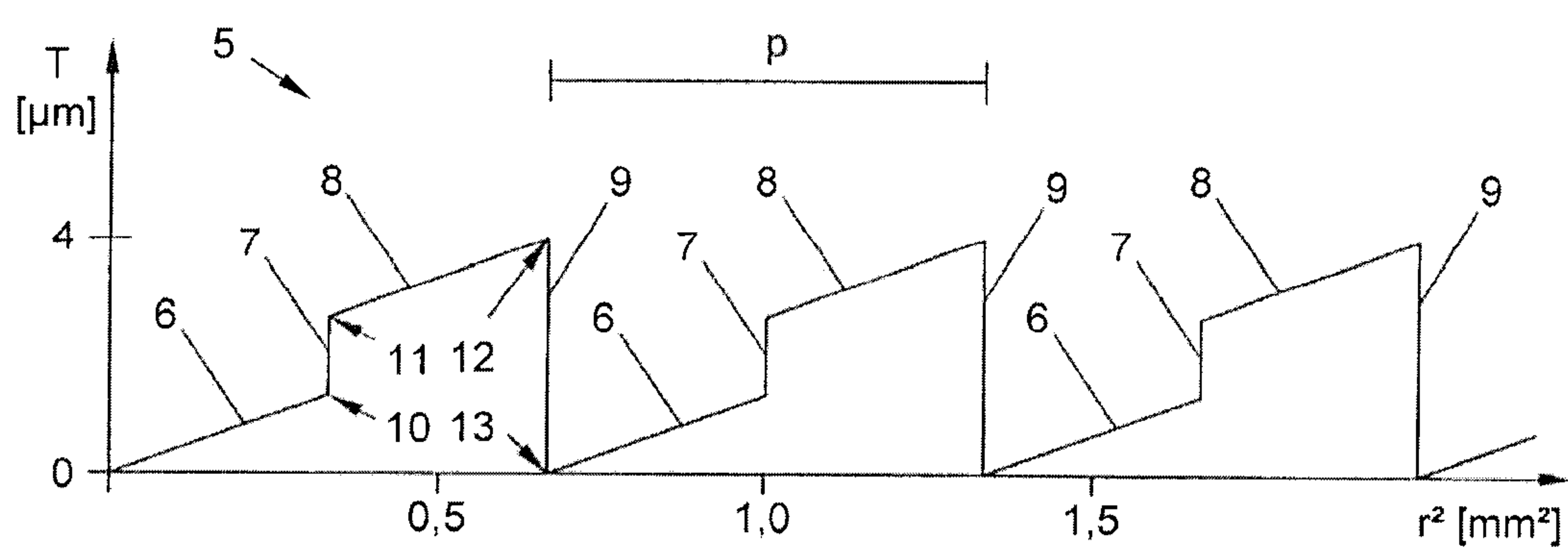


Fig. 4

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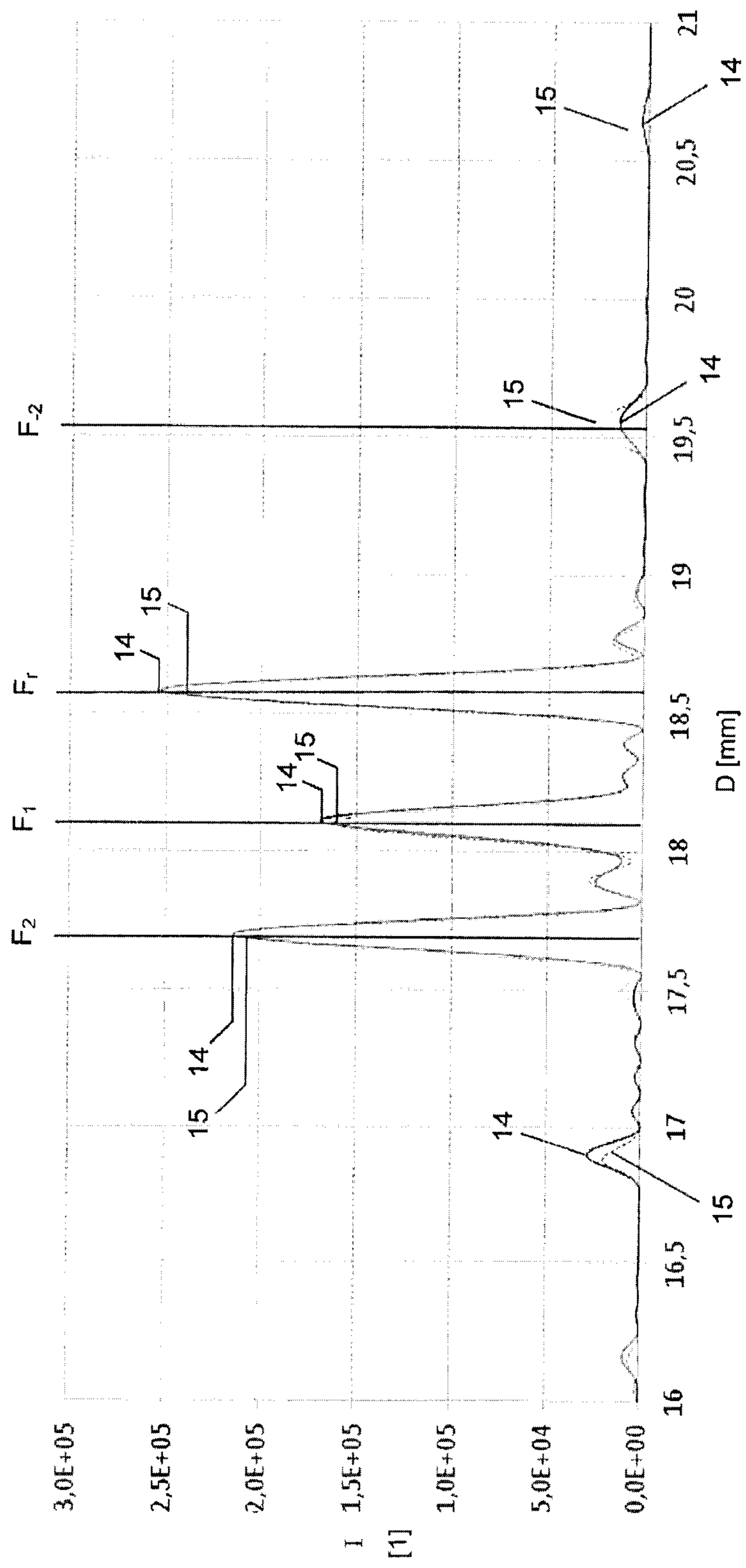


Fig. 5

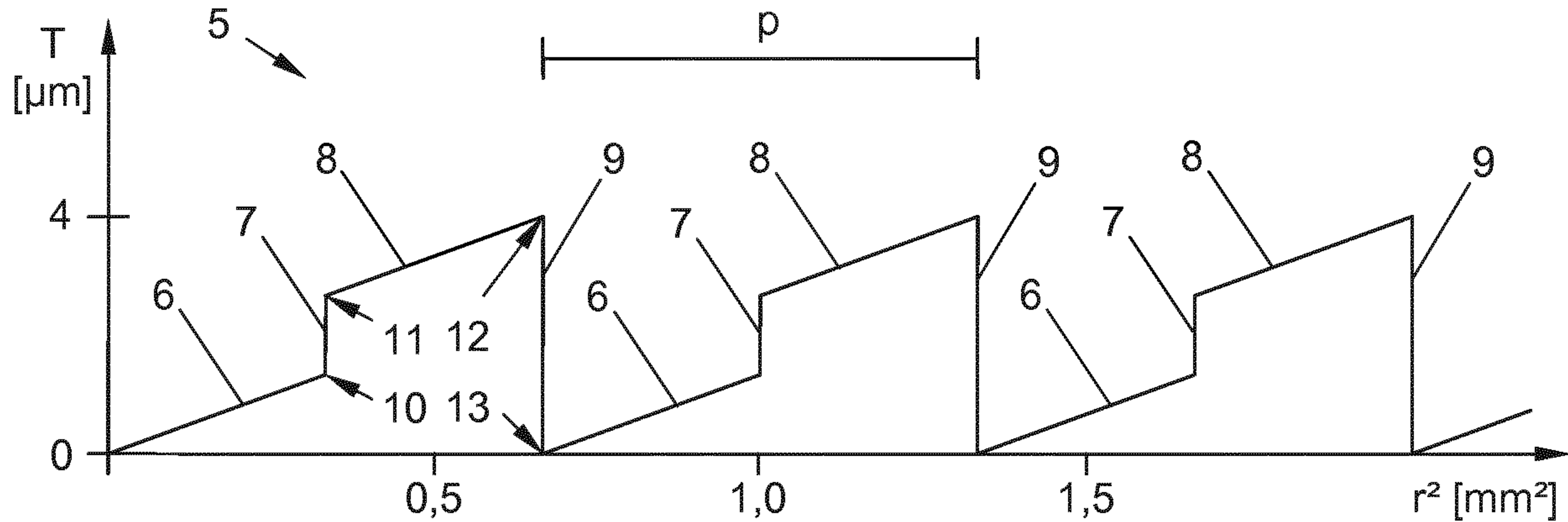


Fig. 4