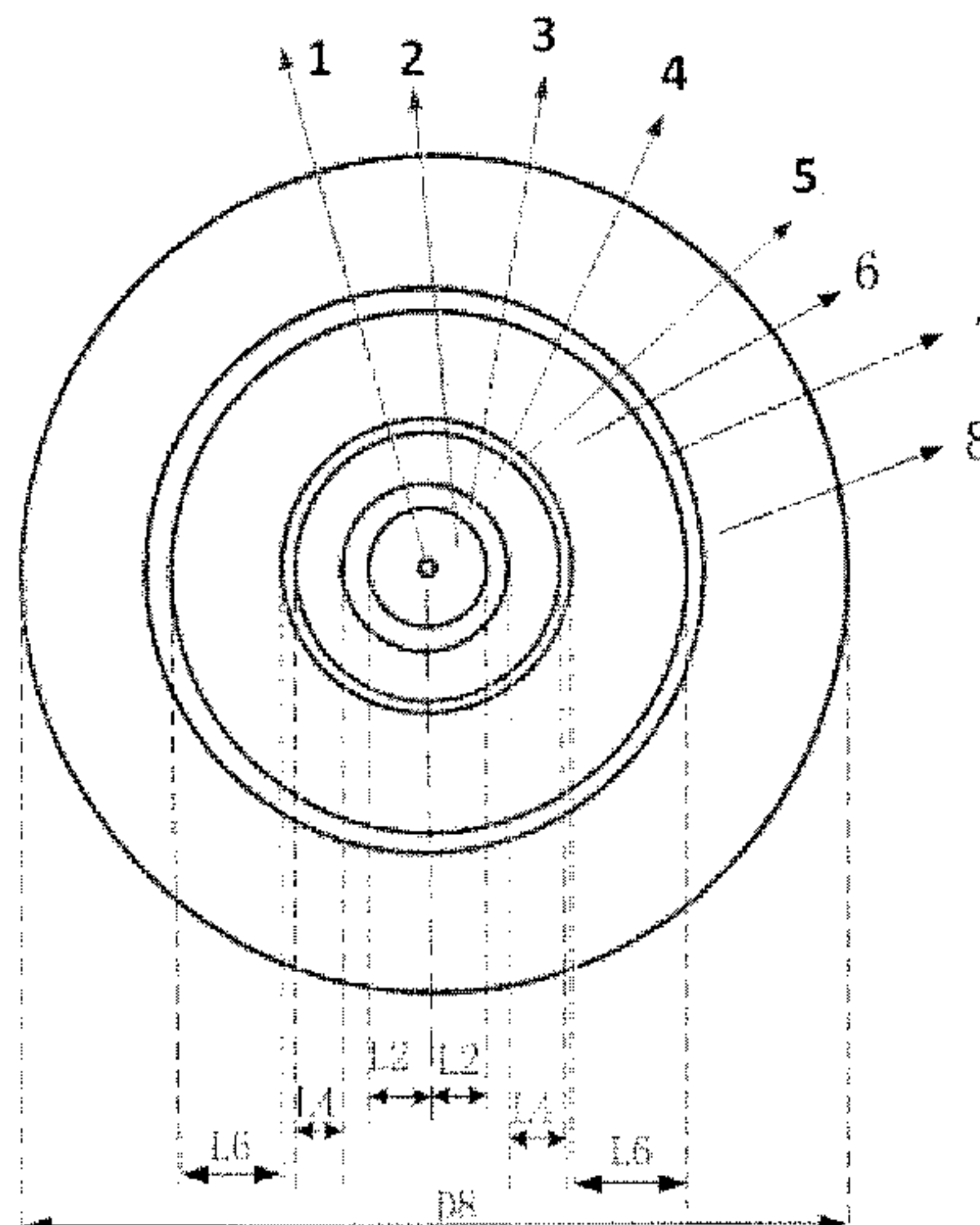




(86) Date de dépôt PCT/PCT Filing Date: 2014/09/23
(87) Date publication PCT/PCT Publication Date: 2015/07/30
(45) Date de délivrance/Issue Date: 2018/01/16
(85) Entrée phase nationale/National Entry: 2016/04/20
(86) N° demande PCT/PCT Application No.: CN 2014/087158
(87) N° publication PCT/PCT Publication No.: 2015/109861
(30) Priorité/Priority: 2014/01/26 (CN201410037490.2)

(51) Cl.Int./Int.Cl. *G02B 6/036* (2006.01),
G02B 6/028 (2006.01)
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(54) Titre : FIBRE OPTIQUE MONOMODE A PETIT RAYON DE COURBURE COMPATIBLE AVEC LES FIBRES
OPTIQUES G.652 CONVENTIONNELLES
(54) Title: SMALL BENDING RADIUS SINGLE-MODE OPTICAL FIBER WITH COMPATIBILITY WITH CONVENTIONAL
G.652 OPTICAL FIBERS



(57) **Abrégé/Abstract:**

A small bending radius single-mode optical fiber with compatibility comprises a core gradient layer (1), a germanium-doped core layer (2), a first transition layer (3), a first wrapping layer (4), a second transition layer (5), a second wrapping layer (6), a third transition layer (7) and a third wrapping layer (8), said layers being arranged concentrically from the inner to the outer. The difference of relative index of refraction of the core gradient layer (1) is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_- + x_-) + b_1$; the difference of relative index of refraction of the first transition layer (3) is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_-)0.5$; the difference of relative index of refraction of the second transition layer (5) is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_- + b_5$; the difference of relative index of refraction of the third transition layer (7) is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7x_- + b_7$. The small bending radius single-mode optical fiber with compatibility achieves a quite strong resistance to bending the radius of which is below 2mm, and is well compatible with conventional single-mode optical fibers.



(12) 按照专利合作条约所公布的国际申请

(19) 世界知识产权组织
国际局(43) 国际公布日
2015 年 7 月 30 日 (30.07.2015)(10) 国际公布号
WO 2015/109861 A1

- (51) 国际专利分类号:
G02B 6/036 (2006.01) *G02B 6/028* (2006.01)
- (21) 国际申请号: PCT/CN2014/087158
- (22) 国际申请日: 2014 年 9 月 23 日 (23.09.2014)
- (25) 申请语言: 中文
- (26) 公布语言: 中文
- (30) 优先权:
201410037490.2 2014 年 1 月 26 日 (26.01.2014) CN
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(81) 指定国 (除另有指明, 要求每一种可提供的国家保护): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW。

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(54) Title: SMALL BENDING RADIUS SINGLE-MODE OPTICAL FIBER WITH COMPATIBILITY

(54) 发明名称: 一种具有兼容性的小弯曲半径单模光纤

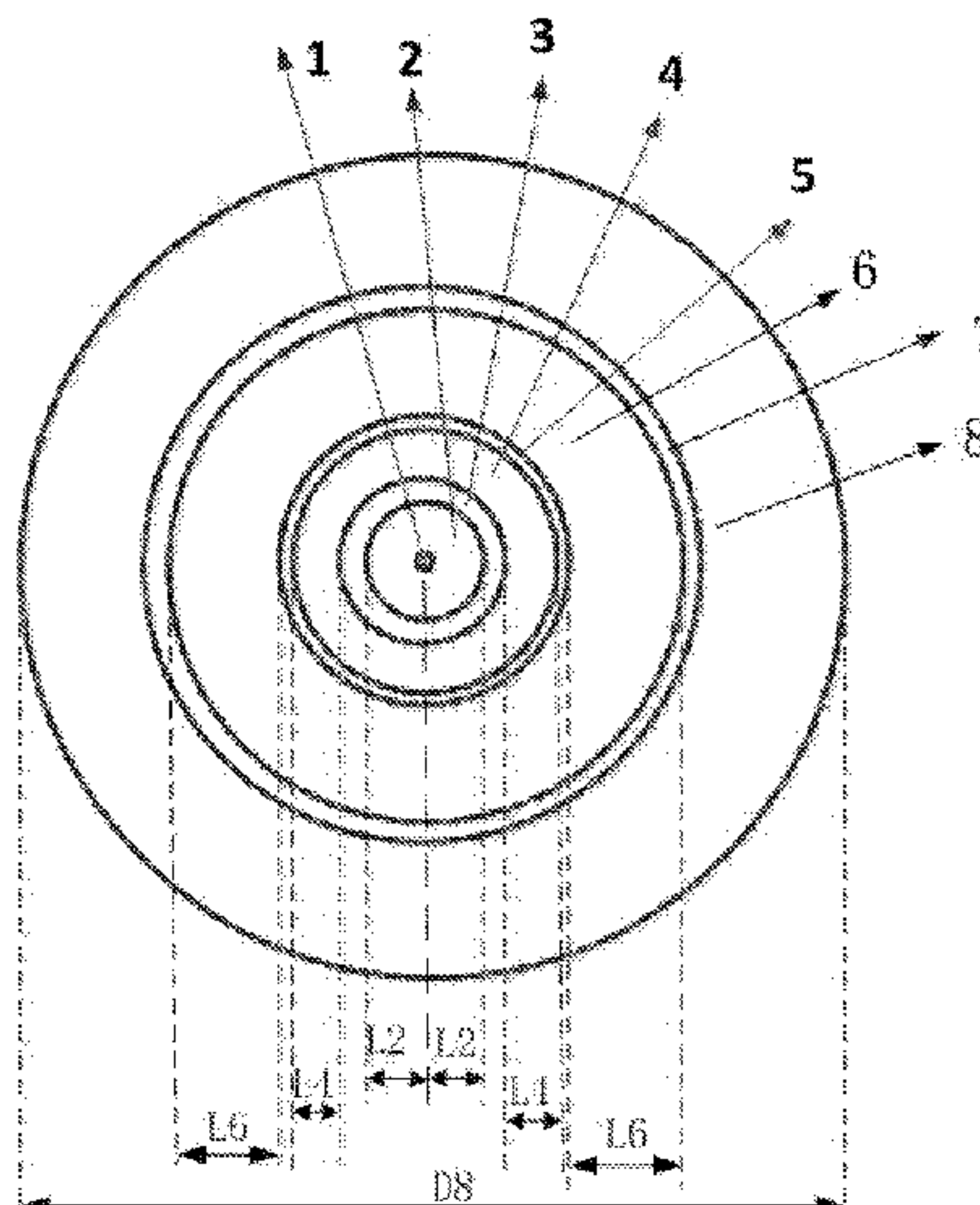


图 1 / Fig. 1

(57) Abstract: A small bending radius single-mode optical fiber with compatibility comprises a core gradient layer (1), a germanium-doped core layer (2), a first transition layer (3), a first wrapping layer (4), a second transition layer (5), a second wrapping layer (6), a third transition layer (7) and a third wrapping layer (8), said layers being arranged concentrically from the inner to the outer. The difference of relative index of refraction of the core gradient layer (1) is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_{-} + x_{-}) + b_1$; the difference of relative index of refraction of the first transition layer (3) is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_{-})^{0.5}$; the difference of relative index of refraction of the second transition layer (5) is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_{-} + b_5$; the difference of relative index of refraction of the third transition layer (7) is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7x_{-} + b_7$. The small bending radius single-mode optical fiber with compatibility achieves a quite strong resistance to bending the radius of which is below 2mm, and is well compatible with conventional single-mode optical fibers.

(57) 摘要:

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WO 2015/109861 A1

WO 2015/109861 A1

(84) 指定国 (除另有指明, 要求每一种可提供的地区保护): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), 欧亚 (AM, AZ, BY, KG, KZ, RU, TJ, TM), 欧洲 (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG)。

本国际公布:
— 包括国际检索报告(条约第 21 条(3))。

一种具有兼容性的小弯曲半径单模光纤, 包括由内至外同心设置的芯层渐变层 (1)、掺铒芯层 (2)、第一过渡层 (3)、第一包层 (4)、第二过渡层 (5)、第二包层 (6)、第三过渡层 (7) 和第三包层 (8); 芯层渐变层 (1) 的相对折射率差为 Δn_1 , 以 $\Delta n_1=a_1(x_1+x_1^2+x_1^3)+b_1$ 实现, 第一过渡层 (3) 的相对折射率差为 Δn_3 , 以 $\Delta n_3=b_3(1-a_3x_3^2)^{0.5}$ 实现, 第二过渡层 (5) 的相对折射率差为 Δn_5 , 以 $\Delta n_5=a_5x_5^2+b_5$ 实现, 所述第三过渡层 (7) 的相对折射率差为 Δn_7 , 以 $\Delta n_7=a_7x_7^2+b_7$ 实现。所述具有兼容性的小弯曲半径单模光纤, 实现弯曲半径达 2mm 以下的超强抗弯曲能力, 同时可实现与常规单模光纤的良好兼容。

SPECIFICATION

SMALL BENDING RADIUS SINGLE-MODE OPTICAL FIBER WITH COMPATIBILITY WITH CONVENTIONAL G.652 OPTICAL FIBERS

TECHNICAL FIELD

The present invention relates to the field of single-mode optical fibers, and specifically to a small bending radius single-mode optical fiber with compatibility.

BACKGROUND ART

At present, the construction of communication networks has mobilized the rapid development of fiber-to-the-home (FTTH) and ODN technology, which put forward a high requirement upon the resistance-to-bending performance of optical fibers. When the optical fibers are bent, some light of power leaks to make optical signals attenuated. Materials such as the coating absorb the leaked light and thus are heated. Studies have found that after running for a long time under the bending radius of 15mm, a jumper made of conventional G.652D single-mode optical fibers will be destroyed between two connection end points due to continued heating, thus leading to the continued reduction of splicing loss and non-recoverable damage. In the ODN, a great number of optical fibers are arranged in a bending manner in a small distributor. As the bending of the optical fibers leads to the leak of optical power, heating is resulted. It will severely influence the communication stability of the ODN.

Improving the resistance-to-bending performance of optical fibers can not only be good for guaranteeing the high-quality transmission of optical signals, but also reduce the overall heating value of the

communication system of the optical fibers so as to promote the overall performance of the system. Global leading enterprises of optical fibers have carried out in-depth studies on the requirements of the hotspot ODN technology of communication networks upon super-strong bending-resistant optical fibers. Domestic optical fiber and cable enterprises have currently focused on the technical studies of a 10mm bending radius required by the ITUT-G.657 or a smaller bending radius single-mode optical fiber, like G.657B2/3.

However, to meet the floor space requirement of the construction of optical fiber networks and 3G networks, the ODN technology demands that a great number of devices are disposed in a rather small distributor. As a consequence, the space for the optical fibers for high-speed high-bandwidth communication connection between the devices is narrowed, and the bending performance of the optical fibers must be higher. Super-strong bending-resistant single-mode optical fibers, of which the bending radius is 3mm or even 2mm below, are needed in more and more applications. Besides, such super-strong bending-resistant single-mode optical fibers must be well compatible with common single-mode optical fibers; their single-point fusion loss must be controlled within an acceptable small range.

Optical fibers for FTTH actually need two key characteristics, one is resistance to bending, a fundamental characteristic to achieve the small bending radius and low loss transmission of optical signals, the other is certain compatibility with conventional G.652 optical fibers. Nearly all the optical fibers arranged in a large number at the front end of the current backbone network and metropolitan area network or even access network are G.652 optical fibers. If the optical fibers chosen for the FTTH section cannot be well compatible with the G.652 optical fibers, even though they have high bending performance, a large loss can be caused

when they are fused with the conventional G.652 optical fibers, and the optical signals can also be largely depleted at the connection of the two optical fibers, thus an additionally greater optical gain is needed, or else the G.652 optical fibers will still be used at the FTTH end. Therefore, although bending-resistant optical fibers have been supplied now, as they cannot be well compatibility with the conventional G.652 optical fibers, they are not massively adopted in the FTTH market.

SUMMARY

Aiming to overcome the defects of the prior art, the present invention provides a small bending radius single-mode optical fiber with compatibility, which achieves a quite strong resistance to bending, the radius of which is below 2mm, and is well compatible with conventional single-mode optical fibers.

To achieve the above-mentioned aim, the present invention adopts a technical scheme as follows: a small bending radius single-mode optical fiber with compatibility comprises a core gradient layer and a germanium-doped core layer arranged concentrically, and a first wrapping layer, a second wrapping layer and a third wrapping layer arranged concentrically from the inner to the outer; a first transition layer is arranged between the germanium-doped core layer and the first wrapping layer, a second transition layer is arranged between the first wrapping layer and the second wrapping layer, and a third transition layer is arranged between the second wrapping layer and the third wrapping layer; the difference of relative index of refraction of the core gradient layer is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer to the axis of said layer, a_1 is gradient factor of the core gradient layer, ranging from 0.5% to 2%, and b_1 is gradient stability

factor of the core gradient layer, ranging from 0 to 0.2%; the difference of relative index of refraction of the first transition layer is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, both ranging from 0.3% to 0.8%; the difference of relative index of refraction of the second transition layer is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 ranging from -1.0% to -0.3%, and b_5 ranging from 0 to 0.1%; and the difference of relative index of refraction of the third transition layer is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 ranging from 0.1% to 0.4%, and b_7 ranging from -1.3% to -0.3%.

Based on the above-mentioned technical scheme, the ratio of the thickness of the germanium-doped core layer to the thickness of the first wrapping layer is from 0.5 to 2.0.

Based on the above-mentioned technical scheme, the ratio of the thickness of the germanium-doped core layer to the thickness of the second wrapping layer is from 0.2 to 1.0.

Based on the above-mentioned technical scheme, the difference of relative index of refraction of the germanium-doped core layer is from 0.2% to 0.8%.

Based on the above-mentioned technical scheme, the difference of

relative index of refraction of the first wrapping layer is from 0 to 0.1%.

Based on the above-mentioned technical scheme, the difference of relative index of refraction of the second wrapping layer is from -1.3% to -0.3%.

Based on the above-mentioned technical scheme, the diameter of the third wrapping layer, a quartz wrapping layer, is 80 μ m or 125 μ m.

Based on the above-mentioned technical scheme, when the operating wavelength is 1550nm, the attenuation of the small bending radius single-mode optical fiber is below 0.2dB/km, and when the bending radius is below 2mm, the additional loss is below 0.35dB.

The present invention has the following beneficial effects:

1. a plurality of wrapping layers, namely a first wrapping layer doped with low germanium, a second wrapping layer doped with high fluorine and a third wrapping layer composed of quartz, are arranged outside a germanium-doped core layer to form a mountain-shaped waveguide structure, thus strengthening the resistance to bending of the optical fiber through the reduction of macrobend and microbend losses; and

2. a transition layer is arranged between the germanium-doped core layer and the first wrapping layer, as well as between the first and the second wrapping layers and between the second and the third wrapping layers, and a core gradient layer is arranged inside the germanium-doped core layer, so that the mode and stress characteristics of the optical fiber are optimized; therefore, when the small bending radius single-mode optical fiber is fused with conventional G.652 single-mode optical fibers, the loss at the fusion point can be controlled to the minimum, and the small bending radius single-mode optical fiber is well compatible with the conventional single-mode optical fibers, thus laying the foundation for optical fibers for FTTH and ODN technology.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic structural diagram of an end face of a small bending radius single-mode optical fiber with compatibility of the present invention;

FIG. 2 is a schematic structural diagram of a waveguide of a small bending radius single-mode optical fiber with compatibility of the present invention;

FIG. 3 is a schematic structural diagram of mode field control of a small bending radius single-mode optical fiber with compatibility;

FIG. 4 is an additional loss for optical fiber bending when a wrapping layer in FIG. 1 is 125 μ m in diameter; and

FIG. 5 is an additional loss for optical fiber bending when a wrapping layer in FIG. 1 is 80 μ m in diameter.

DESCRIPTION OF EMBODIMENTS

The following will further describe the present invention according to drawings.

As shown in FIG. 1, a small bending radius single-mode optical fiber with compatibility of the present invention comprises a core gradient layer 1, a germanium-doped core layer 2, a first transition layer 3, a first wrapping layer 4, a second transition layer 5, a second wrapping layer 6, a third transition layer 7 and a third wrapping layer 8, said layers being arranged concentrically from the inner to the outer, wherein the core gradient layer 1 is arranged inside the germanium-doped core layer 2, the first transition layer 3 is located between the core gradient layer 1 and the first wrapping layer 4, the second transition layer 5 is located between the first wrapping layer 4 and the second wrapping layer 6, and the third

transition layer 7 is located between the second wrapping layer 6 and the third wrapping layer 8; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the first wrapping layer 4 is from 0.5 to 2.0; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L6 of the second wrapping layer 6 is from 0.2 to 1.0; the diameter D8 of the third wrapping layer 8, a quartz wrapping layer, is 80 μ m or 125 μ m; after being coated, the small bending radius single-mode optical fiber of the present invention has the diameter of 200 μ m or 245 μ m.

As shown in FIG. 2, the index of refraction of the core gradient layer 1 is n1, the index of refraction of the germanium-doped layer 2 is n2, the index of refraction of the first transition layer 3 is n3, the index of refraction of the first wrapping layer 4 is n4, the index of refraction of the third transition layer 5 is n5, the index of refraction of the second wrapping layer 6 is n6, the index of refraction of the third wrapping layer 7 is n7, and the index of refraction of the third wrapping layer 8 is n8; the index of refraction of the third wrapping layer 8, namely n8, is chosen as the index of refraction of an equivalent quartz wrapping layer, namely n. To realize these indexes of refraction, a method of difference of relative index of refraction is adopted. On the basis of the index of refraction of the quartz wrapping layer, namely n, a difference of relative index of refraction occurs between each waveguide layer and the quartz wrapping layer. Accordingly, the index of refraction of each layer included in the mountain-shaped waveguide structure of the present invention is measured and realized. An equation is adopted for the difference of relative index of refraction:

$$\Delta n = (n' - n) / (n' + n) \times 100\% \quad (1)$$

wherein n is the index of refraction of the quartz wrapping layer, namely the index of refraction of the third wrapping layer 8 of the present

invention, n_8 , and n' is the index of refraction of the corresponding layer.

As for the present invention, to calculate the difference of relative index of refraction of the core gradient layer 1 and the quartz wrapping layer, n' in the equation adopts the index of refraction of the fiber core, namely n_1 ; to calculate the difference of relative index of refraction of the germanium-doped core layer and the quartz wrapping layer, n' in the equation adopts the index of refraction of the fiber core, namely n_2 ; to calculate the difference of relative index of refraction of the core of the first transition layer 3 and the quartz wrapping layer, n' in the equation adopts the index of refraction of the first transition layer, namely n_3 ; to calculate the difference of relative index of refraction of the first wrapping layer 4 and the quartz wrapping layer, n' in the equation adopts the index of refraction of the first wrapping layer, namely n_4 ; to calculate the difference of relative index of refraction of the second transition layer 5 and the quartz wrapping layer, n' in the equation adopts the index of refraction of the second transition layer, namely n_5 ; to calculate the difference of index of refraction of the second wrapping layer 6 and the fluorine-doped wrapping layer, n' in the equation adopts the index of refraction of the second wrapping layer, namely n_6 ; to calculate the difference of index of refraction of the third transition layer 7 and the quartz wrapping layer, n' in the equation adopts the index of refraction of the second transition layer, namely n_7 .

Accordingly, it can be figured out by the equation (1) that the difference of relative index of refraction of the core gradient layer 1 is Δn_1 , the difference of relative index of refraction of the germanium-doped core layer 2 is Δn_2 , the difference of relative index of refraction of the first transition layer 3 is Δn_3 , the difference of relative index of refraction of the first wrapping layer 4 is Δn_4 , the difference of relative index of refraction of the second transition layer 5 is Δn_5 , the

difference of relative index of refraction of the second wrapping layer 6 is Δn_6 , and the difference of relative index of refraction of the third transition layer 7 is Δn_7 . The difference of relative index of refraction of the germanium-doped core layer 2 is between 0.2% and 0.8%; the difference of relative index of refraction of the first wrapping layer 4, a low germanium-doped wrapping layer, is between 0 and 0.1%; the difference of relative index of refraction of the second wrapping layer 6, a high fluorine-doped wrapping layer, is between -1.3% and -0.3%.

The difference of relative index of refraction of the core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, ranging from 0.5% to 2%, and b_1 is gradient stability factor of the core gradient layer 1, ranging from 0 to 0.2%.

The difference of relative index of refraction of the first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, both ranging from 0.3% to 0.8%.

The difference of relative index of refraction of the second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 ranging from -1.0% to -0.3%, and b_5 ranging from 0 to 0.1%.

The difference of relative index of refraction of the third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an

optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 ranging from 0.1% to 0.4%, and b_7 ranging from -1.3% to -0.3%.

As shown in FIG. 3, according to the present invention, a triplex control is applied to the mode field of the small bending radius optical fiber through the germanium-doped fiber core 2, the first wrapping layer 4, the second wrapping layer 6 and the third wrapping layer 8, and the characteristics of the mode field are optimized to adapt to G.652 through the core gradient layer 1, the first transition layer 3, the second transition layer 5 and the third transition layer 7, thus the epitaxial mode field of the optical fiber is approximate to the mode field of G.652, and the central mode field is the characteristic mode field of the small bending radius optical fiber.

The following will further describe the present invention according to embodiments.

Embodiment 1:

in this embodiment, a small bending radius single-mode optical fiber, the diameter D_8 of a third wrapping layer 8 is 125 μm ; the difference of relative index of refraction of a core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, falling within 0.5%, and b_1 is gradient stability factor of the core gradient layer 1, falling within 0;

the difference of relative index of refraction of a germanium-doped core layer 2, namely Δn_2 , keeps stable, constantly 0.2%;

the difference of relative index of refraction of a first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an

optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, a_3 falling within 0.8%, and b_3 falling within 0.3%;

the difference of relative index of refraction of a first wrapping layer 4, namely Δn_4 , keeps stable, constantly 0; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the first wrapping layer 4 is 2.0;

the difference of relative index of refraction of a second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5 x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 falling within -0.65%, and b_5 falling within 0.05%;

the difference of relative index of refraction of a second wrapping layer 6, namely Δn_6 , keeps stable, constantly -0.8%; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the second wrapping layer 6 is 1.0;

the difference of relative index of refraction of a third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7 x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 falling within 0.25%, and b_7 falling within -0.8%;

according to FIG. 4, in this embodiment, the 1550nm attenuation of the small bending radius single-mode optical fiber is 0.191dB/km, the fusion loss between the small bending radius single-mode optical fiber and a conventional G.652 optical fiber reaches 0.08dB, and the additional loss under the bending radius of 2mm is below 0.345dB.

Embodiment 2:

this embodiment is of a structure basically the same as embodiment 1; the diameter D8 of a third wrapping layer 8 is 125 μ m; the difference of relative index of refraction of a core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, falling within 1%, and b_1 is gradient stability factor of the core gradient layer 1, falling within 0.2;

the difference of relative index of refraction of a germanium-doped core layer 2, namely Δn_2 , keeps stable, constantly 0.5%;

the difference of relative index of refraction of a first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, a_3 falling within 0.5, and b_3 falling within 0.5%;

the difference of relative index of refraction of a first wrapping layer 4, namely Δn_4 , keeps stable, constantly 0; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the first wrapping layer 4 is 1.0;

the difference of relative index of refraction of a second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 falling within -0.3%, and b_5 falling within 0.1%;

the difference of relative index of refraction of a second wrapping layer 6, namely Δn_6 , keeps stable, constantly -0.3%; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of

the second wrapping layer 6 is 0.5;

the difference of relative index of refraction of a third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7 x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 falling within 0.1%, and b_7 falling within -0.3%;

according to FIG. 4, in this embodiment, the 1550nm attenuation of the small bending radius single-mode optical fiber is 0.193dB/km, the fusion loss between the small bending radius single-mode optical fiber and a conventional G.652 optical fiber reaches 0.11dB, and the additional loss under the bending radius of 2mm is below 0.332dB.

Embodiment 3:

this embodiment is of a structure basically the same as embodiment 1; the diameter D8 of a third wrapping layer 8 is 125 μ m; the difference of relative index of refraction of a core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, falling within 2%, and b_1 is gradient stability factor of the core gradient layer 1, falling within 0.1;

the difference of relative index of refraction of a germanium-doped core layer 2, namely Δn_2 , keeps stable, constantly 0.8%;

the difference of relative index of refraction of a first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3 x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, a_3 falling within 0.3, and b_3 falling within 0.8%;

the difference of relative index of refraction of a first wrapping layer 4, namely Δn_4 , keeps stable, constantly 0; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the first wrapping layer 4 is 0.5;

the difference of relative index of refraction of a second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5 x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 falling within -1.3%, and b_5 falling within 0%;

the difference of relative index of refraction of a second wrapping layer 6, namely Δn_6 , keeps stable, constantly -1.3%; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the second wrapping layer 6 is 0.2;

the difference of relative index of refraction of a third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7 x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 falling within 0.4%, and b_7 falling within -1.3%;

according to FIG. 4, in this embodiment, the 1550nm attenuation of the small bending radius single-mode optical fiber is 0.194dB/km, the fusion loss between the small bending radius single-mode optical fiber and a conventional G.652 optical fiber reaches 0.15dB, and the additional loss under the bending radius of 2mm is below 0.311dB.

Embodiment 4:

in this embodiment, the diameter D8 of a third wrapping layer 8 is 80 μ m; the difference of relative index of refraction of a core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 +$

$x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, falling within 0.5%, and b_1 is gradient stability factor of the core gradient layer 1, falling within 0;

the difference of relative index of refraction of a germanium-doped core layer 2, namely Δn_2 , keeps stable, constantly 0.2%;

the difference of relative index of refraction of a first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, a_3 falling within 0.8, and b_3 falling within 0.3%;

the difference of relative index of refraction of a first wrapping layer 4, namely Δn_4 , keeps stable, constantly 0; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the first wrapping layer 4 is 2.0;

the difference of relative index of refraction of a second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 falling within -0.75%, and b_5 falling within 0.06%;

the difference of relative index of refraction of a second wrapping layer 6, namely Δn_6 , keeps stable, constantly -0.9%; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the second wrapping layer 6 is 1.0;

the difference of relative index of refraction of a third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an

optical fiber at any point within the third transition layer 7 to a concentric circle around the centre of an optical fiber at the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 falling within 0.3%, and b_7 falling within -0.9%;

according to FIG. 5, in this embodiment, the 1550nm attenuation of the small bending radius single-mode optical fiber is 0.195dB/km, the fusion loss between the small bending radius single-mode optical fiber and a conventional G.652 optical fiber reaches 0.13dB, and the additional loss under the bending radius of 2mm is below 0.332dB.

Embodiment 5:

this embodiment is of a structure basically the same as embodiment 5; the diameter D8 of a third wrapping layer 8 is 80 μ m; the difference of relative index of refraction of a core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, falling within 1.3%, and b_1 is gradient stability factor of the core gradient layer 1, falling within 0.2;

the difference of relative index of refraction of a germanium-doped core layer 2, namely Δn_2 , keeps stable, constantly 0.6%;

the difference of relative index of refraction of a first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, a_3 falling within 0.6, and b_3 falling within 0.45%;

the difference of relative index of refraction of a first wrapping layer 4, namely Δn_4 , keeps stable, constantly 0; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the first

wrapping layer 4 is 0.9;

the difference of relative index of refraction of a second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5 x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 falling within -0.3%, and b_5 falling within 0.1%;

the difference of relative index of refraction of a second wrapping layer 6, namely Δn_6 , keeps stable, constantly -0.3%; the ratio of the thickness L2 of the germanium-doped core layer 2 to the thickness L4 of the second wrapping layer 6 is 0.4;

the difference of relative index of refraction of a third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7 x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors, a_7 falling within 0.1%, and b_7 falling within -0.3%;

according to FIG. 5, in this embodiment, the 1550nm attenuation of the small bending radius single-mode optical fiber is 0.197dB/km, the fusion loss between the small bending radius single-mode optical fiber and a conventional G.652 optical fiber reaches 0.16dB, and the additional loss under the bending radius of 2mm is below 0.312dB.

Embodiment 6:

this embodiment is of a structure basically the same as embodiment 5; the diameter D8 of a third wrapping layer 8 is 80 μ m; the difference of relative index of refraction of a core gradient layer 1 is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is the distance from any point within the core gradient layer 1 to the axis of said layer, a_1 is gradient factor of the core gradient layer 1, falling within

2%, and b_1 is gradient stability factor of the core gradient layer 1, falling within 0.1%;

the difference of relative index of refraction of a germanium-doped core layer 2, namely Δn_2 , keeps stable, constantly 0.8%;

the difference of relative index of refraction of a first transition layer 3 is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is the distance from a concentric circle around the centre of an optical fiber at any point within the first transition layer 3 to the outer edge of the germanium-doped core layer 2, and a_3 and b_3 are transition factors, a_3 falling within 0.3, and b_3 falling within 0.8%;

the difference of relative index of refraction of a first wrapping layer 4, namely Δn_4 , keeps stable, constantly 0.1%; the ratio of the thickness L_2 of the germanium-doped core layer 2 to the thickness L_4 of the first wrapping layer 4 is 0.5;

the difference of relative index of refraction of a second transition layer 5 is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_5^2 + b_5$, wherein x_5 is the distance from a concentric circle around the centre of an optical fiber at any point within the second transition layer 5 to the outer edge of the first wrapping layer 4, and a_5 and b_5 are transition factors, a_5 falling within -1.3%, and b_5 falling within 0;

the difference of relative index of refraction of a second wrapping layer 6, namely Δn_6 , keeps stable, constantly -1.3%; the ratio of the thickness L_2 of the germanium-doped core layer 2 to the thickness L_4 of the second wrapping layer 6 is 0.2;

the difference of relative index of refraction of a third transition layer 7 is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7x_7^2 + b_7$, wherein x_7 is the distance from a concentric circle around the centre of an optical fiber at any point within the third transition layer 7 to the outer edge of the second wrapping layer 6, and a_7 and b_7 are transition factors,

a_7 falling within 0.4%, and b_7 falling within -1.3%;

according to FIG. 5, in this embodiment, the 1550nm attenuation of the small bending radius single-mode optical fiber is 0.199dB/km, the fusion loss between the small bending radius single-mode optical fiber and a conventional G.652 optical fiber reaches 0.19dB, and the additional loss under the bending radius of 2mm is below 0.297dB.

The present invention is not limited to the above-mentioned embodiments. A person of ordinary skill in the technical field may make certain improvements or polishing without departing from the principle of the present invention; the improvements or polishing shall fall within the protection scope of the present invention. Those not described in detail in the specification shall be prior art known to persons professionally skilled in the field.

CLAIMS

1. A small bending radius single-mode optical fiber with compatibility with conventional G.652 optical fibers, comprising a core gradient layer and a germanium-doped core layer arranged concentrically, and a first wrapping layer, a second wrapping layer and a third wrapping layer arranged concentrically, wherein a first transition layer is arranged between the germanium-doped core layer and the first wrapping layer, a second transition layer is arranged between the first wrapping layer and the second wrapping layer, and a third transition layer is arranged between the second wrapping layer and the third wrapping layer;

a difference of relative index of refraction of the core gradient layer is Δn_1 , which is realized through an equation: $\Delta n_1 = a_1(x_1 + x_1^2 + x_1^3) + b_1$, wherein x_1 is a distance from any point within the core gradient layer to an axis of said core gradient layer, a_1 is gradient factor of the core gradient layer, ranging from 0.5% to 2%, and b_1 is gradient stability factor of the core gradient layer, ranging from 0 to 0.2%;

a difference of relative index of refraction of the first transition layer is Δn_3 , which is realized through an equation: $\Delta n_3 = b_3(1 - a_3x_3^2)^{0.5}$, wherein x_3 is a distance from a concentric circle around the centre of the small bending radius single-mode optical fiber at any point within the first transition layer to an outer edge of the germanium-doped core layer, and a_3 and b_3 are transition factors, both ranging from 0.3% to 0.8%;

a difference of relative index of refraction of the second transition layer is Δn_5 , which is realized through an equation: $\Delta n_5 = a_5x_5^2 + b_5$, wherein x_5 is a distance from a concentric circle around the centre of the

small bending radius single-mode optical fiber at any point within the second transition layer to an outer edge of the first wrapping layer, and a_5 and b_5 are transition factors, a_5 ranging from -1.0% to -0.3%, and b_5 ranging from 0 to 0.1%; and

a difference of relative index of refraction of the third transition layer is Δn_7 , which is realized through an equation: $\Delta n_7 = a_7 x_7^2 + b_7$, wherein x_7 is a distance from a concentric circle around the centre of the small bending radius single-mode optical fiber at any point within the third transition layer to an outer edge of the second wrapping layer, and a_7 and b_7 are transition factors, a_7 ranging from 0.1% to 0.4%, and b_7 ranging from -1.3% to -0.3%.

2. The small bending radius single-mode optical fiber according to claim 1, wherein the germanium-doped core layer has a thickness, wherein the first wrapping layer has a thickness, and wherein a ratio of the thickness of the germanium-doped core layer to the thickness of the first wrapping layer is from 0.5 to 2.0.

3. The small bending radius single-mode optical fiber according to claim 1, wherein the germanium-doped core layer has a thickness, wherein the second wrapping layer has a thickness, and wherein a ratio of the thickness of the germanium-doped core layer to the thickness of the second wrapping layer is from 0.2 to 1.0.

4. The small bending radius single-mode optical fiber according to claim 1, wherein a difference of relative index of refraction of the germanium-doped core layer is from 0.2% to 0.8%.

5. The small bending radius single-mode optical fiber according to claim 1, wherein a difference of relative index of refraction of the first wrapping layer is from 0 to 0.1%.

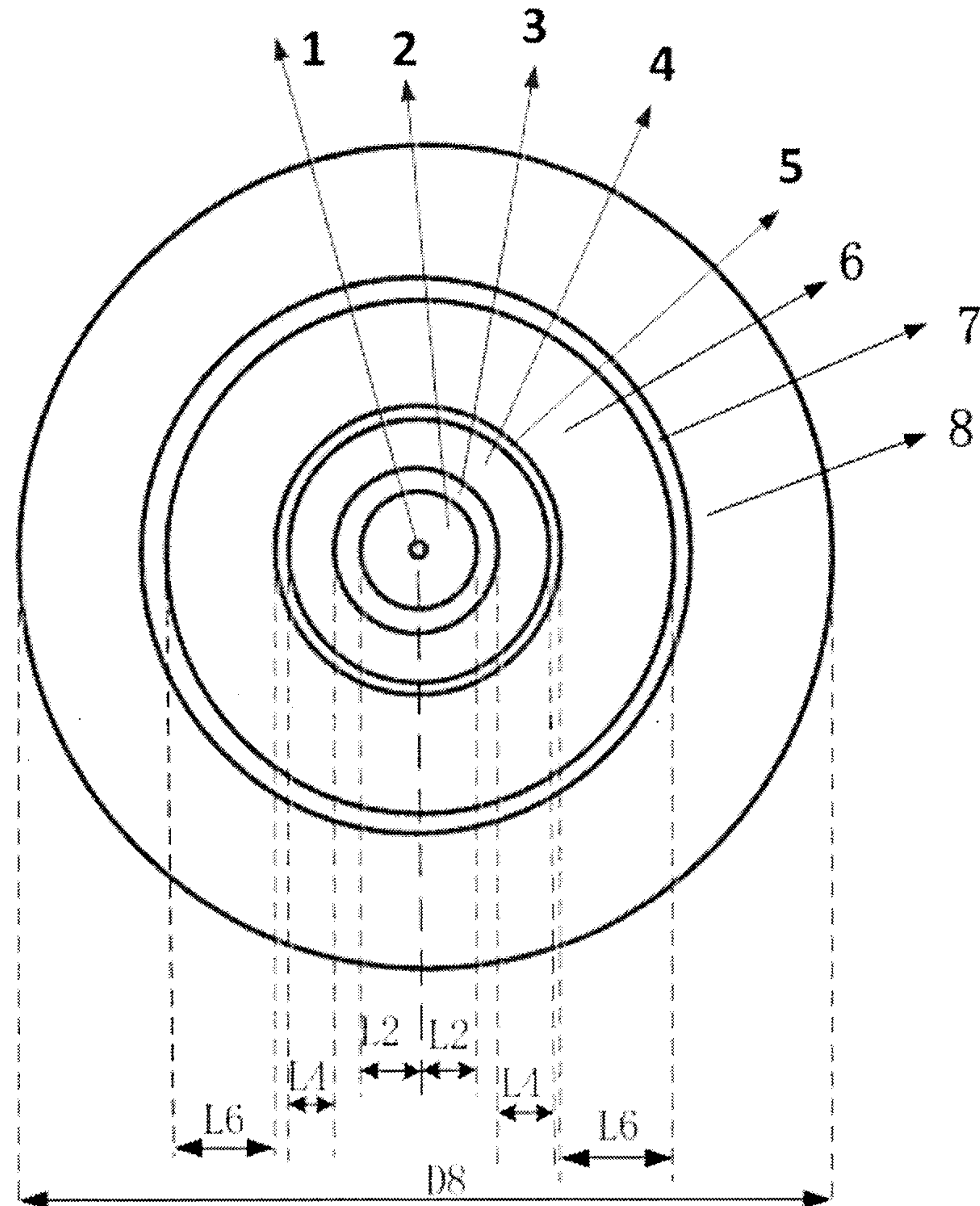
6. The small bending radius single-mode optical fiber according to claim 1, wherein a difference of relative index of refraction of the second wrapping layer is from -1.3% to -0.3%.

7. The small bending radius single-mode optical fiber according to claim 1, wherein the third wrapping layer, a quartz wrapping layer, has a diameter of 80 μ m.

8. The small bending radius single-mode optical fiber according to claim 1, wherein the third wrapping layer, a quartz wrapping layer, has a diameter of 125 μ m.

9. The small bending radius single-mode optical fiber according to claim 1, wherein when an operating wavelength is 1550nm, attenuation of the small bending radius single-mode optical fiber is below 0.2dB/km, and when a bending radius of the small bending radius single-mode optical fiber is below 2mm, additional loss is below 0.35dB.

DRAWING OF THE ABSTRACT



DRAWINGS OF THE SPECIFICATION

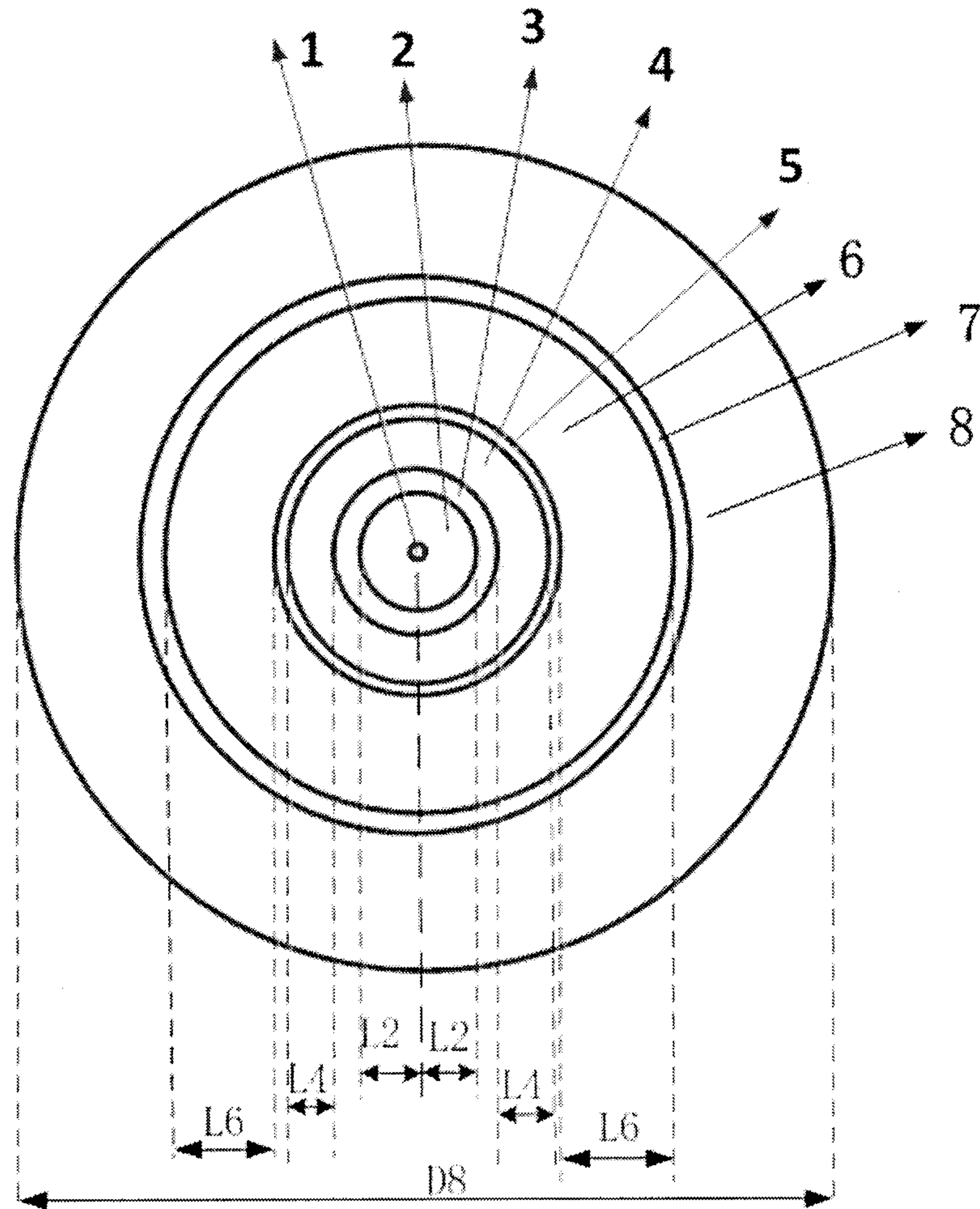


FIG. 1

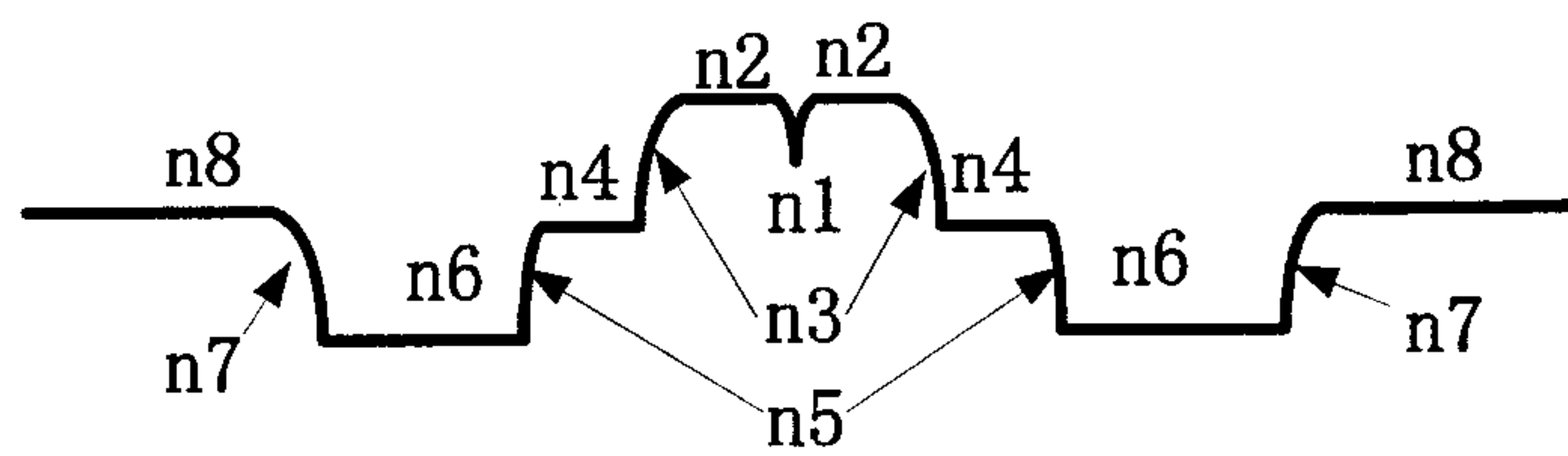


FIG. 2

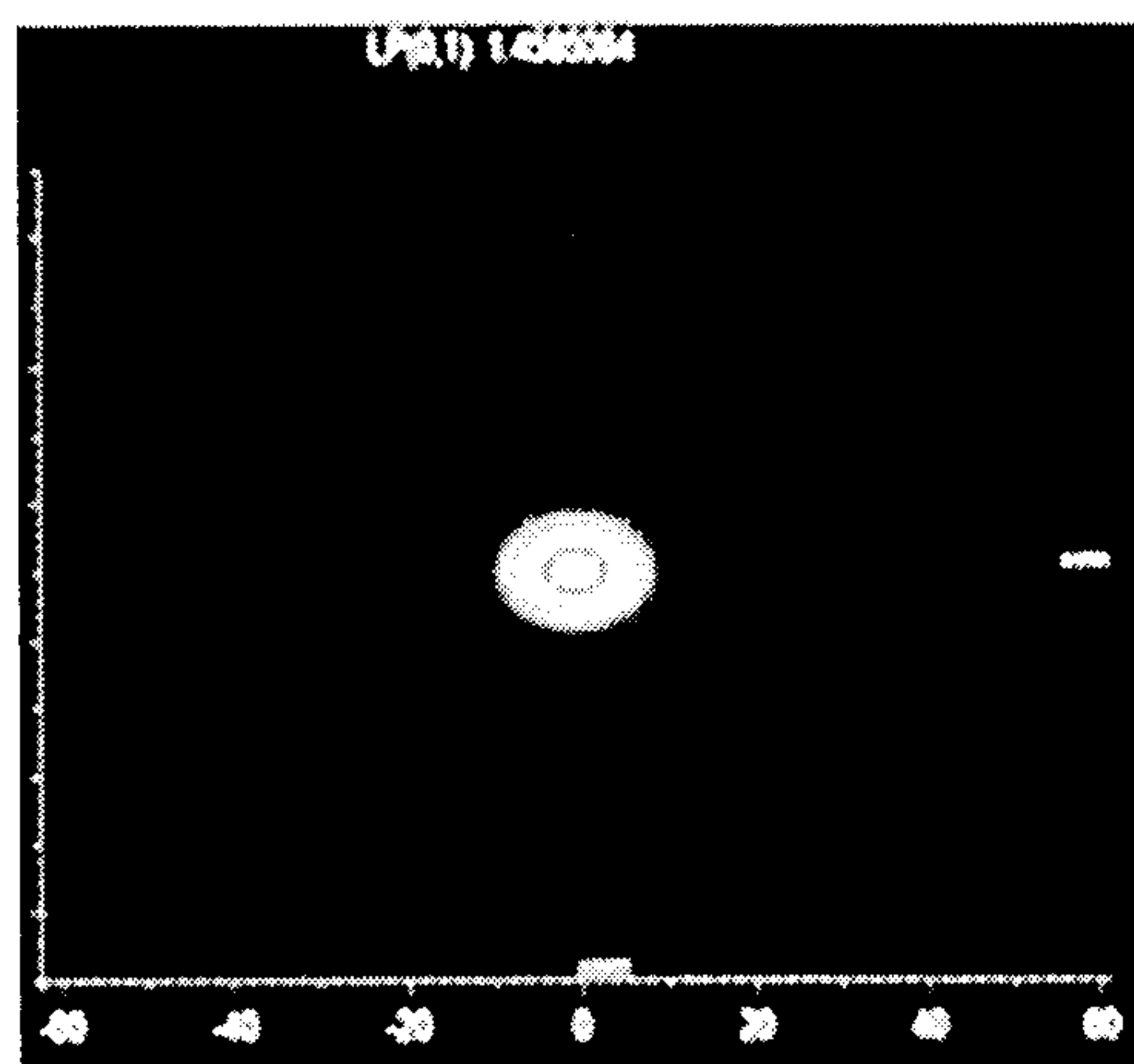


FIG. 3

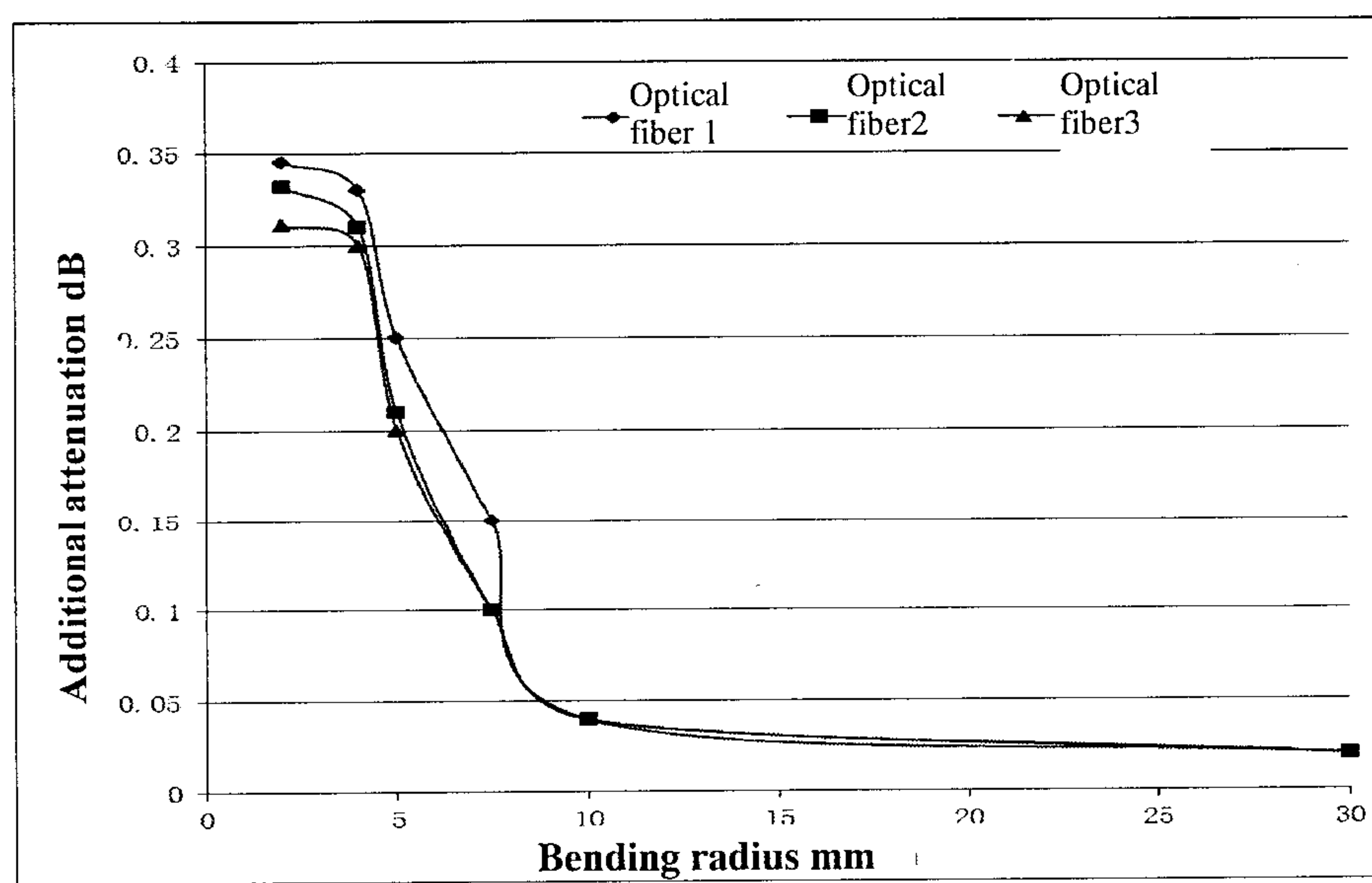


FIG. 4

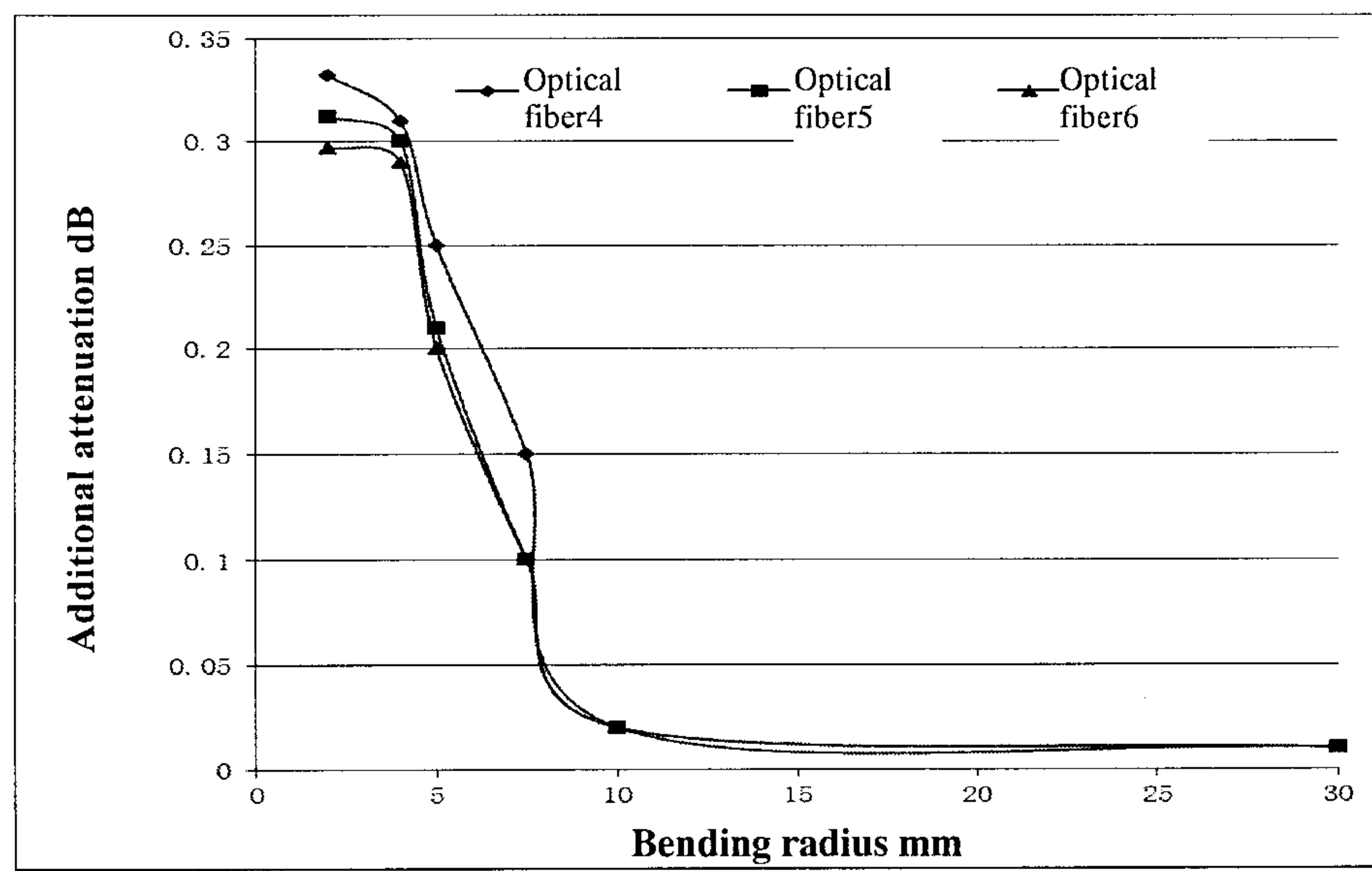


FIG. 5

