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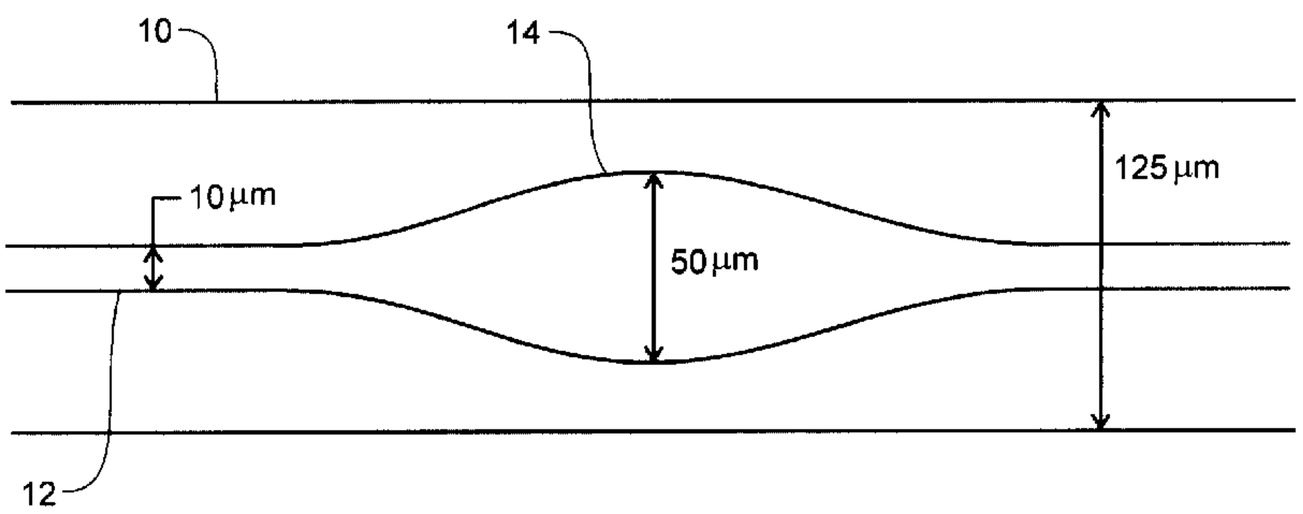
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(54) **ATTENUATEUR OPTIQUE ET SON PROCEDE DE FABRICATION**

(54) **OPTICAL ATTENUATOR AND METHOD OF MAKING SAME**



(57) A compact, tunable, wavelength independent, all-fiber attenuator is produced by heating a single-mode fiber to create at least a section of optical fiber having an expanded mode field therein. The attenuator may be tuned to achieve the desired value of attenuation and wavelength independence by imparting a small bend to the section having an expanded mode filed. An expanded mode field section can be achieved in ways other than heating the fiber, however using an optical fibre having a thermally expanded core section is preferred. The attenuator may be a fixed value attenuator or a variable attenuator. When a fixed value attenuator is desired, the expanded core section is bent suitably and the structure is encapsulated in an adhesive and glued onto a substrate. The mode field of the expanded core optical fibre should have substantially no attenuation when the expanded mode field portion of the optical fibre is un-bent.

Abstract of the Disclosure

A compact, tunable, wavelength independent, all-fiber attenuator is produced by heating a single-mode fiber to create at least a section of optical fiber having an expanded mode field therein. The attenuator may be tuned to achieve the desired value of attenuation and wavelength independence by imparting a small bend to the section having an expanded mode filed. An expanded mode field section can be achieved in ways other than heating the fiber, however using an optical fibre having a thermally expanded core section is preferred. The attenuator may be a fixed value attenuator or a variable attenuator. When a fixed value attenuator is desired, the expanded core section is bent suitably and the structure is encapsulated in an adhesive and glued onto a substrate. The mode field of the expanded core optical fibre should have substantially no attenuation when the expanded mode field portion of the optical fibre is un-bent.

OPTICAL ATTENUATOR AND METHOD OF MAKING SAME

Field of the Invention

This invention relates to an optical attenuator and more particularly to a compact, tunable, wavelength independent all-fiber optical attenuator produced by creating a mode-field expanded section within or optically coupled (for example by fusion splicing) with a single-mode fiber and, eventually, bending said structure to induce, adjust or control optical loss, which makes it possible to achieve a wavelength independent attenuator with the desired value of attenuation. The method of making such attenuator is also part of the invention.

Background of the Invention

In optical fiber communication systems, optical detectors are calibrated to function linearly in a given range of optical power. However, depending on the quality of the different connections and components in the system and on the power budget allowed in the design, the optical power available at the detector is often greater than the desirable upper limit of operation of the detector. An optical attenuator can be used to solve this problem. In other applications, optical attenuators can be used to balance the optical power between several lines of a system. They are also useful in calibrating systems at different power levels. In system design, they can be used in planning future development of a network by increasing the power budget available in case new connections are made.

The attenuators used in systems often have a fixed value of attenuation, and are usually packaged in a small robust case. The attenuation value normally covers a range from 1 dB to 25 dB or more. Attenuators used in testing equipment or procedure may have adjustable values. In both cases, attenuators that have a direct connection to the optical fiber have an advantage. A compact attenuator can also be easily integrated in a patch cord or cable, or even in a connector casing. Another important property is to have a very small wavelength dependence in the wavelength window or windows of operation.

Furthermore, it is often very important for the attenuator to have a very low back reflection in order not to perturb the optical fiber system.

In the prior art, various types of attenuators have been described and the following are examples of prior patents in this area:

U.S. Pat. No. 4,529,262 teaches an inline single-mode fiber attenuator which requires special polarization preserving fibers.

U.S. Pat. No. 4,697,869 discloses a variable attenuator is described comprising a bend mechanism with different radii.

U.S. Pat. No. 4,884,859 teaches an all-fiber optical attenuator made by heating a part of an optical fiber and applying a tension and/or twist to form an optical attenuator area having fine cracks in the heated part of the optical fiber. This attenuator is found not to be practicable in certain instances.

In U.S. Pat. No. 5,311,614 a continuously variable fiber optic attenuator is disclosed which is produced by bending at least a portion of an optical fiber which is supported by a resilient support member.

In U.S. Pat. No. 5,321,790 of Jun. 14, 1994 teaches an inline type optical attenuator which is formed by heating a portion of a single continuous optical fiber and then physically deforming said portion in the axial direction while maintaining it in a heated state. This attenuator cannot be used over a wide range of wavelengths.

U.S. Patent No. 5,694,512 incorporated herein by reference, discloses an all-fiber or inline type of optical attenuator which is formed by heating and then drawing a portion of a single mode continuous fibre which is then used as an attenuator by applying a small bend to the drawn narrowed section. Although this invention may be useful in some

instances where polarization dependent loss is not a consideration, this solution is found to be somewhat polarization dependent.

The instant invention provides, in a sense, an opposite solution to the '512 patent which narrows the core of the fibre. In the instant invention the core or mode field is expanded in a section where a controlled bend will be applied to achieve attenuation.

And, finally, UK patent application GB 2128766 A in the name of Harding et al, published May 2, 1984 discloses a single-mode optical fibre attenuator which provides a fixed an non-variable attenuation of light passing therethrough. The attenuator is based on creating a splice joint which is lossy, i.e. where light will leak out. Alternatively, it is suggested that suitable heat can be applied to the fibre other than a splice joint to provide an attenuator.

In nearly direct contrast to this, the instant invention provides a thermally expanded portion of the optical fibre, which exhibits nearly no loss when the fibre is unbent. Hence, the system operates as if there was no attenuator in-line in under normal circumstances when the bend radius of the fibre is greater than 30 cm. In practice it is possible to make a TEC region with and attenuation less than 0.1 dB. Furthermore, to attain a useful device as is defined in the claims of this invention, the optical fibre should not be heated to the melting point as is done for example during fusion splicing; by ensuring that the fibre is not overheated in this manner, a very low attenuation can be maintained i.e. substantially about or less than 1 or 2 dB within a straight region of this fibre. However, when such carefully fabricated expanded core optical fibre is bent sufficiently or at a plurality of locations, significant attenuation is attainable. In a preferred embodiment less than 0.5 dB of attenuation is attained within the straight region of the expanded core fibre.

The loss from the fibre described in the '766 UK patent application is a function of distortions in the core region of the fiber caused by the fusion or heating process which cause light to be scattered out of the core of the fiber even when the fiber is held straight, wherein the desired loss attained by bending the otherwise nearly lossless expanded core

optical fibre in accordance with the teaching of this invention is attributed to a controlled misalignment of a lensed fiber-to-fiber coupling system. In this system the TEC region of the fiber can be thought of as two adjacent ¼ pitch GRIN lenses which serve to first collimate the light in the fiber to an expanded beam at the mid-point of the TEC region and then refocus the light into the downstream fiber section. Attenuation is created by bending the TEC region which can be thought of as equivalent to misaligning two quarter pitch GRIN lenses so that they no longer focus the light into the downstream fiber with low loss.

Summary of the Invention

In accordance with the invention, there is provided a compact, tunable, all-fiber optical attenuator comprising:

a single mode optical fibre having a portion with a core diameter d1 and having a portion with a core diameter of d2 where d2 is substantially greater than d1;

means for controllably imparting at least a small bend to the portion of the fibre having a core diameter d2 to provide a controlled amount of attenuation.

In accordance with the invention there is further provided, a compact, tunable, all-fiber optical attenuator comprising:

a single mode optical fibre having mode field diameter d_1 and having one or more sections with a mode field diameter of d_2 where d_2 is substantially greater than d_1;

a mechanism for controllably imparting at least a small bend to the portion of the fibre having a core diameter d_2 to provide a controlled amount of attenuation.

In accordance with another aspect of the invention there is provided a method of attenuating a beam of light in a controlled and wavelength independent manner comprising the steps of:

launching the beam of light into a portion of optical fibre having a thermally expanded core (TEC); and,

in a controlled manner, applying at least a small bend to the portion of TEC optical fibre to achieve a desired amount of attenuation.

According to the present invention there is provided an all-fiber attenuator which is compact, tunable, wavelength independent over a range of several hundred nanometers and has negligible back reflection. Depending on the final packaging, it can be either fixed and be very stable with the environment, or have an adjustable value. It is made by creating a TEC structure on a single-mode fiber and bending said TEC structure to adjust or control the optical loss of the attenuator. One or a plurality of expanded mode field sections may be created. The expanded mode field section or sections of the fiber is/are formed by heating the fiber without subjecting it to any physical distortion such as pulling, pushing, twisting or the like. Another application using an expanded mode field fibre is described in the a patent in the name of one of the applicant's entitled A Method of Reducing Unwanted Effects Associated with High Power Density at an Optical Connector Coupling, now issued as U.S. Patent No. 5,594,825 issued January 14, 1997.

In the preferred embodiments of the invention, since there is no discontinuity in the fiber, this attenuator has negligible back reflection. Its typical size is smaller than 4 mm long, and the bend radius, when bending is performed, is normally in the range of 1 cm to 10 cm.

The attenuator of the present invention is fabricated by creating one or more expanded mode field sections on the single-mode fiber, preferably by approaching a small heat source, such as a micro-torch, to the fiber for a period of time of about 30 minutes. Once the heat source is removed, the mode field of the single mode fibre is expanded from ~10μm to ~30-50μm; the level of attenuation can be adjusted or controlled by bending the expanded mode field section or sections. One way the bend can be achieved is by compressing the structure.

The present invention has small levels of polarization dependent loss (PDL) since the attenuation occurs as a result of a portion of the light propagating within the expanded

mode field section, not coupling into its destination single mode fibre, after the TEC or expanded mode field section. The result is an almost wavelength independent attenuated spectral response with little PDL.

Advantageously, the attenuator described hereafter, in accordance with this invention, is suitable and capable of attenuating high power optical signals, without resulting in damage to the attenuator.

Brief Description of the Drawings

Exemplary embodiments of the invention will now be described in conjunction with the drawings in which:

Fig. 1 is a side view of a optical fiber having a thermally expanded mode field diameter as is known in the prior art;

Fig. 2 is a side view of an optical fibre having a section with a mode field expanded core wherein that section is shown to be held in a bent position by a positioning device;

Fig. 3 is a block diagram depicting the optical fibre attenuator with feedback control circuitry; and,

Fig. 4 is a side view of an attenuator in accordance with an embodiment of the invention wherein a plurality of sections having mode field expanded cores are utilized, to reduce PDL.

Fig. 5 is a side view of an embodiment similar to that of Fig. 4, wherein a plurality of sections having mode field expanded cores are utilized, to reduce PDL.

Detailed Description

"Since the core diameter of fiber is not always precisely measurable, due to diffusion effects, reference is usually made to the "mode field diameter" or "MFD", and the kind of fiber with an expanding core may be termed "expanded MFD" fiber. Such a fiber is disclosed in a reference entitled "Beam Expanding Fiber Using Thermal Diffusion of the Dopant" in Journal of Lightwave Technology. Vol. 8, No. 8 August 1990. The beam

expanding fiber of the above reference has a core whose index of refraction is determined by the dopant e.g., Ge, that is thermally diffused so that a spot size of the fundamental mode, which corresponds to the mode-field diameter of the optical fiber, is partially expanded. Fibers produced by such methods are known as "Thermally-diffused Expanded Core" or TEC fibers. For convenience, the term "expanding core fiber" will be used to include all such beam expanding type fibers. This method has been conventionally used because of its practicality.

The enlarged mode filed diameter (MFD) of thermally-diffused expanded core (TEC) optical fibre is obtained by diffusing the dopant in the core. The manufacture of TEC fibres using a reproducible fabrication technique with a MFD of 40 μm while preserving the outer diameter, is described in a paper entitled Fabrication of an Expanded Core Fiber Having MFD of 40 μm While Preserving the Outer Diameter, IEEE Photonics Technology Letters, Vol 6, No. 7 July 1994, by Osamu Hanaizumi, Yoshizo Aizawa, Hiroaki Minamide, and Shojiro Kawakami. Ge-doped silica single-mode fibers (SMFs) are used in the experiment. The heat treatment of the fiber is performed by a electric cylindrical furnace, as schematically shown in Fig. 1. In the Hanaizumi paper. Fibers are put into a silica vacuum tube after stripping off the protective-coating layer. The silica tube is set perpendicularly. In this paper it is said that diffusion at high temperature and for a long time is required for realizing larger MFD.

In another paper entitled High-performance lensless in-line filters by Yimin Wang, Takashi Sato, Junichiro Minowa, and Haruki Kataoka published in Applied Opticss Vol. 34, No. 4, 1 February, 1995 the process of Fabricating TEC fibres is well described.

Referring now to Fig. 1, a conventional thermally expanded core (TEC) optical fiber 10 is shown. The fiber 10 is typical single mode fiber having a core diameter 12 throughout most of its length 10 μm; through the application of heat by flame, by a resistive heater, or by conduction, a 3 mm to 5 mm portion 14 of the fiber end is expanded to have a mode field diameter (MFD) of between 20 to 50 μm.

Turning now to Fig. 2, an arrangement is shown, wherein the optical fibre is bent about two posts 22a and 22b when a force is applied on the TEC section 14 by an adjustable screw-like macrobending member 20. Of course a motor and control circuitry (now shown) is adapted to turn the screw to achieve a desired amount of attenuation. The control circuitry is responsive to an optical tap monitor so that a desired amount of attenuation can be maintained. This is shown schematically in Fig. 3.

In Fig. 3 a tap is provided by a filter 32 which provides a 1% tap signal to a detector 36. The detector 36 provides a electrical signal proportional to the power of the optical signal launched into an input end of the optical fibre 10. This electrical signal is provided to a control circuit for example in the form of a suitably programmed microcontroller 37 which provides a control signal to the motor 38. This feedback loop allows constant monitoring and adjustment of the attenuator.

Referring now to Fig. 4, an attenuator is shown wherein a plurality of sections 40a, 40b, 40c, 40d are shown having thermally expanded cores. Conveniently, these sections can be one contiguous section of mode field expanded fibre or alternatively as is shown in Fig. 5, can be separate spaced sections. A form shaped to conform with the shape shown in Fig. 4 can be used having two similar sides to press in the fibre (by varying amounts) to form the sine like length of fibre to achieve a controlled attenuation.

Of course in a more simple embodiment, the optical fibre shown in Fig. 1 can be bent a predetermined or suitable amount and then can be held in place with an adhesive to provide a fixed attenuator.

Numerous other embodiments may be envisaged, without departing from the spirit and scope of the invention.

Claims

What is claimed is:

1. A compact, tunable, all-fiber optical attenuator comprising:
a single mode optical fibre having a portion with a mode field diameter d1 and having a portion with a mode field diameter of d2 where d2 is substantially greater than d1;
means for controllably imparting at least a small bend to the portion of the fibre having a mode field diameter d2 to provide a controlled amount of attenuation, the single mode optical fibre being such that light propagating through a straight un-bent length including the portion having a mode field diameter of d1 and the portion having a mode field diameter d2 is substantially un-attenuated.

2. A compact, tunable all-fibre optical attenuator as defined in claim 1, wherein the amount of attenuation caused by passing light through the straight un-bent length of expanded mode field optical fibre is less than 0.5 dB.

3. A compact, tunable all-fibre optical attenuator as defined in claim 2, wherein the attenuator is substantially wavelength independent, and wherein the portion of the fiber having a mode field or core diameter d2 has been thermally expanded.

4. A compact, tunable all-fibre optical attenuator as defined in claim 1, wherein the portion of the fibre with a mode field or core diameter d_1 and the portion having a mode field or core diameter d_2 are portions of one contiguous section of optical fibre.

5. A compact, tunable all-fibre optical attenuator as defined in claim 1, wherein the portion of the fibre with a mode field or core diameter d_1 and the portion having a mode field or core diameter d_2 are different separate sections of optical fibre that have been optically coupled together to form a single waveguide.

6. A compact, tunable all-fibre optical attenuator as defined in claim 1, wherein the means for imparting at least a small bend is a mechanical means, the optical attenuator further comprising control circuitry coupled to the mechanical means for controllably controlling an amount of attenuation upon a beam launched into the single mode optical fibre.

7. A compact, tunable all-fibre optical attenuator as defined in claim 1, wherein a plurality of sections of the single mode optical fibre have expanded cores each having a mode field diameter of at least d_2.

8. A compact, tunable, all-fiber optical attenuator comprising:
a single mode optical fibre having mode field diameter d_1 and having one or more sections with a mode field diameter of d_2 where d_2 is substantially greater than d_1;
a mechanism for controllably imparting at least a small bend to the portion of the fibre having a core diameter d_2 to provide a controlled amount of attenuation, the single mode optical fibre being such that light propagating through a straight un-bent length including the portion having a mode field diameter of d1 and the portion having a mode field diameter d2 is substantially un-attenuated.

9. A compact, tunable, all-fibre optical attenuator as defined in claim 8, wherein the mechanism for controllable imparting at least a small bend is a microbending or macrobending mechanism.

10. A compact, tunable, all-fibre optical attenuator as defined in claim 8, comprising a plurality of spaced apart sections having an expanded mode field diameter of at least d_2, the spaced apart sections being separated from other expanded mode field diameter sections by single mode fibre having a diameter of d_1.

11. A compact, tunable all-fibre optical attenuator as defined in claim 10, wherein the expanded mode field diameter sections are provided within the single mode optical fibre

having a diameter of d_1 by heating the single mode optical fibre at various spaced locations with a suitable heat for a suitable length of time.

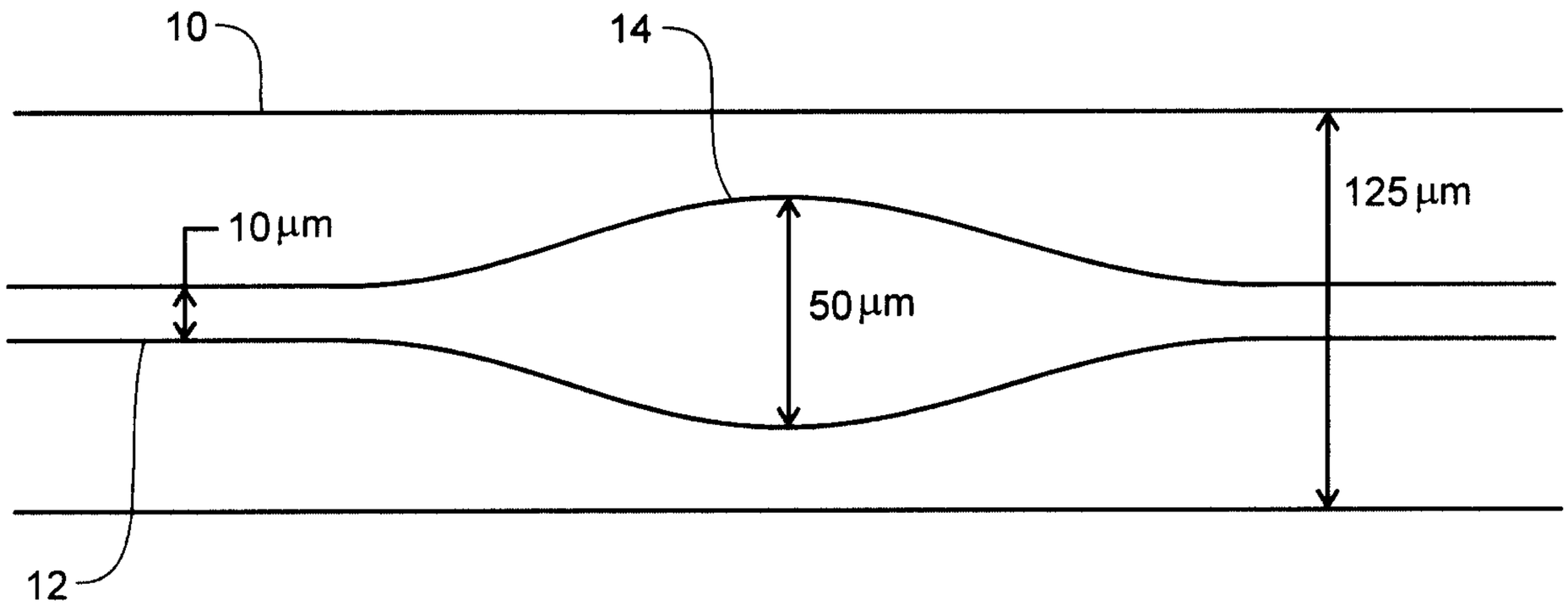
12. A method of attenuating a beam of light in a controlled and wavelength independent manner comprising the steps of:
launching the beam of light into a portion of optical fibre having a thermally expanded core (TEC); and,
in a controlled manner, applying at least a small bend to the portion of TEC optical fibre to achieve a desired amount of attenuation, the TEC optical fibre having substantially little attenuation when it is unbent.

13. a method of attenuation a beam of light as defined in claim 12, wherein the substantially little attenuation is less than 1 dB.

14. A method of attenuating a beam of light in a controlled and wavelength independent manner as defined in claim 12, wherein the step of launching the beam comprises:
launching the beam of light into a portion of optical fibre having a plurality of thermally expanded core (TEC) sections; and,
in a controlled manner, applying at least a small bend to at least some of the TEC sections of optical fibre to achieve a desired amount of attenuation.

15. A method as defined in claim 12 wherein the TEC optical fibre has been made by heating the optical fibre to significantly less than the melting point of the optical fibre.

Figure 1



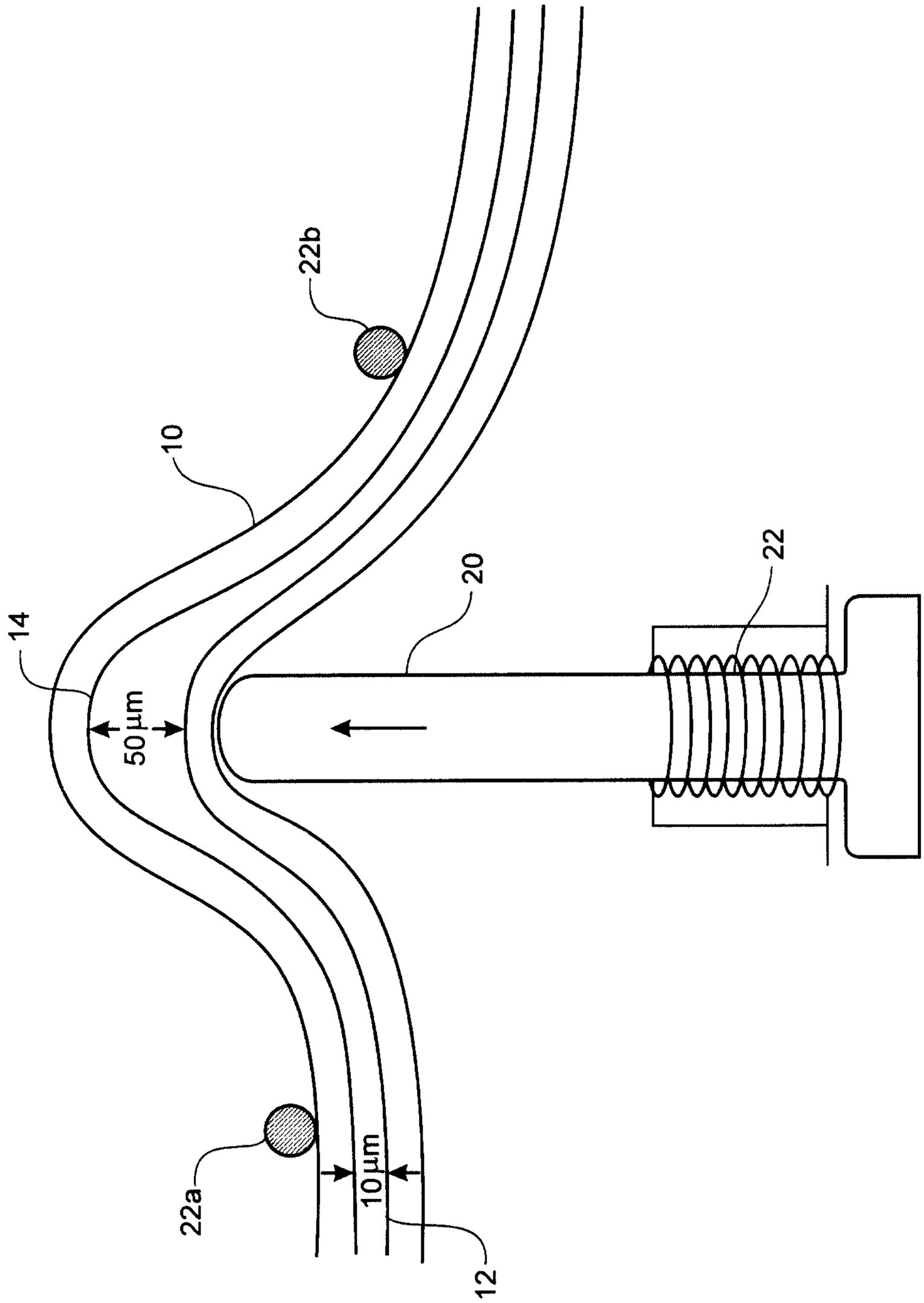


Figure 2

Figure 3

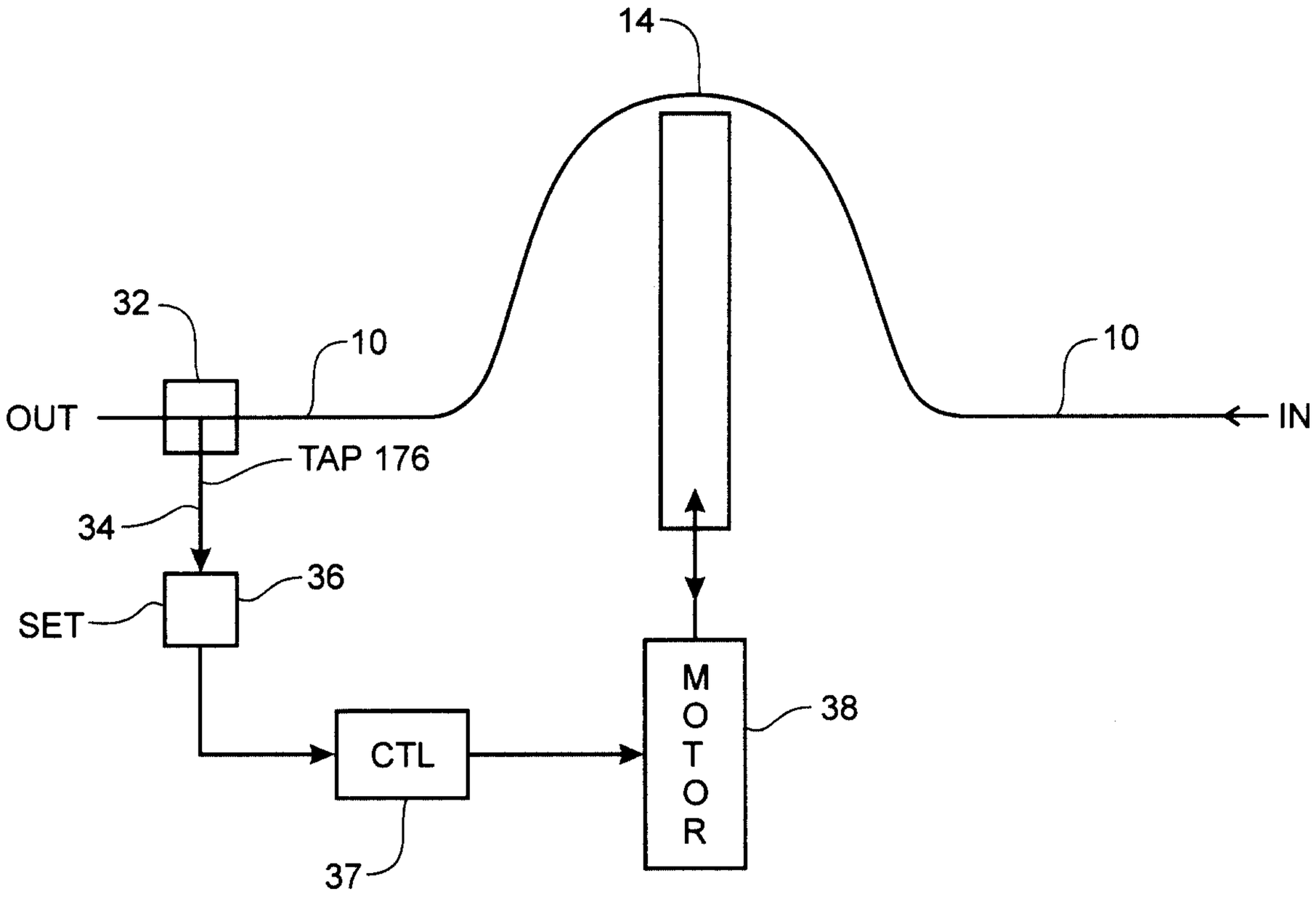


Figure 4

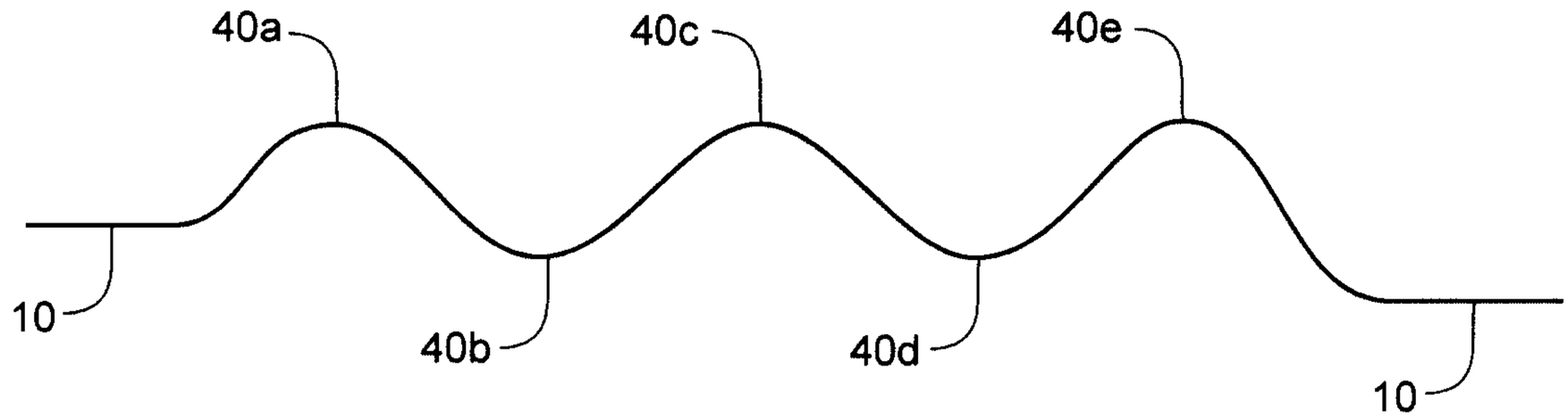
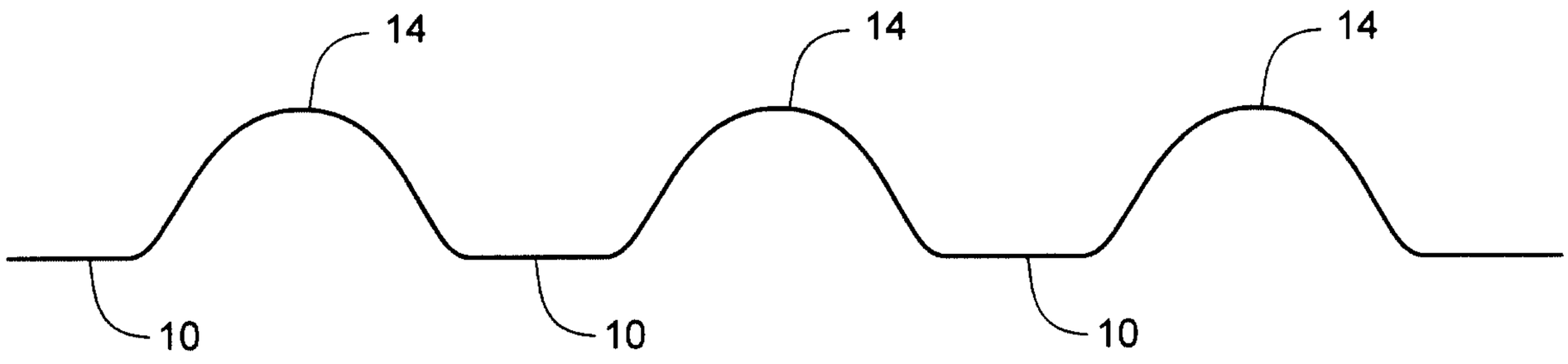
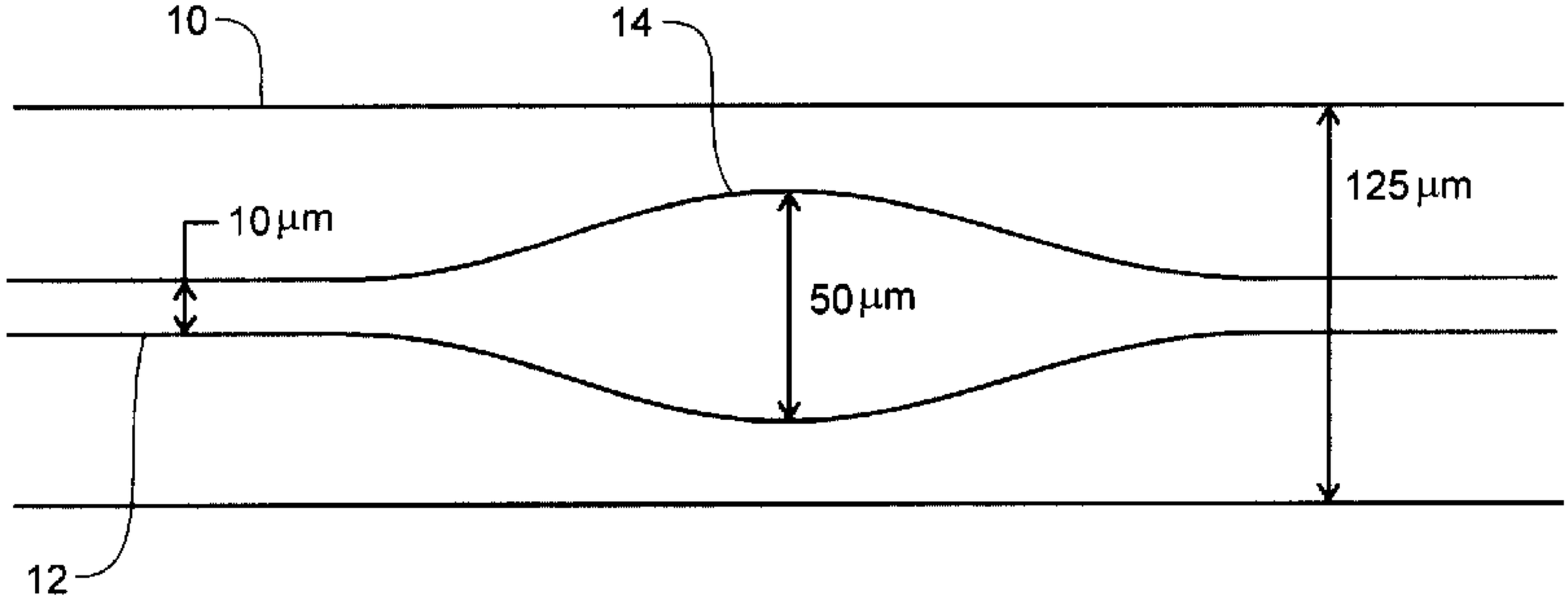


Figure 5




10
14
125 µm
10 µm
50 µm
12