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(54) **FIBER OPTIC CHIP WITH LENSLET ARRAY
AND METHOD OF FABRICATION**

Publication Classification

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(57) **ABSTRACT**

A fiber optic chip having one or more fiber-retaining channels and a respective number of lenslets disposed in registry with the channels is provided. The fiber optic chip includes a substrate having a first surface and an etch stop layer disposed proximate the first surface of the substrate. A fiber retaining channel is disposed within the substrate. The fiber channel has an end disposed proximate the first surface of the substrate and has a longitudinal axis extending along the channel. A lenslet is disposed on the etch stop layer and has an optical axis substantially aligned with the longitudinal axis of the channel.

(21) Appl. No.: **10/792,513**

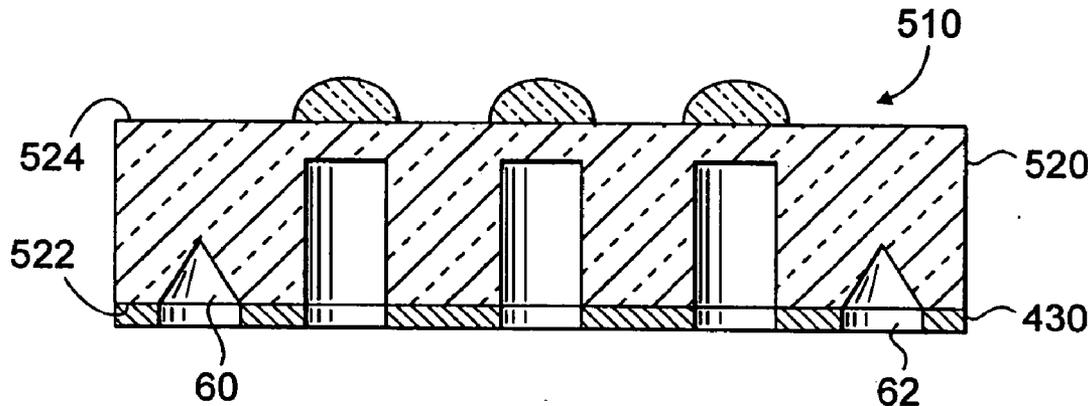
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Related U.S. Application Data

(62) Division of application No. 09/903,077, filed on Jul. 11, 2001, now Pat. No. 6,737,223.

(60) Provisional application No. 60/223,163, filed on Aug. 7, 2000.

In addition, a process is provided for creating a fiber optic chip. The process utilizes the channels as an exposure mask to mark the locations of the lenslets relative to the channels to ensure that the lenslets are accurately registered relative to the respective channels.



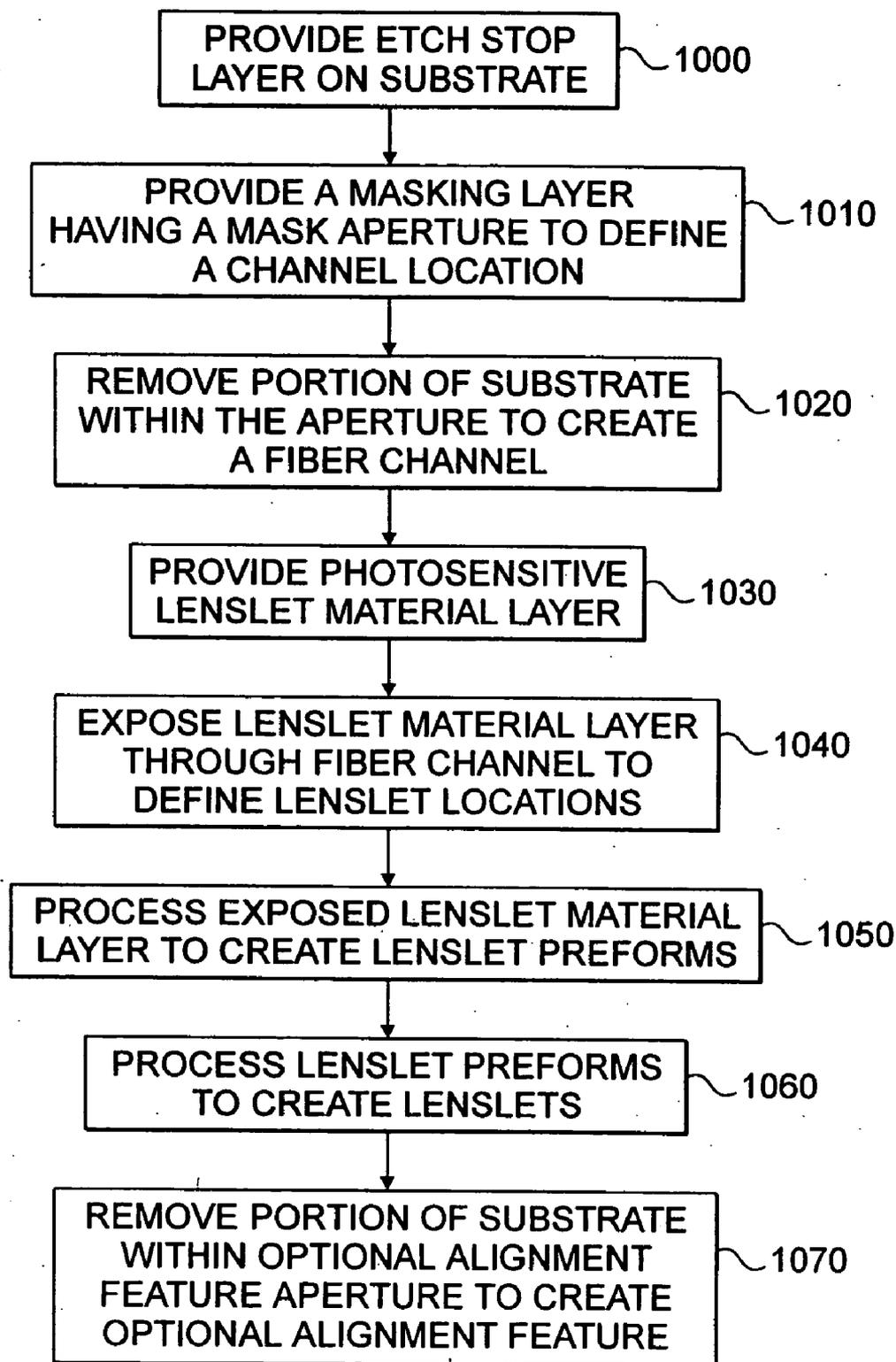


Fig. 1

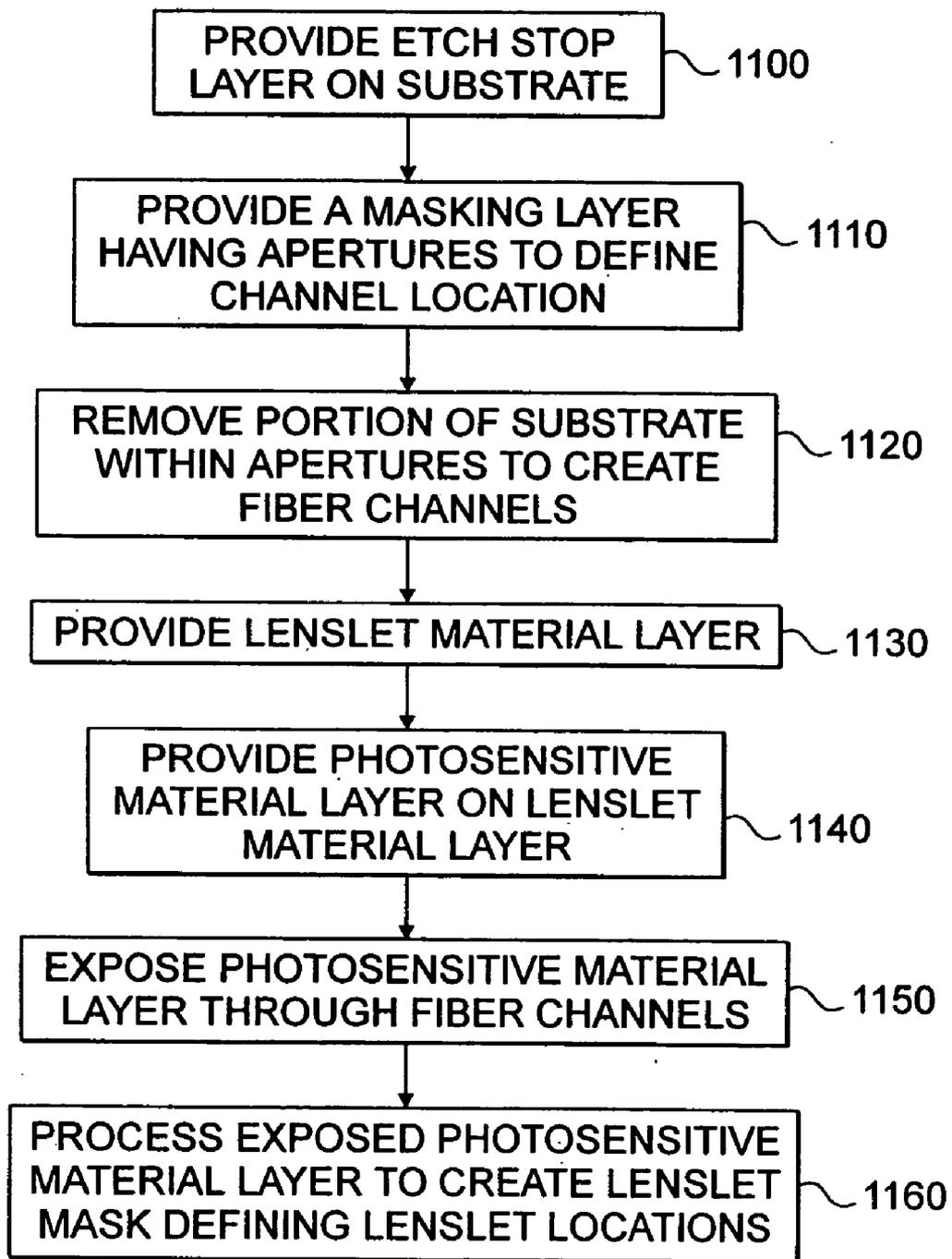


Fig. 2A

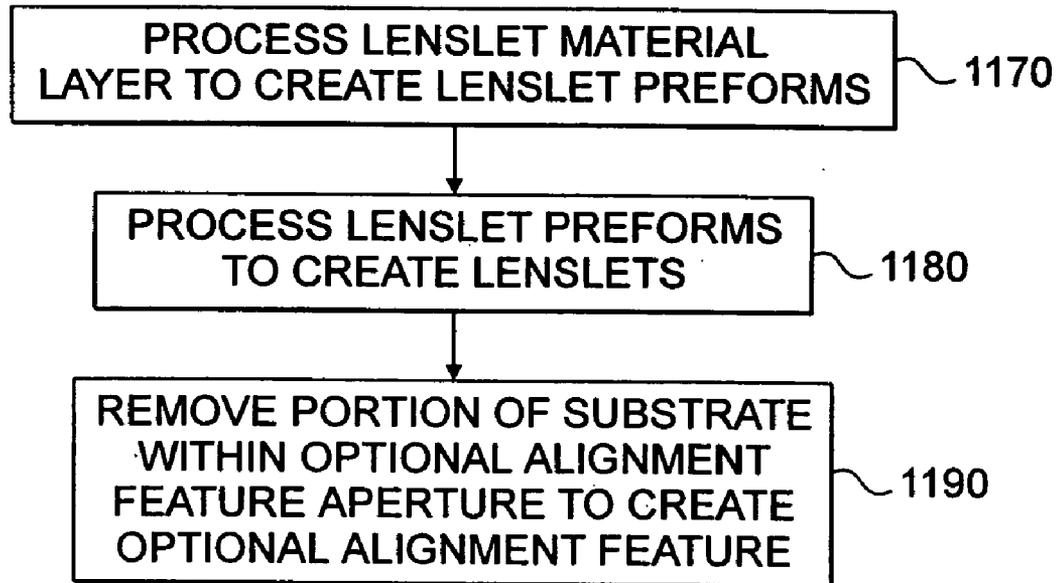


Fig. 2B

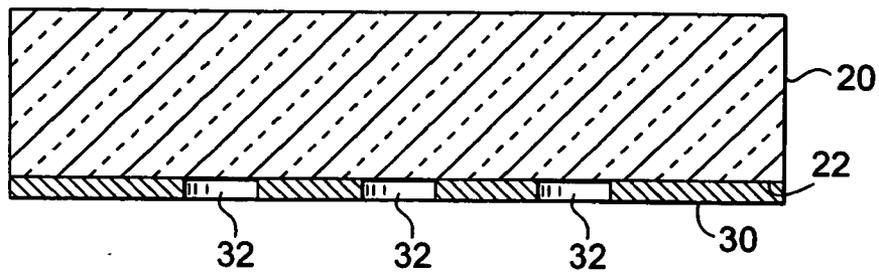


Fig. 3

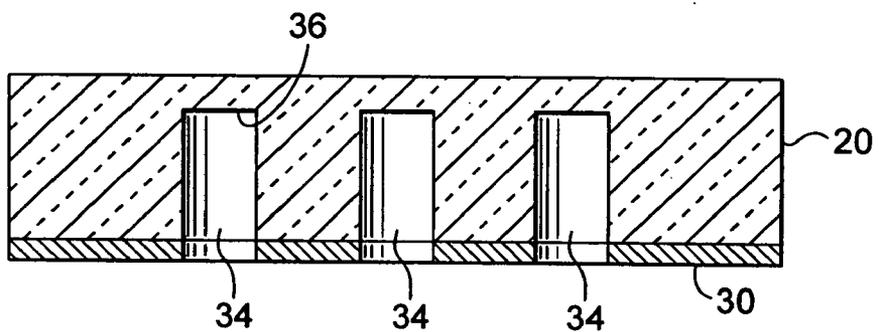


Fig. 4

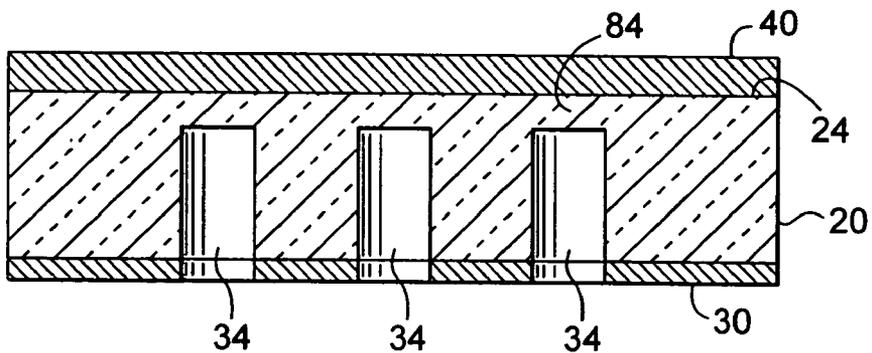


Fig. 5

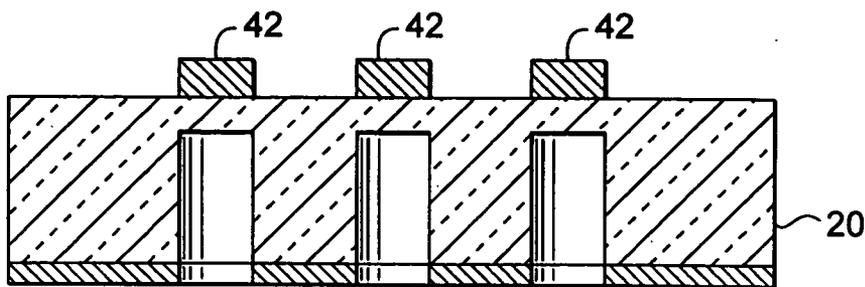


Fig. 6

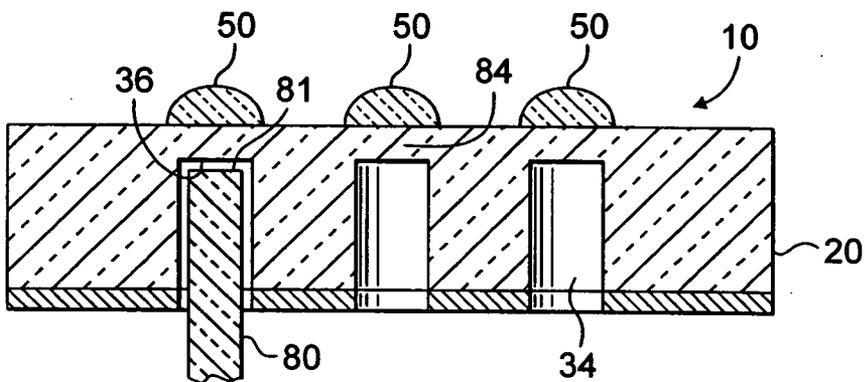


Fig. 7

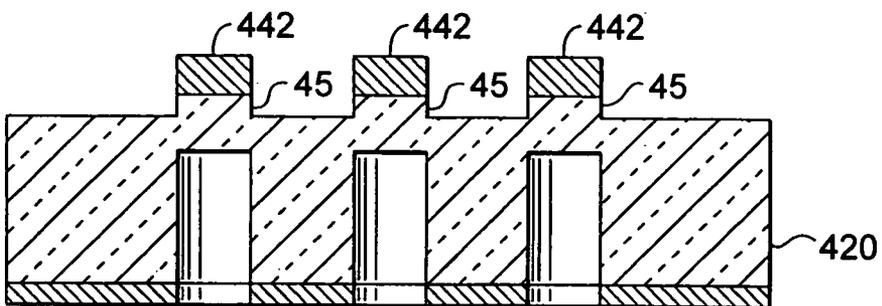


Fig. 8

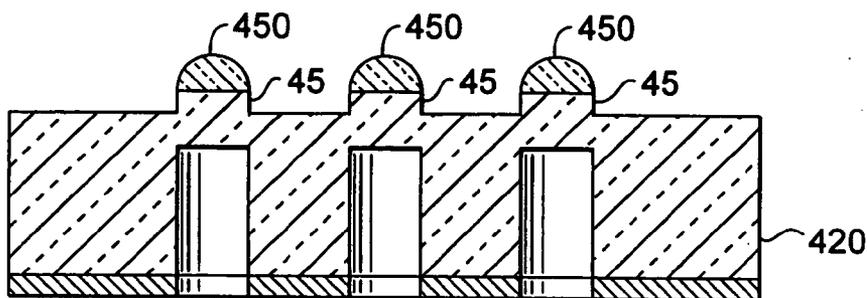


Fig. 9

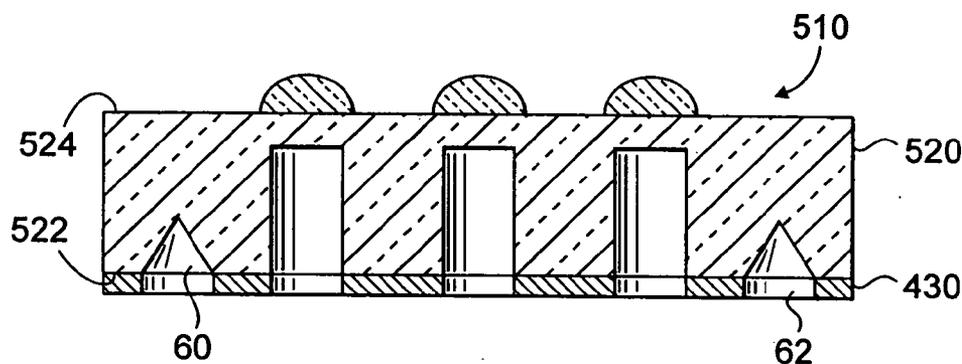


Fig. 10

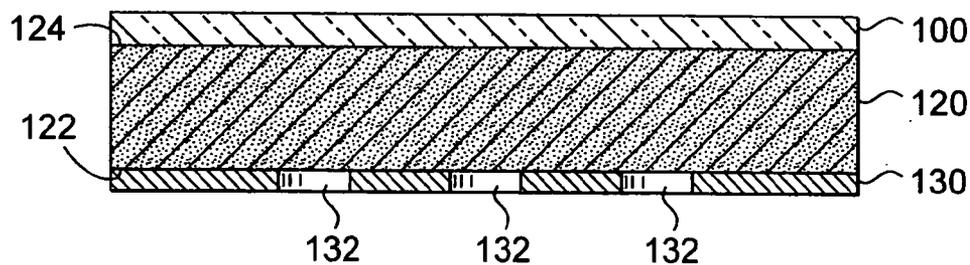


Fig. 11

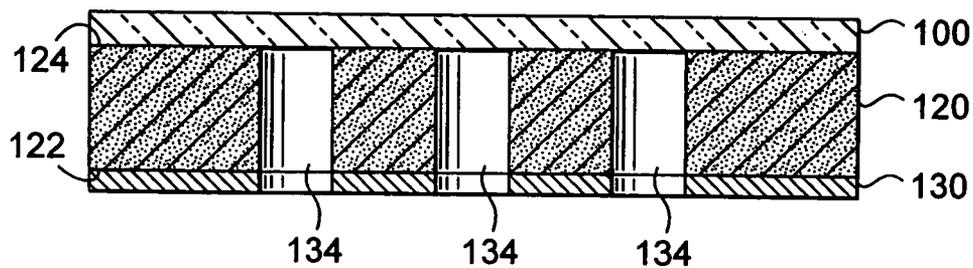


Fig. 12

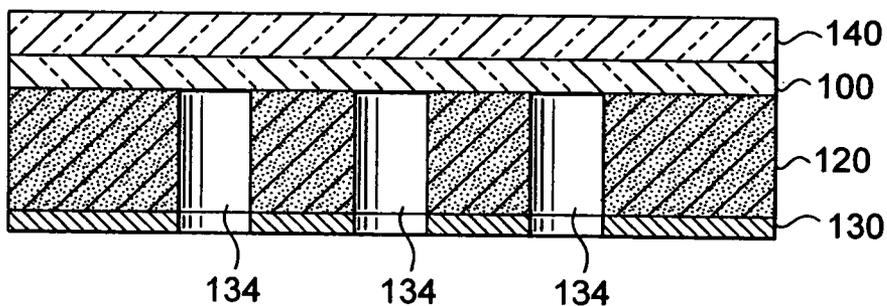


Fig. 13

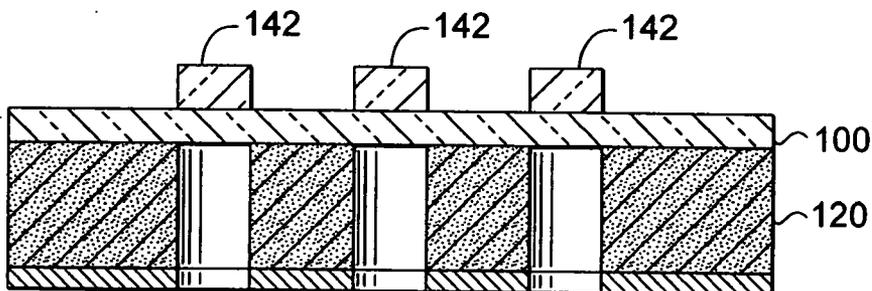


Fig. 14

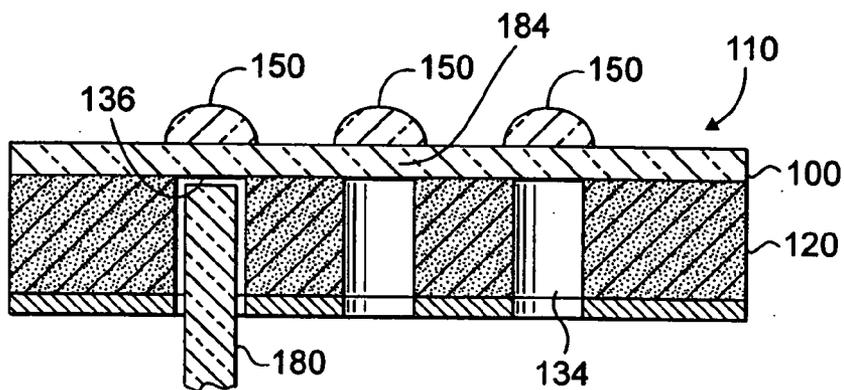


Fig. 15

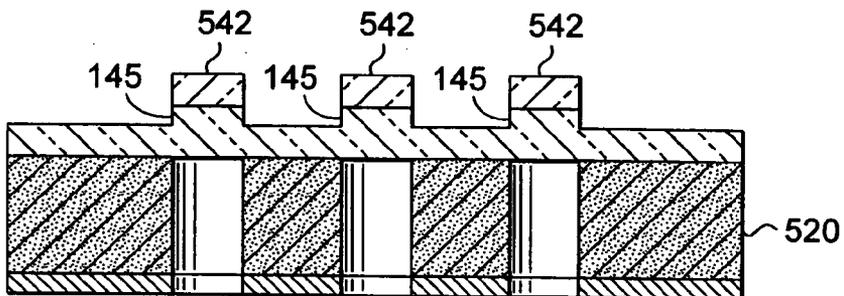


Fig. 16

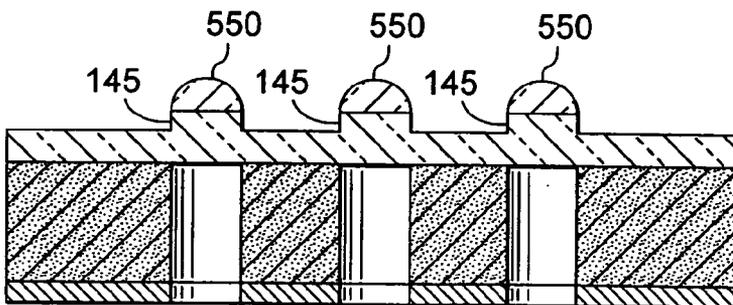


Fig. 17

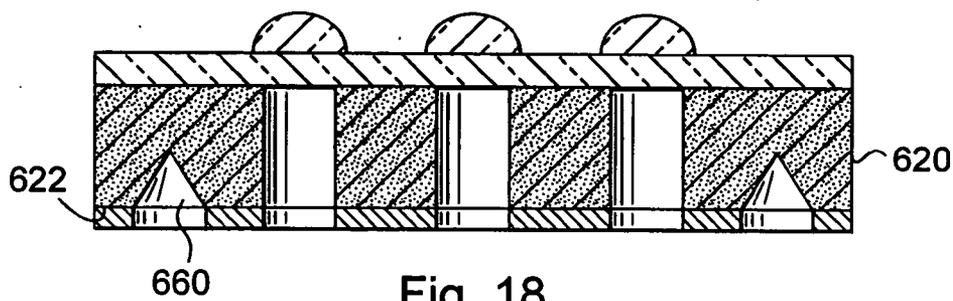


Fig. 18

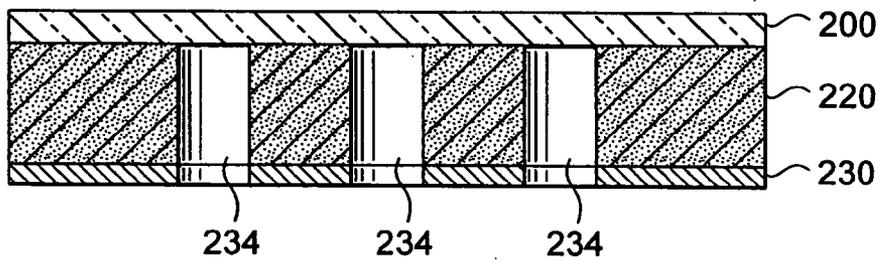


Fig. 19

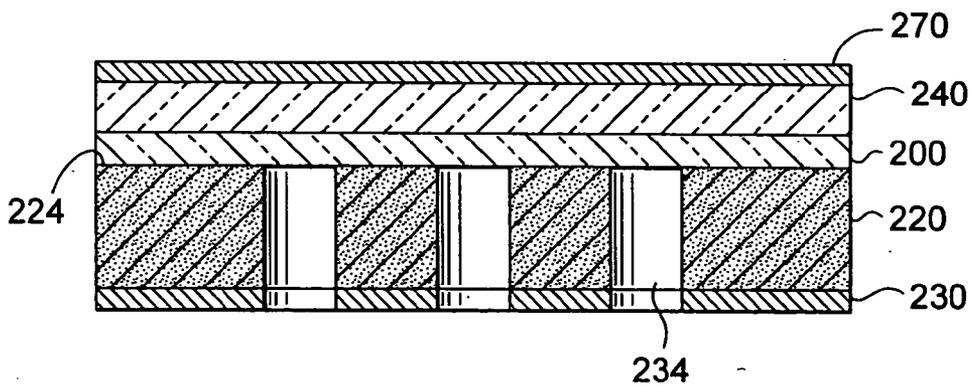


Fig. 20

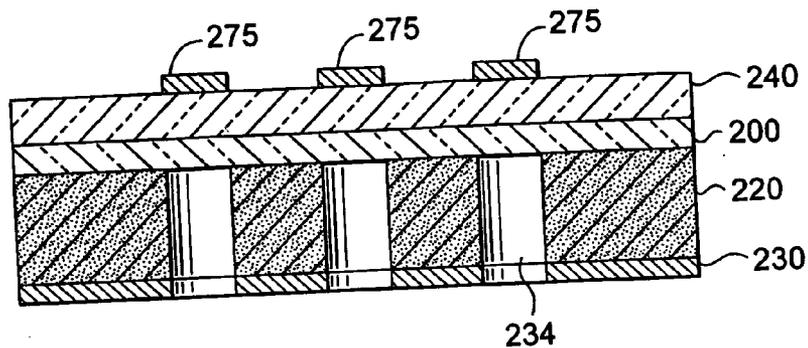


Fig. 21

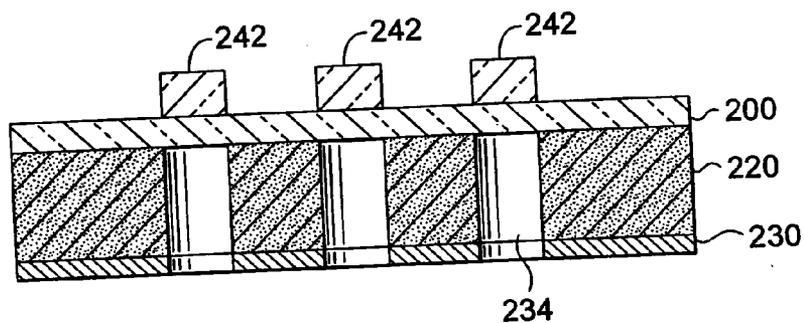


Fig. 22

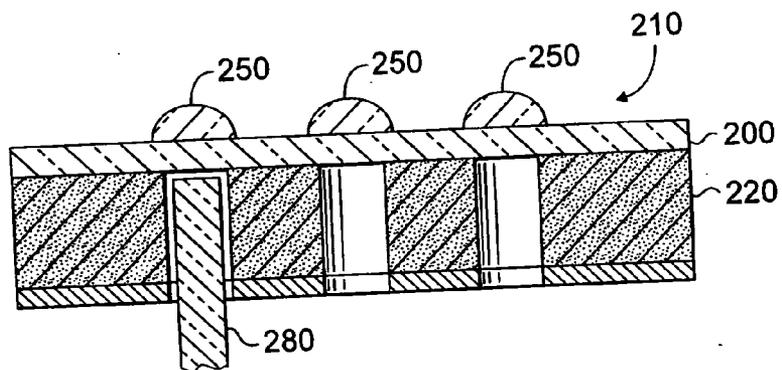


Fig. 23

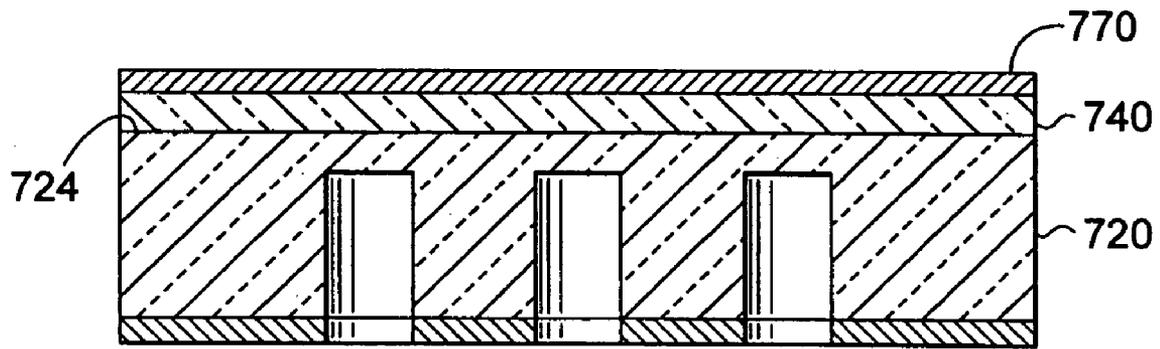


Fig. 24

FIBER OPTIC CHIP WITH LENSLET ARRAY AND METHOD OF FABRICATION

RELATED APPLICATIONS

[0001] This is a divisional application of application Ser. No. 09/903,077, filed Jul. 11, 2001, which claims the benefit of priority of U.S. Provisional Application 60/223,163, filed on Aug. 7, 2000, the entire contents of which applications are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates generally to a chip for retaining optical fibers in registry with a lenslet and a process for fabrication of the chip, and more specifically to a process which uses fiber-retaining channels in the chip as an exposure mask for the creation of the lenslet.

BACKGROUND OF THE INVENTION

[0003] Optical data communication networks utilize a large number of optical fibers which need to be accurately aligned with other system components to effect efficient coupling between the fibers and the system components. Similarly, fiber optic imaging systems make use of a plurality of optical fibers having inputs that need to be aligned and coupled, i.e. spaced at proper conjugates to the object and image planes

[0004] The coupling of optical signals from the fibers of both data communication networks and imaging systems benefits from fiber optic chips that include lenslets disposed near the endface of the fibers. Such lenslets focus and direct the light emitted or received by the fibers.

[0005] However, the use of lenslets creates additional degrees of freedom which must be controlled during the manufacturing process of the fiber optic chip. In particular, it is important to align the lenslet to the optical axis of the fiber, which may be accomplished by aligning the lenslet to a fiber-retaining channel that holds the optical fiber within the chip.

[0006] With conventional photolithographic processes, the alignment of the lenslet to a fiber-retaining channel requires additional processing steps in which an exposure mask must be separately registered to the fiber-retaining channel to define the location of the lenslet to be formed. Using an exposure mask in this manner introduces additional processing variables that must be controlled. As a result, the cost of the manufacturing process ultimately increases while the accuracy with which the lenslet location may be determined potentially decreases. A need therefore remains for a manufacturing process for creating a fiber array having lenslets registered to respective optical fibers, which utilizes fewer processing steps. In particular, it would be desirable to provide a process which effects registry between a lenslet and its respective fiber-retaining channel as the lenslet is formed.

SUMMARY OF THE INVENTION

[0007] In accordance with the present invention, a fiber optic chip having one or more fiber-retaining channels and a respective number of lenslets disposed in registry with the channels is provided. In addition, a process is provided for creating the fiber optic chip, where the process utilizes the

channels as an exposure mask to define the locations of the lenslets. The use of the channels as an exposure mask ensures that the lenslets are accurately registered relative to the respective channels.

[0008] The fiber optic chip includes a substrate having a first surface and an etch stop layer disposed proximate the first surface of the substrate. A fiber retaining channel is disposed within the substrate. The fiber channel has an end disposed proximate the first surface of the substrate and has a longitudinal axis extending along the channel. A lenslet is disposed on the etch stop layer and has an optical axis substantially aligned with the longitudinal axis of the channel. The fiber optic chip may optionally include an alignment feature in the substrate.

[0009] The process includes a step of providing a masking layer, which includes a mask aperture, on a first surface of a substrate to mark the intended location of a fiber channel. A portion of the substrate located within the mask aperture is selectively removed to create the fiber channel. In addition, a processing material layer is provided on a second surface of the substrate opposite the first surface of the substrate. The processing material is exposed with light of a selected wavelength which is transmitted through the fiber channel to create an exposed region in the processing material layer. In this manner, the fiber channel functions as a mask, ensuring that the exposed region of the processing material layer is in registry with the fiber channel. Next the unexposed portion of the processing material layer is selectively removed to create a lenslet preform which is positioned in registry with the fiber channel. The lenslet preform is then processed, for example by heating, to impart a lenticular shape to the preform, thereby creating a lenslet in registry with the fiber channel.

[0010] Optionally, the masking layer may include an alignment feature aperture for the purpose of defining the location of an optional alignment feature. The optional alignment feature is formed by selectively removing a portion of the substrate located within the alignment layer aperture. For example, the alignment feature may be formed by an anisotropic etching process to create an alignment feature having a sidewall which is inclined with respect to the first surface of the substrate.

[0011] Additionally, the step of providing the processing material layer may optionally comprise providing one or more additional layers. A first such variation of the process comprises providing an optional etch stop layer adjacent the second surface of the substrate and providing a photosensitive lenslet-forming layer adjacent the etch stop layer. The etch stop layer is provided so that the substrate removal step may extend to the depth of the second surface of the substrate. Such a fiber channel extends from the first surface of the substrate to the second surface of the substrate. The photosensitive lenslet-forming layer may be further processed to create a lenslet, in a manner similar to that described above.

[0012] A second variation of the process comprises providing a processing material layer having an etch stop layer adjacent the second surface of the substrate, a lenslet-forming layer adjacent the etch stop layer, and a photosensitive layer adjacent the lenslet-forming layer. This three-layer configuration, which includes a separate photosensitive layer, permits the use of the lenslet-forming layer

which is not photosensitive. The photo-sensitive layer is then exposed with light of a selected wavelength through the fiber channel to create an exposed region of the photo-sensitive layer. The process further comprises the step of removing the unexposed region of the photo sensitive layer to provide a lenslet mask comprising the exposed region of the light-sensitive layer. In turn, creation of the lenslet preform includes the step of selectively removing a portion of the lenslet forming layer not protected by the lenslet mask. Subsequent the formation of the lenslet preform, the lenslet mask may be removed from the lenslet preform, prior to creation of a lenslet from the lenslet preform. A third variation of the process is also provided and is substantially the same as the second variation but omits the etch stop layer. In this third case, the lenslet-forming layer is disposed adjacent the second surface of the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The foregoing summary and the following detailed description of the preferred embodiments of the present invention will be best understood when read in conjunction with the appended drawings, in which:

[0014] **FIG. 1** illustrates a flowchart representing a process in accordance with the present invention for creating a fiber optic chip having a fiber optic channel that is used as an exposure mask to mark the location of a lenslet on the chip in registry with the channel;

[0015] **FIGS. 2A and 2B** illustrate a flowchart representing another process of the present invention for creating a fiber optic chip having a fiber optic channel positioned in registry with a lenslet;

[0016] **FIG. 3** schematically illustrates a cross-sectional view of a substrate on which a masking layer is disposed to mark intended locations of fiber channels;

[0017] **FIG. 4** schematically illustrates a cross-sectional view of the substrate of **FIG. 3** with a portion of the substrate removed to create fiber channels;

[0018] **FIG. 5** schematically illustrates a cross-sectional view of the substrate of **FIG. 4** on which a photosensitive lenslet material layer is disposed;

[0019] **FIG. 6** schematically illustrates a cross-sectional view of the substrate of **FIG. 5** having portions of the photosensitive lenslet material layer removed to create lenslet preforms in registry with the fiber channels;

[0020] **FIG. 7** schematically illustrates a cross-sectional view of a fiber optic chip formed from the substrate of **FIG. 6** having lenslets formed by processing of the lenslet preforms depicted in **FIG. 6**;

[0021] **FIG. 8** schematically illustrates a cross-sectional view of a substrate having portions of a photosensitive lenslet material layer and the substrate removed to create lenslet preforms disposed on pedestals;

[0022] **FIG. 9** schematically illustrates a cross-sectional view of a fiber optic chip formed from the substrate of **FIG. 8** having lenslets formed by processing of the lenslet preforms depicted in **FIG. 8**;

[0023] **FIG. 10** schematically illustrates a cross-sectional view of a fiber optic chip in which an alignment feature is provided;

[0024] **FIG. 11** schematically illustrates a cross-sectional view of a substrate having a masking layer and an etch stop layer disposed on opposite sides of the substrate, where the masking layer includes apertures to define intended locations of fiber channels;

[0025] **FIG. 12** schematically illustrates a cross-sectional view of the substrate of **FIG. 11** with a portion of the substrate removed to create fiber channels;

[0026] **FIG. 13** schematically illustrates a cross-sectional view of the substrate of **FIG. 12** having a photosensitive lenslet material layer disposed on the etch stop layer;

[0027] **FIG. 14** schematically illustrates a cross-sectional view of the substrate of **FIG. 13** having portions of the photosensitive lenslet material layer removed to create lenslet preforms in registry with the fiber channels;

[0028] **FIG. 15** schematically illustrates a cross-sectional view of a fiber optic chip formed from the substrate of **FIG. 14** having lenslets formed by processing of the lenslet preforms depicted in **FIG. 14**;

[0029] **FIG. 16** schematically illustrates a cross-sectional view of a substrate having portions of the photosensitive lenslet material layer and the etch stop layer removed to create lenslet preforms disposed on pedestals;

[0030] **FIG. 17** schematically illustrates a cross-sectional view of a fiber optic chip formed from the substrate of **FIG. 16** having lenslets formed by processing of the lenslet preforms depicted in **FIG. 16**;

[0031] **FIG. 18** schematically illustrates a cross-sectional view of a fiber optic chip in which an alignment feature is provided;

[0032] **FIG. 19** schematically illustrates a cross-sectional view of a substrate having fiber channels and an etch stop layer;

[0033] **FIG. 20** schematically illustrates a cross-sectional view of the substrate of **FIG. 19** having a lenslet material layer disposed on the etch stop layer and a photosensitive material layer disposed on the lenslet material layer;

[0034] **FIG. 21** schematically illustrates a cross-sectional view of the substrate of **FIG. 20** having portions of the photosensitive material layer removed to create a lenslet mask in registry with the fiber channels;

[0035] **FIG. 22** schematically illustrates a cross-sectional view of the substrate of **FIG. 21** having portions of the photosensitive lenslet material layer removed to create lenslet preforms in registry with the fiber channels;

[0036] **FIG. 23** schematically illustrates a cross-sectional view of a fiber optic chip formed from the substrate of **FIG. 22** having lenslets formed by processing of the lenslet preforms depicted in **FIG. 22**; and

[0037] **FIG. 24** schematically illustrates a cross-sectional view of a substrate having a lenslet material layer disposed on the substrate and a photosensitive material layer disposed on the lenslet material layer.

DETAILED DESCRIPTION OF THE INVENTION

[0038] In accordance with the present invention, a fiber optic chip **10**, having one or more fiber-retaining channels

34 and a respective number of lenslets **50** disposed in registry with the channels **34**, and a process for fabricating the fiber optic chip **10** are provided, as best shown, for example, in **FIG. 7**. Registration between the lenslets **50** and the channels **34** is ensured by using the channels **34** as an exposure mask during creation of the lenslets **50**. Such a use of the channels **34** inherently creates registration between the lenslets **50** and the channels **34**, which in turn provides proper alignment between the lenslets **50** and the fibers **80** retained in the fiber optic chip **10**.

[0039] A process of the present invention for creating a fiber optic chip **10** having a fiber retaining channel **34** formed in a substrate **20** in registry with a lenslet **50** is illustrated in the flowchart of **FIG. 1**. The process in accordance with the present invention may be practiced having an etch stop layer, as provided at step **1000** of **FIG. 1**, disposed on a substrate for fabrication of the fiber optic chip as depicted in **FIGS. 11-17**. Alternatively, the process of the present invention may also be performed without providing an etch stop layer on the substrate for the purpose of fabricating, for example, the fiber optic chip depicted in **FIGS. 3-10**. Providing an optional etch stop layer, at step **1000**, provides certain advantages, such as permitting the use of a non-transparent substrate material. On the other hand, a more simplified process may be practiced by omitting the step of providing the etch stop layer. Accordingly, the present invention provides for processes for creating a fiber optic chip that may either include or omit the etch stop layer set forth as step **1000** of **FIG. 1**.

[0040] Beginning with the process variation depicted in **FIGS. 3-10**, which omits step **1000**, a substrate **20** is shown having a masking layer **30** disposed on a first surface **22** of the substrate **20**, as provided by step **1010** of **FIG. 1**. The masking layer **30** includes one or more mask apertures **32** which provide access to associated portions of the substrate **20**. The location and size of the mask apertures **32** provide a template in the masking layer for marking the location and width of fiber-retaining channels **34** to be created in the substrate **20**. The mask apertures **32** may have a circular cross-section corresponding to the diameter of a fiber **80** to be retained in the fiber optic chip **10**. Alternatively, the mask apertures **32** may have a cross-section corresponding to that of a polarization-maintaining fiber, such as a D-shaped cross-section, for example.

[0041] The masking layer **30** may be provided using any suitable technique, such as photolithographic processes, for applying or depositing such masking layer **30** on the first surface **22** of the substrate **20**. Such processes may be used to provide a masking layer **30** comprising, for example, silicon nitride, silicon dioxide, or a metal, or other material capable of selectively resisting subsequent substrate removal processes, such as reactive ion etching (RIE).

[0042] Turning to **FIG. 4**, fiber-retaining channels **34** of a desired shape and depth are formed in the substrate **20** by removing, at step **1020**, portions of the substrate **20** which are accessible through the mask apertures **32**. The channels **34** do not necessarily pass entirely through the substrate **20**. Instead, the channels **34** may be formed as cavities having terminating end walls **36** disposed internal to the substrate **20**. The channels **34** may be created using any process suited to removing portions of the substrate **20** without degrading or removing the masking layer **30**. Such processes may

include, for example, reactive ion etching, physical etching, focused ion-beam milling, photochemical etching, electrochemical etching, and wet and dry chemical etching. In particular, processes by which step **1020** may be practiced should permit removal of sufficient substrate material to create a fiber channel **34** which extends a suitable distance into the fiber optic chip **10** to permit retention of a fiber **80** therein and particularly a fiber end **81**, as illustrated in **FIG. 7**. Preferably, the removal process of step **1020** should be selected to avoid undercutting of the masking layer **30**.

[0043] The substrate **20** is formed from a material that permits creation of the fiber channels **34** therein and has sufficient mechanical strength to support a fiber **80** within a fiber channel **34**. Furthermore, the substrate **20** should comprise a material that is optically transparent to light transmitted by a fiber **80**. The fiber **80** is contained within the channel **34** so that the fiber end **81** is positioned proximate to channel end wall **36**. Transparency of the substrate **20** is desirable, because light transmitted by a fiber **80** within the channel **34** must pass through a bridge portion **84** of the substrate **20** disposed intermediate channel end wall **36** and lenslet **50**, as shown in **FIG. 7**. In addition, the substrate **20** should comprise a material that is optically transparent to the wavelength of light used to expose a lenslet material deposited on the substrate to create lenslets **50**. Since the substrate **20** is transparent, the marking layer **30** should be substantially opaque to the wavelength of light.

[0044] Returning to **FIG. 1**, photosensitive lenslet material layer **40** is provided, at step **1030**, on a second surface **24** of the substrate **20**, as shown in **FIG. 5**. The photosensitive layer **40** is applied to the second surface **24** of the substrate **20** opposite to the first surface **22** on which the masking layer **30** is applied. The photosensitive lenslet material layer **40** comprises a material that can be processed to create lenslets **50**. In particular, the photosensitive lenslet material layer **40** comprises a material that may be exposed to light of a selected wavelength to create exposed regions from which the lenslets **50** are formed. The photosensitive lenslet material layer **40** may comprise, for example, photoresist.

[0045] The photosensitive lenslet material layer **40** is exposed, at step **1040**, to light of a selected wavelength transmitted through the mask apertures **32** into the channels **34**. The light is transmitted through the bridge portions **84** of the substrate **20** disposed between the end walls **36** and the photosensitive lenslet material layer **40** to create exposed regions in the photosensitive lenslet material layer **40**. Collimated light may be used to create exposed regions having a cross-section matched to that of the channels **34**. By using the channels **34** to create the exposed regions, such exposed regions are thereby positioned in registry with the respective channels **34**. Since the exposed regions mark the future location of the lenslets **50**, exposure of the photosensitive lenslet material layer **40** through the channels **34** ensures that the lenslets **50** will be accurately positioned in registry with the channels **34**.

[0046] Next, unexposed portions of the photosensitive lenslet material layer **40** are selectively removed, at step **1050**, to create lenslet preforms **42** from the exposed portions of the photosensitive lenslet material layer **40**, as shown in **FIG. 6**. Standard photoresist processing techniques, or other suitable methods, may be used to selectively

remove the unexposed portions of the photosensitive lenslet material layer **40**. Optionally, a portion of the substrate **420** proximate the unexposed portions of the photosensitive lenslet material layer may also be removed to create pedestals **45** on which the lenslet preforms **442** are disposed, as depicted in **FIG. 8**.

[0047] The lenslet preforms **42**, **442** of the configurations of **FIGS. 6 and 8** are further processed to impart a lenticular shape to the lenslet preforms **42**, **442** creating the lenslets **50**, **450** at step **1060**. For example, the lenslet preforms **42** may be heated at step **1060** to cause flow of the lenslet preforms **42** to form lenslets **50**. In a similar manner, the lenslet preforms **442** of **FIG. 8** may be heated to create the lenslets **450** shown in **FIG. 9**.

[0048] As an additional optional step, an alignment feature **60** may be formed, at step **1070**, within the first surface **522** of the substrate **520**, as shown in **FIG. 10**. An alignment feature **60** permits registration of the fiber optic chip **510** with other system components. If an alignment feature **60** is desired, the masking layer **430** may include an alignment feature aperture **62** positioned to mark the location of the alignment feature **60** to be formed in the substrate **520**. The alignment feature **60** may be formed by a suitable process that imparts a desired shape, such as a V-shaped groove or pit. The alignment feature **60** may be formed with other desired shapes. For example, the alignment feature **60** may be formed having sidewalls perpendicular to the first surface **522**. Although the alignment feature **60** is illustrated in the first surface **522** of the substrate **520**, the alignment feature may also be formed in the second surface **524** as well as in other surfaces of the substrate **520**.

[0049] Turning to **FIGS. 11-17**, a fiber optic chip **110** is shown which is made by the process in accordance with the present invention in which an etch stop layer **100** is provided on surface **124** of the substrate **120**. The inclusion of the etch stop layer **100** is a principal difference between the process used to make the fiber optic chip **10** illustrated in **FIGS. 3-10** and the process used to make the fiber optic chip **110** depicted in **FIGS. 11-18**. Use of an etch stop layer **100** permits a fiber channel **134** to pass entirely through the substrate **120**.

[0050] Beginning with step **1000** of **FIG. 1**, an etch stop layer **100** is provided on a second surface **124** of the substrate **120** opposite a first surface **122** of the substrate **120** on which a masking layer **130** is provided, as depicted in **FIG. 11**. The etch stop layer **100** may comprise a suitable material, such as silicon nitride or silicon dioxide, capable of resisting the removal of substrate during the subsequent processing. In addition, the etch stop layer **100** should be optically transparent to the light transmitted by a fiber **180** retained in the fiber optic chip **110**, as shown in **FIG. 15**. Typically, the etch stop layer **100** may have a thickness of one to three microns. In addition, the masking layer **130** is provided on the first surface **122** of the substrate **120**, at step **1010**, in a similar fashion to that described above with respect to the configuration of **FIG. 3**. While the flowchart of **FIG. 1** shows step **1000** occurring before step **1010**, the masking layer **130** can also be provided prior to providing the etch stop layer **100**.

[0051] When the etch stop layer **100** is used, the step of creating the fiber channels **134**, step **1020**, may include the creation of fiber channels **134** that extend from the first

surface **122** of the substrate **120** to the second surface **124** of the substrate **120**, as shown in **FIG. 12**. A first advantage provided by the etch stop layer **100** is the ability to control the depth of the channels **134**. By optionally selecting the composition of the etch stop layer **100** to include a material substantially resistant to the substrate removal process of step **1020**, the substrate material within the channels can be removed, or etched away, until the etch stop layer **100** is encountered. In addition, since no substrate material is needed to form a bridge portion between the channels **134** and respective lenslets **150**, as shown in **FIG. 15**, the substrate **120** need not comprise a material that is optically transparent to light transmitted by the fiber **180**. Likewise, the substrate **120** need not comprise a material that is optically transparent to the light used to expose the lenslet material layer **140** in the process of forming lenslets from the lenslet material layer. Consequently, the use of an etch stop layer **100** permits the use of a greater range of substrate materials. For example, the substrate **120** may be formed of silicon.

[0052] Returning to **FIG. 1**, the process proceeds by providing, at step **1030**, a photosensitive lenslet material layer **140** on the etch stop layer **100**, as shown in **FIG. 13**. The composition of the lenslet material layer **140** and the method of its application may be similar to that described above with respect to the configuration of **FIG. 5**. The principal difference between providing the lenslet material layer **140** in the configuration as shown in **FIG. 13** relative to providing the lenslet material layer in the configuration shown in **FIG. 5** is that the lenslet material layer **140** is provided on the etch stop layer **100**, rather than on the second surface **24** of the substrate **20**.

[0053] The remaining steps of the process, steps **1040** through **1060**, may be performed to provide the configurations illustrated in **FIGS. 14-17** in substantially the same manner as described in connection with the respective configurations shown in **FIGS. 6-9**. Elements shown in the embodiment of **FIGS. 14-17**, which correspond to the same elements shown in the embodiment of **FIGS. 6-9**, are designated by the addition of **100** to the reference marks used in **FIGS. 6-9**. Likewise, the optional step of providing an alignment feature, at step **1070**, may be performed to yield the configuration of **FIG. 18** in substantially the same manner as described in connection with the configuration of **FIG. 10**. The alignment feature **660** may be formed by anisotropic wet etching, such as etching by KOH, to create an alignment feature **660** in the form of V-shaped grooves or V-shaped pits in [100]-oriented silicon. Alternatively, wet or dry etching may be used to create an alignment feature **660** having vertical sidewalls perpendicular to the first surface **622** of the substrate **620** in [110]-oriented silicon.

[0054] In each of the above processes, the lenslet material is preferably selected to be photosensitive. However, it may be desirable to create lenslets from materials that are not photosensitive. For example, it may be desirable to form lenslets from a low melting temperature glass. Accordingly, the flowchart of **FIGS. 2A and 2B** diagram a process for creating a fiber optic chip **210** having lenslets **250** which may be formed from a non-photosensitive material. In this variation of the process shown in **FIGS. 2A and 2B**, steps **1100** through **1120** are substantially similar to steps **1000** through **1020** described in connection with **FIG. 1**. A configuration of the substrate **220** that results from the

process of steps 1100 through 1120 is depicted in FIG. 19. The substrate shown in FIG. 19 is similar to the structure depicted in FIG. 12, but where like elements are designated with reference marks with a 200-series reference number instead of a 100-series reference number. Likewise, as shown in FIG. 20, a lenslet material layer 240 may be applied to the etch stop layer 200, at step 1130, in an analogous manner to that described with respect to step 1030 of FIGS. 1 and 13. Alternatively, the lenslet material layer 740 may be provided directly on the second surface 724 of the substrate 720 for a process which does not use the optional etch stop layer, as shown in FIG. 24. For illustration purposes, FIGS. 19-23 depict the configuration in which an etch stop layer 200 is provided.

[0055] A principal difference between the steps of providing a lenslet material layer by the process of FIG. 1 and the process of FIGS. 2A and 2B is that the lenslet material layer 240 provided by step 1130 need not be photosensitive. However, the lenslet material layer 240 should comprise a material that is optically transparent to the wavelength of light to be transmitted by fiber 280. In addition, the lenslet material layer 240 should be transparent to the wavelength of light used to expose an overlying photosensitive material layer 270. The lenslet material layer 240 may comprise, for example, a low melting temperature plastic or glass, such as a phospho-silicate or lead-silicate glass.

[0056] Since the lenslet material layer 240 need not be photosensitive, a photosensitive material layer 270 is applied, at step 1140 of FIG. 2A, on the lenslet material layer 240 to create the substrate structure shown in FIG. 20. Likewise, in the configuration where an etch stop layer is not used, the photosensitive material layer 770 is applied on the lenslet material layer 740, as shown in FIG. 20. The photosensitive material layer 270 is provided so that the photosensitive material layer 270 may be patterned to mark the locations of lenslet preforms 242 as shown in FIG. 22. The photosensitive material layer 270 may comprise photoresist, for example, or any other photo-patternable material which can create a lenslet mask 275 used in creating the lenslet preforms 242.

[0057] The photosensitive material layer 270 is patterned, at step 1150, by exposing the photosensitive material layer 270 with a selected wavelength of light transmitted through the channels 234. The exposure of the photosensitive material layer 270 creates exposed regions within the photosensitive material layer 270 which are in registry with the channels 234. Standard photoresist processing techniques, or other suitable methods, may be used to selectively remove the unexposed portions of the photosensitive material layer 270, at step 1160, to create a lenslet mask 275, as shown in FIG. 21.

[0058] The lenslet preforms 242 are created, at step 1170 of FIG. 2B, by selective removal of a portion of the lenslet material layer 240 which is not covered by the lenslet mask 275, as shown in FIG. 22. The method of removing the portions of the lenslet material layer 240 may comprise physical etching, focused ion-beam milling, photochemical etching, electrochemical etching, and wet and dry chemical etching. The lenslet mask 275 may be removed during the lenslet preform creation step, or may be removed subsequent to the preform creation step. Once the lenslet preforms 242 are formed, the lenslets 250 are created, at step 1180 of FIG. 2B, for example by heating, as shown in FIG. 23.

[0059] These and other advantages of the present invention will be apparent to those skilled in the art from the foregoing specification. Accordingly, it will be recognized by those skilled in the art that changes or modifications may be made to the above-described embodiments without departing from the broad inventive concepts of the invention. It should therefore be understood that this invention is not limited to the particular embodiments described herein, but is intended to include all changes and modifications that are within the scope and spirit of the invention as set forth in the claims.

What is claimed is:

1. A fiber optic chip for retaining an optical fiber, comprising:

a substrate having a first surface;

an etch stop layer disposed proximate the first surface of the substrate;

a fiber channel having an end disposed proximate the first surface of the substrate and a longitudinal axis extending along the channel; and

a lenslet disposed on the etch stop layer and having an optical axis substantially aligned with the longitudinal axis of the channel.

2. The fiber optic chip according to claim 1, wherein the etch stop layer is disposed on the first surface of the substrate.

3. The fiber optic chip according to claim 1, wherein the substrate comprises an alignment feature.

4. The fiber optic chip according to claim 3, wherein the substrate has a second surface disposed in opposition to the first surface, and the alignment feature is disposed proximate the second surface.

5. The fiber optic chip according to claim 1, wherein the channel end terminates at the etch stop layer.

6. The fiber optic chip according to claim 1, wherein the lenslet comprises one or more of a plastic, a photosensitive material, and glass.

7. A fiber optic chip for retaining an optical fiber, comprising:

a substrate comprising an etch stop layer;

a fiber channel disposed in the substrate, the channel having an end disposed proximate the etch stop layer; and

a lenslet disposed over the etch stop layer in registration with the channel.

8. The fiber optic chip according to claim 7, wherein the lenslet is disposed on the etch stop layer.

9. The fiber optic chip according to claim 7, wherein the lenslet comprises one or more of a plastic, a photosensitive material, and glass.

10. The fiber optic chip according to claim 7, wherein the substrate comprises silicon.

11. The fiber optic chip according to claim 7, wherein the etch stop layer comprises one or more of silicon nitride and silicon dioxide.

12. The fiber optic chip according to claim 7, wherein the etch stop layer is disposed on an external surface of the substrate.

13. The fiber optic chip according to claim 7, wherein the substrate comprises an alignment feature disposed therein.

14. The fiber optic chip according to claim 7, wherein the etch stop layer is optically transparent.

15. The fiber optic chip according to claim 7, wherein the channel communicates with the etch stop layer.

16. A fiber optic chip for retaining an optical fiber, comprising:

a substrate;

a fiber channel disposed in the substrate, the channel having an end disposed proximate the etch stop layer;

a pedestal disposed over the substrate in registration with the channel; and

a lenslet disposed over the pedestal.

17. The fiber optic chip according to claim 16, wherein the pedestal is monolithic to the substrate.

18. The fiber optic chip according to claim 16, wherein the lenslet comprises one or more of a plastic, a photosensitive material, and glass.

19. The fiber optic chip according to claim 16, wherein the substrate comprises silicon.

20. The fiber optic chip according to claim 16, wherein the substrate comprises an alignment feature disposed therein.

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