(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 September 2008 (04.09.2008)

PCT

(10) International Publication Number
WO 2008/106065 A1

(51) International Patent Classification:
G02B 6/38 (2006.01) *G01B 11/27* (2006.01)
G01B 5/25 (2006.01)

(21) International Application Number:
PCT/US2008/002415

(22) International Filing Date:
25 February 2008 (25.02.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/712,036 28 February 2007 (28.02.2007) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, 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, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(54) **Title:** MULTI-FIBER FERRULES AND ASSOCIATED METHOD OF MANUFACTURE

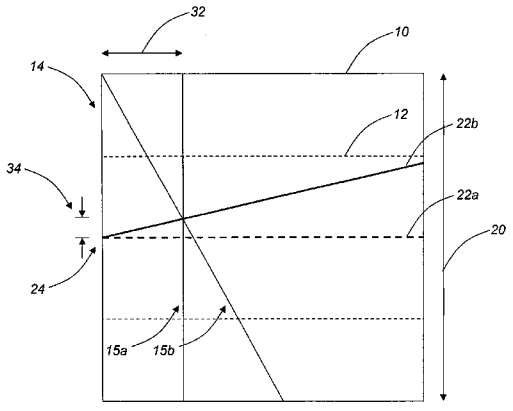

FIG. 3

(57) **Abstract:** The present invention provides a method of manufacture that minimizes the lateral offset of a plurality of optical fiber holes associated with a multi-fiber ferrule, including: determining an initial offset distance of each of the plurality of optical fiber holes from each of a plurality of corresponding target locations on an initial endface of a test multi-fiber ferrule; removing a predetermined amount of material from ^,the test multi-fiber ferrule to form a subsequent endface; determining a subsequent offset distance of each of the plurality of optical fiber holes from each of the plurality of corresponding target locations on the subsequent endface; and determining an angle of each of the plurality of optical fiber holes relative to the initial endface. The method of manufacture also includes, using the angle, determining an optimal amount (32) of material that is removed from another similarly situated multi-fiber ferrule in order to minimize the offset distance of the plurality of optical fiber holes (22b) from the plurality of corresponding target locations (34). The method of manufacture further includes, removing this amount of material.

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MULTI-FIBER FERRULES AND ASSOCIATED METHOD OF MANUFACTURE

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates generally to multi-fiber (MF) ferrules used to connect optical fibers and devices within optical communications networks. More specifically, the present invention relates to angle-specific, lateral offset-optimized MF ferrules and associated methods of manufacture.

Technical Background of the Invention

[0002] A conventional MF ferrule includes two guide pin holes or bores and a plurality of optical fiber holes or bores that are disposed substantially between the two guide pin holes. Two MF ferrules are assembled together and optically coupled using two guide pins that are disposed in the two guide pin holes of each of the MF ferrules, aligning the plurality of optical fiber holes and corresponding plurality of optical fibers. The same mechanism is often used to assemble together and optically couple an MF ferrule and a device. The alignment of each of the optical fiber holes from one MF ferrule to another, or from one MF ferrule to a device, is critical in order to achieve low insertion or connectivity loss. The farther the plurality of optical fiber holes are from their desired target locations, due to manufacturing tolerances, for example, the higher the insertion loss. In general, a 1.3μm radial offset for one MF ferrule is considered to be acceptable. This is true for MF ferrules with both flat and pre-angled (8-degree) endfaces.

[0003] As of yet, there is an unresolved need for methods of manufacture that minimize the lateral offset of the plurality of optical fiber holes associated with MF ferrules. This problem is exacerbated by the fact that, as optical fiber and ferrule materials are removed from the endface of an MF ferrule, such as during polishing, for example, this lateral

offset often changes, both in degree and potentially direction, becoming more or less pronounced in an unpredictable manner. This is caused by the fact that, due to manufacturing tolerances, for example, each of the optical fiber holes may be angled with respect to the endface of the MF ferrule. The methods of manufacture that minimize the lateral offset of the plurality of optical fiber holes associated with the MF ferrule should take advantage of this lateral offset change.

BRIEF SUMMARY OF THE INVENTION

[0004] In various embodiments, the present invention provides methods of manufacture that minimize the lateral offset of the plurality of optical fiber holes associated with an MF ferrule. These methods of manufacture take advantage of the lateral offset change described above, considering the position of the plurality of optical fiber holes before and after optical fiber and ferrule materials are removed from the endface of the MF ferrule, such as during polishing, for example. It should be noted that "gapping" or "tilting" also increases insertion loss, but is not specifically addressed by the methods of manufacture of the present invention (although they may have advantageous effects related thereto). As used herein, "MF ferrule" refers variously to 2f, 4f, 8f, 12f, 24f, 32f, 48f, 72f, etc. ferrules. Application to single-fiber (1f) ferrules is also contemplated herein.

[0005] In one embodiment, the present invention provides a method of manufacture that minimizes the lateral offset of a plurality of optical fiber holes associated with a multi-fiber ferrule, including: determining an initial offset distance of an optical fiber hole from a target location in one or more directions on an initial endface of a multi-fiber ferrule; removing a predetermined amount of material from the multi-fiber ferrule to form a subsequent endface of the multi-fiber ferrule; determining a subsequent offset distance of the optical fiber hole from the target location in the one or more directions on the subsequent endface of the multi-fiber ferrule; and, using the initial offset distance of the optical fiber hole and the subsequent offset distance of the optical fiber hole, determining

an angle of the optical fiber hole relative to the initial endface of the multi-fiber ferrule. The method of manufacture also includes, using the angle of the optical fiber hole, determining an optimal amount of material that is removed from the multi-fiber ferrule in order to minimize the offset distance of the optical fiber hole from the target location. The method of manufacture further includes, using the optimal amount of material that is removed from the multi-fiber ferrule, removing this amount of material from another similarly-situated multi-fiber ferrule.

[0006] In another embodiment, the present invention provides a method of manufacture that minimizes the lateral offset of a plurality of optical fiber holes associated with a multi-fiber ferrule, including: determining an initial offset distance of each of a plurality of optical fiber holes from each of a plurality of corresponding target locations in one or more directions on an initial endface of a multi-fiber ferrule; removing a predetermined amount of material from the multi-fiber ferrule to form a subsequent endface of the multi-fiber ferrule; determining a subsequent offset distance of each of the plurality of optical fiber holes from each of the plurality of corresponding target locations in the one or more directions on the subsequent endface of the multi-fiber ferrule; and, using the initial offset distance of each of the plurality of optical fiber holes and the subsequent offset distance of each of the plurality of optical fiber holes, determining an angle of each of the plurality of optical fiber holes relative to the initial endface of the multi-fiber ferrule. The method of manufacture also includes, using the angle of each of the plurality of optical fiber holes, determining an optimal amount of material that is removed from the multi-fiber ferrule in order to minimize the offset distance of the plurality of optical fiber holes from the plurality of corresponding target locations. The method of manufacture further includes, using the optimal amount of material that is removed from the multi-fiber ferrule, removing this amount of material from another similarly-situated multi-fiber ferrule.

[0007] In a further embodiment, the present invention provides a multi-fiber ferrule formed by a method of manufacture, comprising: determining an initial offset distance of an optical fiber hole from a target location in one or more directions on an initial endface of a test multi-fiber ferrule; removing a predetermined amount of material from the test multi-fiber ferrule to form a subsequent endface of the test multi-fiber ferrule; determining a subsequent offset distance of the optical fiber hole from the target location in the one or more directions on the subsequent endface of the test multi-fiber ferrule; and, using the initial offset distance of the optical fiber hole and the subsequent offset distance of the optical fiber hole, determining an angle of the optical fiber hole relative to the initial endface of the test multi-fiber ferrule. The method of manufacture also includes, using the angle of the optical fiber hole, determining an optimal amount of material that is removed from the multi-fiber ferrule in order to minimize the offset distance of the optical fiber hole from the target location. The method of manufacture further includes, using the optimal amount of material that is removed from the multi-fiber ferrule, removing this amount of material from the multi-fiber ferrule.

[0008] It is to be understood that both the foregoing general description and the following detailed description provide exemplary embodiments of the present invention, and an overview or framework for understanding the nature and character of the present invention as it is claimed. The accompanying drawings are included in order to provide a further understanding of the present invention, and are incorporated into and constitute a part of this specification. The accompanying drawings illustrate the various exemplary embodiments of the present invention, and together with the detailed description, serve to explain the principles of operation thereof. The accompanying drawings are meant to be illustrative, and not limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention is illustrated and described herein with reference to the various drawings, in which like reference numbers are used to denote like method steps and/or device components, as appropriate, and in which:

[0010] FIG. 1 is a perspective view of the endface of an MF ferrule that includes two guide pin holes and a plurality of optical fiber holes that are disposed substantially between the two guide pin holes, the perspective view including an overlaid graph.

[0011] FIG. 2 is an isolated view of a portion of the overlaid graph of **FIG. 1**, illustrating the determination of the radial offset of a given optical fiber hole.

[0012] FIG. 3 is a cross-sectional side view of an illustrative MF ferrule that includes a single guide pin hole and a single optical fiber hole, illustrating the lateral offset change of the optical fiber hole that occurs during the polishing process, for example, for both flat and pre-angled configurations.

[0013] FIG. 4 is a cross-sectional side view of another illustrative MF ferrule that includes a single guide pin hole and a single optical fiber hole, illustrating the exploitation of the lateral offset change of the optical fiber hole that occurs during the polishing process, for example, for both flat and pre-angled configurations.

[0014] FIG. 5 is a plot illustrating the X-offset of an 8f MF ferrule both before polishing in a flat endface configuration and after polishing in an angled endface configuration.

[0015] FIG. 6 is a plot illustrating the Y-offset of the 8f MF ferrule both before polishing in the flat endface configuration and after polishing in the angled endface configuration.

[0016] FIG. 7 is a plot illustrating the X-pinbending offsets from nominal as a function of the distance from the endface.

[0017] FIG. 8 is a plot illustrating the Y-pinbending offsets from nominal as a function of the distance from the endface.

DETAILED DESCRIPTION OF THE INVENTION

[0018] In various embodiments, the present invention provides methods of manufacture that minimize the lateral offset of the plurality of optical fiber holes associated with an MF ferrule. These methods of manufacture take advantage of the lateral offset change described above, considering the position of the plurality of optical fiber holes before and after optical fiber and ferrule materials are removed from the endface of the MF ferrule, such as during polishing, for example. Again, it should be noted that "gapping" or "tilting" also increases insertion loss, but is not specifically addressed by the methods of the present invention (although they may have advantageous effects related thereto).

[0019] Referring to **FIG. 1**, given an MF ferrule **10**, the center **12** of the endface **14** between the two guide pin holes **16** (and, specifically, between the centers of the two guide pin holes **16**) is selected as the origin **12** of the X-axis **18** and Y-axis **20** of the endface **14**. The target location **24** (**FIGS. 2-4**) of each of the optical fiber holes **22** is measured along the X-axis **18** and Y-axis **20**. This hypothetical distance of each of the optical fiber holes **22** from the origin **12** along the X-axis **18** and Y-axis **20** represents the target X-offset and Y-offset of each of the optical fiber holes **22**, respectively. In an ideal case, the target X-offset for each of the optical fiber holes **22** is a predetermined value, while the target Y-offset for each of the optical fiber holes **22** is zero (i.e., the optical fiber holes **22** lie substantially along the X-axis **18**).

[0020] Referring to **FIG. 2**, the distance of each of the optical fiber holes **22** from the target location **24** of each of the optical fiber holes **22** along the X-axis **18** (**FIG. 1**) and Y-axis **20** (**FIG. 1**) represents the observed X-offset **26** and Y-offset **28** of each of the optical fiber holes **22**, respectively. The observed X-offset **26** and Y-offset **28** are used to calculate the radial offset **30** of the corresponding optical fiber hole **22**, indicating where the optical fiber hole **22** actually is in relation to where it should be. This initial radial offset **30** is calculated for each of the optical fiber holes **22**. The optical fiber hole **22** with the greatest radial offset **30** establishes the maximum radial offset (RMAX). RMAX is used to determine whether a given MF ferrule **10** (**FIG. 1**) is initially within or outside of specification with respect to optical fiber hole location. Other specifications must be met as well, including guide pin hole location, hole diameter, etc.

[0021] Once the MF ferrule **10** (**FIG. 1**) is assembled with the plurality of optical fibers and related hardware, the endface **14** (**FIG. 1**) of the MF ferrule **10** is polished in order to remove excess optical fiber and endface materials and provide an acceptable mating surface. Typically, about 50μm of optical fiber and ferrule materials are removed from the endface **14**. As these optical fiber and ferrule materials are removed from the endface **14**, the lateral offset (and the corresponding insertion loss) of each of the optical fiber holes **22** often changes, both in degree and potentially direction, becoming more or less pronounced in an unpredictable manner. This is caused by the fact that, due to manufacturing tolerances, for example, each of the optical fiber holes **22** may be angled with respect to the endface **14** of the MF ferrule **10**.

[0022] This is shown in **FIG. 3**, which illustrates an illustrative MF ferrule **10** including a single guide pin hole **12** and a single optical fiber hole **22** (specifically, an ideal, non-angled optical fiber hole **22a** and an actual, angled optical fiber hole **22b**). Prior to polishing, for example, both the ideal, non-angled optical fiber hole **22a** and the actual, angled optical fiber hole **22b** intersect the endface **14** of the MF ferrule **10** at the target location **24**, for example. However, subsequent to polishing, for example, and the

removal of a predetermined amount of optical fiber and ferrule materials **32**, the lateral offset **34** between the ideal, non-angled optical fiber hole **22a** and the actual, angled optical fiber hole **22b** at the resulting endface **15** (flat **15a** or pre-angled **15b**) of the MF ferrule **10** has a given X-component, Y-component, and, therefore, radial component.

[0023] Referring again to **FIG. 2**, the distance of each of the optical fiber holes **22** from the target location **24** of each of the optical fiber holes **22** along the X-axis **18** (**FIG. 1**) and Y-axis **20** (**FIG. 1**) represents the observed X-offset **26** and Y-offset **28** of each of the optical fiber holes **22**, respectively. The observed X-offset **26** and Y-offset **28** are again used to calculate the radial offset **30** of the corresponding optical fiber hole **22**, indicating where the optical fiber hole **22** actually is in relation to where it should be. This subsequent radial offset **30** is calculated for each of the optical fiber holes **22**. The optical fiber hole **22** with the greatest radial offset **30** again establishes the RMAX. RMAX is used to determine whether a given MF ferrule **10** (**FIG. 1**) is subsequently within or outside of specification with respect to optical fiber hole location. Other specifications must be met as well, including guide pin hole location, hole diameter, etc.

[0024] The method of manufacture described above and below takes advantage of this lateral offset change, as it is used to determine the angle of the actual, angled optical fiber hole **22b**. Once this angle is determined, the predetermined amount of optical fiber and ferrule materials **32** removed may be selected such that the lateral offset **34** is minimized (or optimized) as described below. In practice, these methods of manufacture are applied across the plurality of optical fiber holes **22** associated with the MF ferrule **10**, with the predetermined amount of optical fiber and ferrule materials **32** removed being selected such that the overall or average lateral offset **34** is minimized (or optimized). The methods of manufacture are applied across a group or lot of similarly-situated MF ferrules **10**, all having similarly-angled optical fiber holes **22**. Thus, one measure-polish-measure test is used to determine the angle of the actual, angled optical fiber hole(s) **22b** and the optimal amount of optical fiber and ferrule materials **32** to be removed. This

optimal amount of optical fiber and ferrule materials **32** to be removed is then applied to all MF ferrules **10** in the group or lot of similarly-situated MF ferrules **10**.

[0025] This is shown in **FIG. 4**, which again illustrates an illustrative MF ferrule **10** including a single guide pin hole **12** and a single optical fiber hole **22** (specifically, an ideal, non-angled optical fiber hole **22a** and an actual, angled optical fiber hole **22b**). Prior to polishing, for example, the ideal, non-angled optical fiber hole **22a** and the actual, angled optical fiber hole **22b** intersect the endface **14** of the MF ferrule **10** at different locations, for example. However, subsequent to polishing, for example, and the removal of the predetermined amount of optical fiber and ferrule materials **32** determined using this prior knowledge of the angle of the optical fiber hole(s) **22b**, the lateral offset **34** between the ideal, non-angled optical fiber hole **22a** and the actual, angled optical fiber hole **22b** at the resulting endface **15** (flat **15a** or pre-angled **15b**) of the MF ferrule **10** has a zero X-component, Y-component, and, therefore, radial component.

[0026] Therefore, the methods of manufacture of the present invention control the location of the plurality of optical fiber holes **22** as optical fiber and ferrule materials **32** are removed from the endface **14** of the MF ferrule **10**. This is especially important with respect to MF ferrules **10** having pre-angled endfaces **14** due to the fact that, if the plurality of optical fiber holes **22** are "moving" in the wrong direction relative to the 8-degree angle, the insertion loss is unacceptably high. In addition, such MF ferrules **10** typically shear when assembled, contributing to even greater insertion loss. For MF ferrules **10** having pre-angled endfaces **14**, performance improvement may be a relatively simple matter of determining in which direction the MF ferrules **10** are loaded in the polishing jig, for example, as the MF ferrules **10** will be polished at the 8-degree angle.

[0027] FIG. 5 illustrates the X-offset **40** of an 8f MF ferrule both before polishing in a flat endface configuration **42** and after polishing in an angled endface configuration **44**.

FIG. 6 illustrates the Y-offset **50** of the 8f MF ferrule both before polishing in the flat endface configuration **52** and after polishing in the angled endface configuration **54**.

[0028] FIG. 7 illustrates the X-pinbending offsets from nominal **60** as a function of the distance from the endface. **FIG. 8** illustrates the Y-pinbending offsets from nominal **70** as a function of the distance from the endface.

[0029] As an illustrative example, the process for tuning the Y-component of the plurality of optical fiber holes of an MF ferrule includes measuring the Y-component locations of each of the optical fiber holes on the endface of the MF ferrule. 50μm of optical fiber and ferrule materials are then polished from the endface of the MF ferrule. The Y-component of each of the optical fiber holes of the MF ferrule are again measured on the resulting endface of the MF ferrule. Using this data, the angle of each of the optical fiber holes is determined, i.e. the degree and direction of Y-component movement is determined for each of the optical fiber holes. An optimal polishing depth is then selected, and this optimal polishing depth is applied to all similarly-situated MF ferrules in the group or lot. Thus, insertion loss is minimized for the group or lot. It should be noted that part of this optimization process may include compensating for shear.

[0030] Although the present invention has been illustrated and described herein with reference to preferred embodiments and specific examples thereof, it will be readily apparent to those of ordinary skill in the art that other embodiments and examples may perform similar functions and/or achieve like results. All such equivalent embodiments and examples are within the spirit and scope of the present invention and are intended to be covered by the following claims.

What is claimed is:

1. A method of manufacture that minimizes the lateral offset of a plurality of optical fiber holes associated with a multi-fiber ferrule, comprising:

determining an initial offset distance of an optical fiber hole from a target location in one or more directions on an initial endface of a multi-fiber ferrule;

removing a predetermined amount of material from the multi-fiber ferrule to form a subsequent endface of the multi-fiber ferrule;

determining a subsequent offset distance of the optical fiber hole from the target location in the one or more directions on the subsequent endface of the multi-fiber ferrule; and

using the initial offset distance of the optical fiber hole and the subsequent offset distance of the optical fiber hole, determining an angle of the optical fiber hole relative to the initial endface of the multi-fiber ferrule.

2. The method of manufacture of claim 1, further comprising:

determining an initial offset distance of each of a plurality of optical fiber holes from each of a plurality of corresponding target locations in one or more directions on an initial endface of a multi-fiber ferrule;

determining a subsequent offset distance of each of the plurality of optical fiber holes from each of the plurality of corresponding target locations in the one or more directions on the subsequent endface of the multi-fiber ferrule; and

using the initial offset distance of each of the plurality of optical fiber holes and the subsequent offset distance of each of the plurality of optical fiber holes, determining an angle of each of the plurality of optical fiber holes relative to the initial endface of the multi-fiber ferrule.

3. The method of manufacture of claims 1 or 2, further comprising:

using the angle of the optical fiber hole, determining an optimal amount of material that is removed from the multi-fiber ferrule in order to minimize the offset distance of the optical fiber hole from the target location.

4. The method of manufacture of claim 3, further comprising:

using the optimal amount of material that is removed from the multi-fiber ferrule, removing this amount of material from another similarly-situated multi-fiber ferrule.

5. The method of manufacture of claims 1-4, wherein the multi-fiber ferrule has one of a flat endface and a pre-angled endface.

6. The method of manufacture of claims 1-5, wherein the method of manufacture is used to minimize insertion loss.

7. The method of manufacture of claim 1-6, wherein the method of manufacture is used to compensate for shear.

8. A multi-fiber ferrule formed by the method of manufacture of claims 1-7.

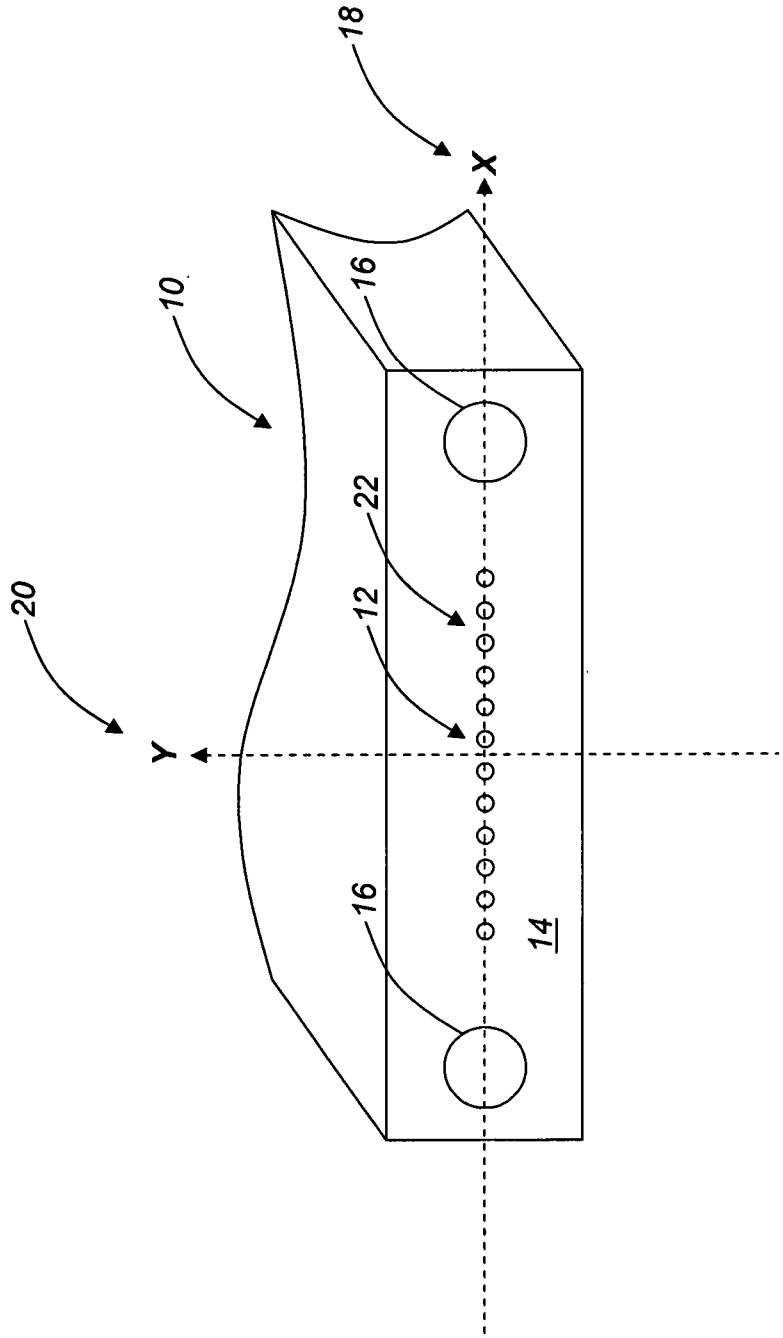

FIG. 1

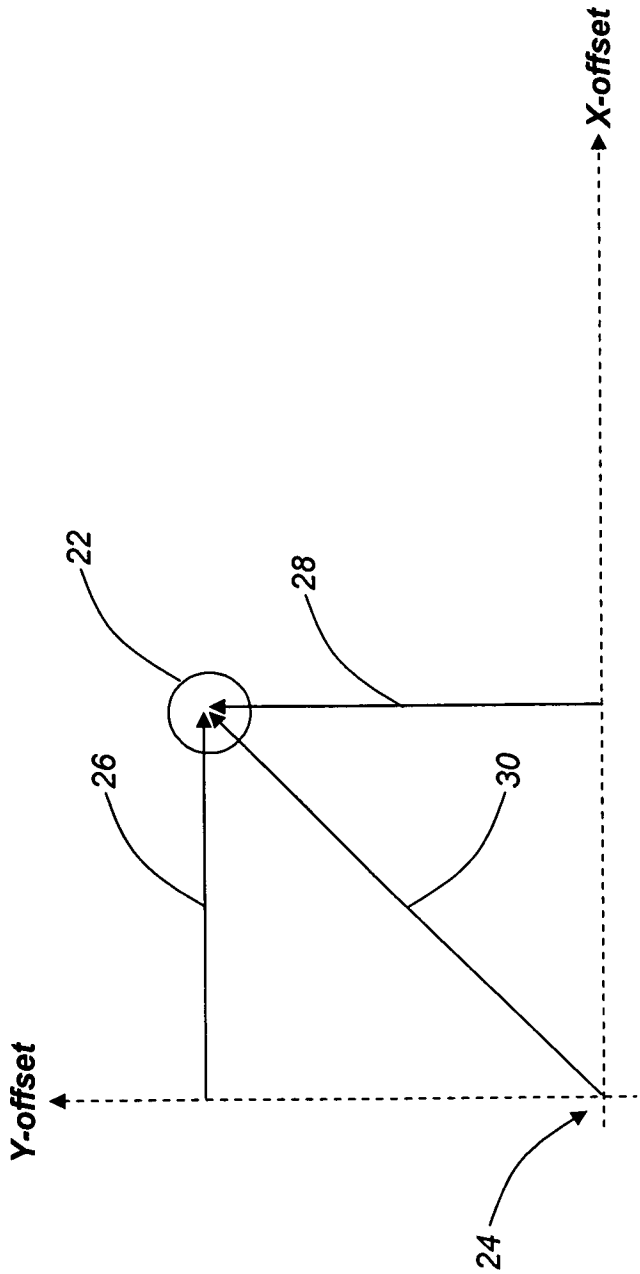

FIG. 2

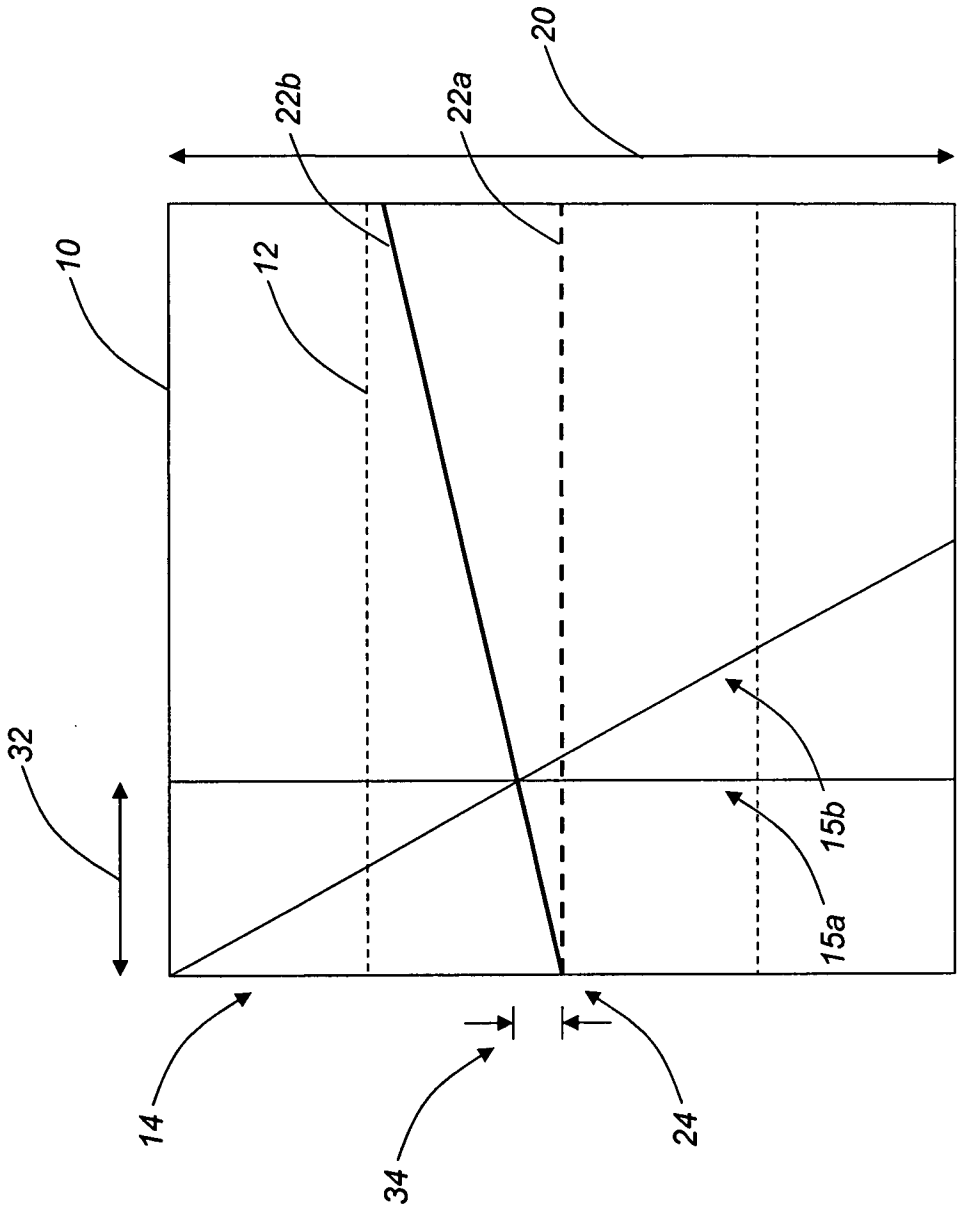

FIG. 3

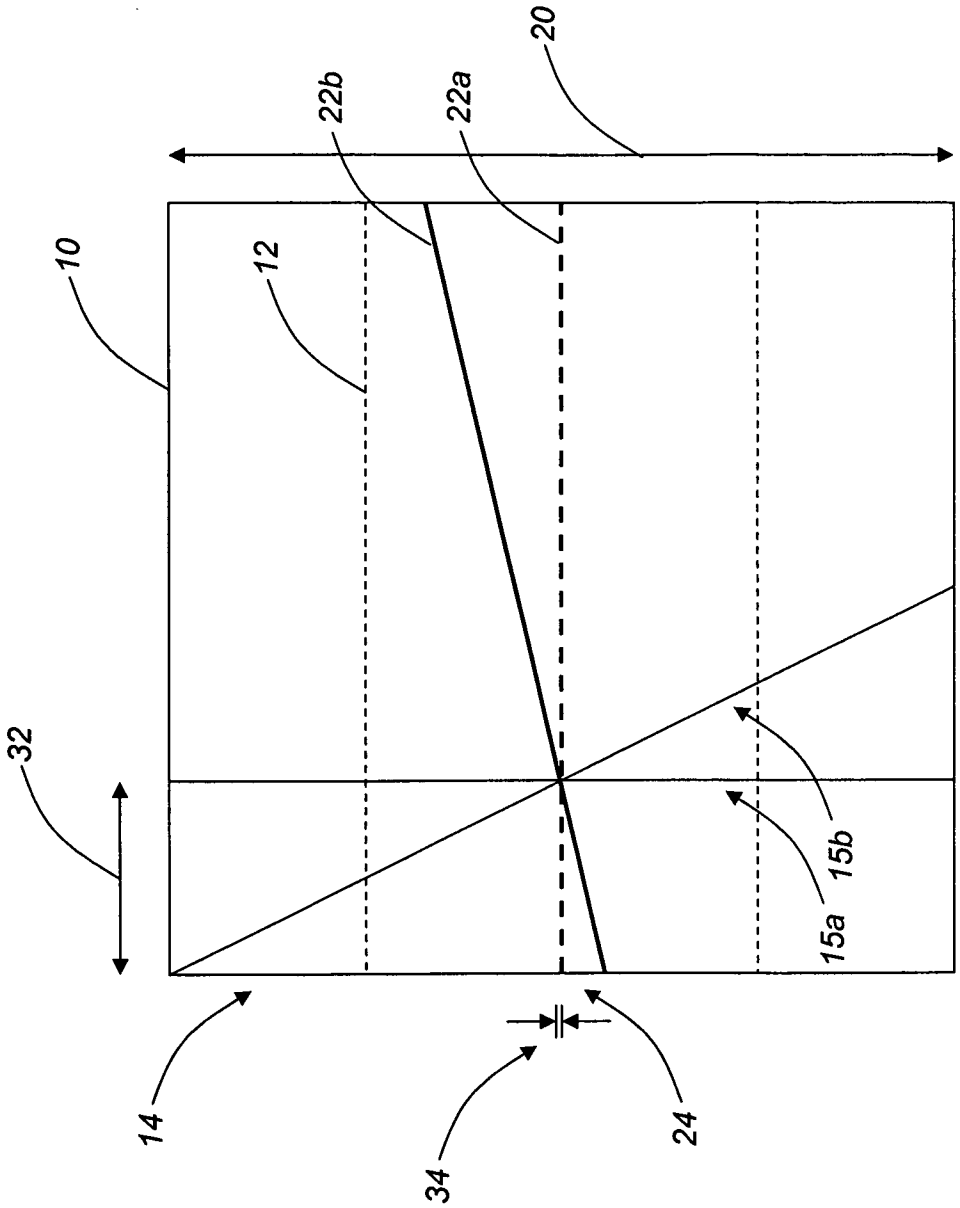

FIG. 4

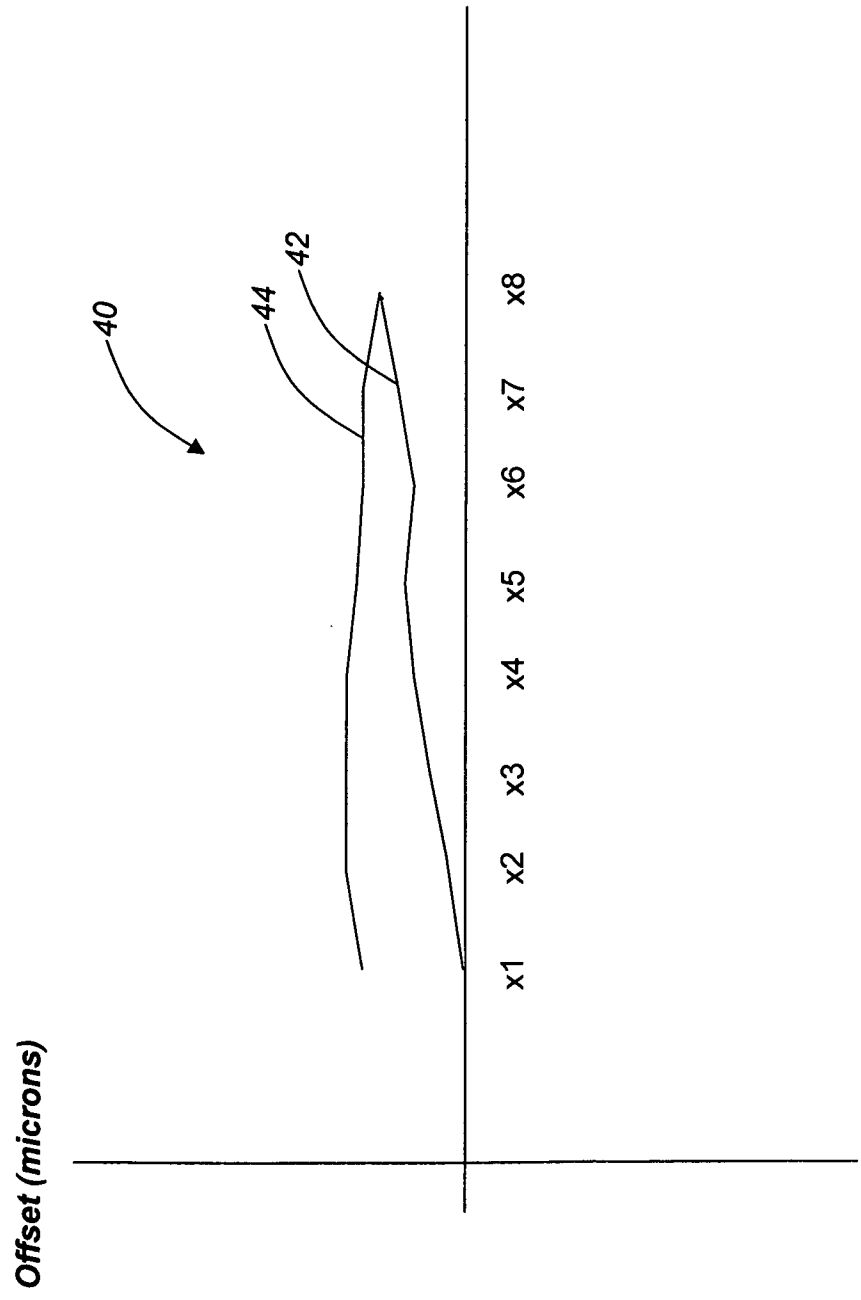

FIG. 5

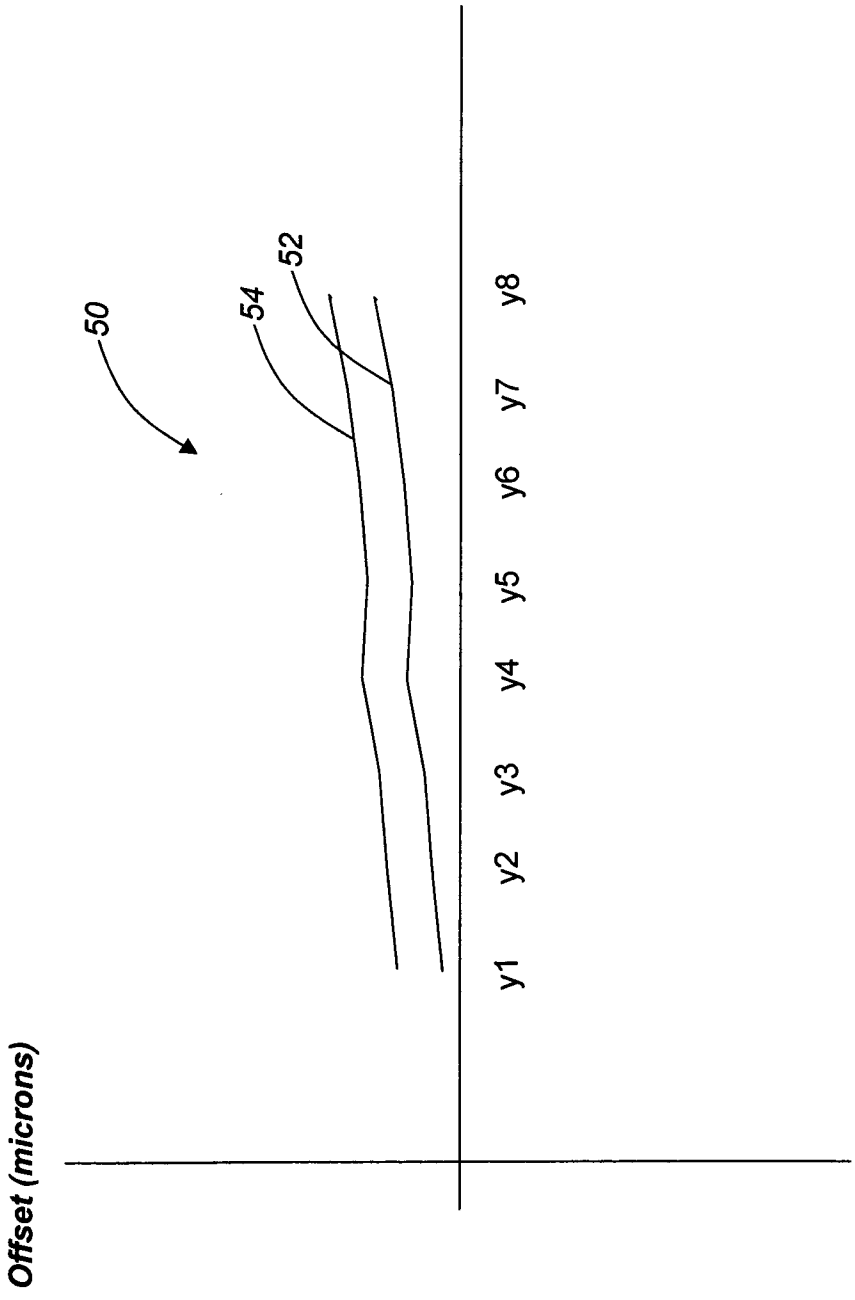

FIG. 6

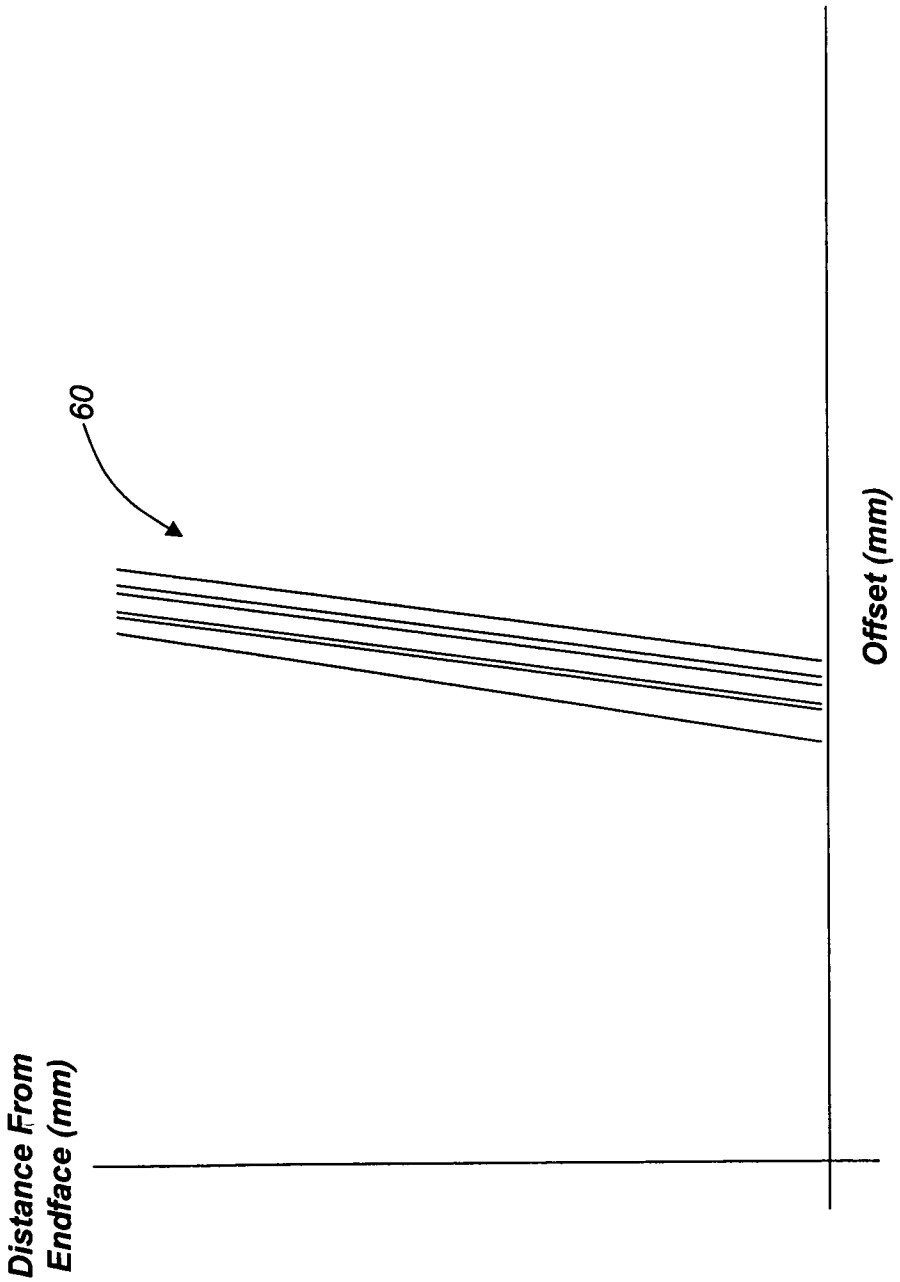

FIG. 7

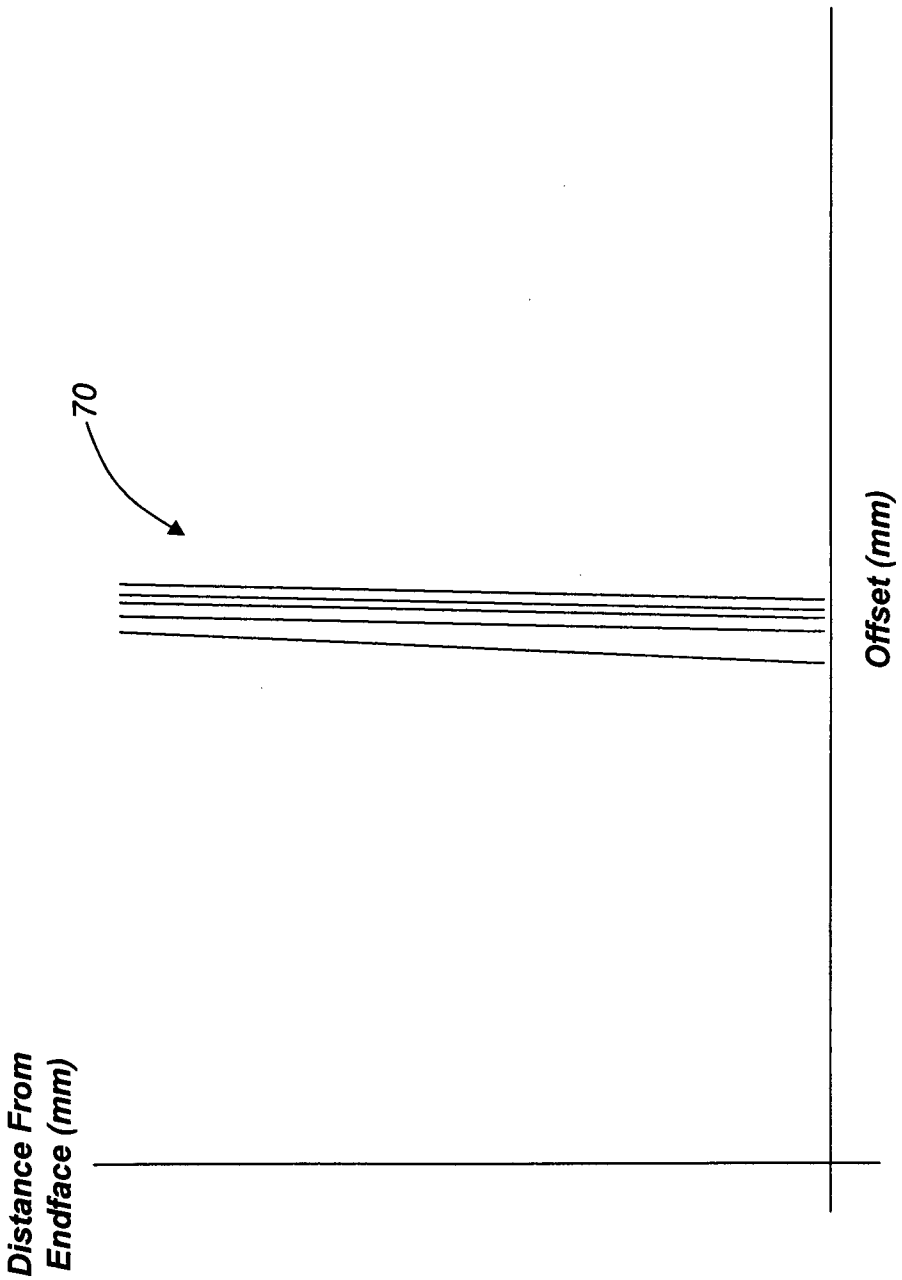

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/002415

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/38 G01B5/25 G01B11/27

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NISHIMURA A ET AL: "LOW LOSS MPO CONNECTOR" PROCEEDINGS OF INTERNATIONAL WIRE AND CABLE SYMPOSIUM, XX, XX, 1 January 2003 (2003-01-01), pages 199-204, XP001500949 the whole document	1-7
X	-----	8
A	JP 62 180206 A (SHINWA KASEI KK) 7 August 1987 (1987-08-07) abstract; figure 1	1

A	JP 06 003134 A (FUJIKURA LTD) 11 January 1994 (1994-01-11) abstract; figures	1

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
18 June 2008	26/06/2008

Name and mailing address of the ISA/	Authorized officer
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