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(54) Title: RESONANT MICROCAVITIES EMPLOYING ONE-DIMENSIONAL PERIODIC DIELECTRIC WAVEGUIDES
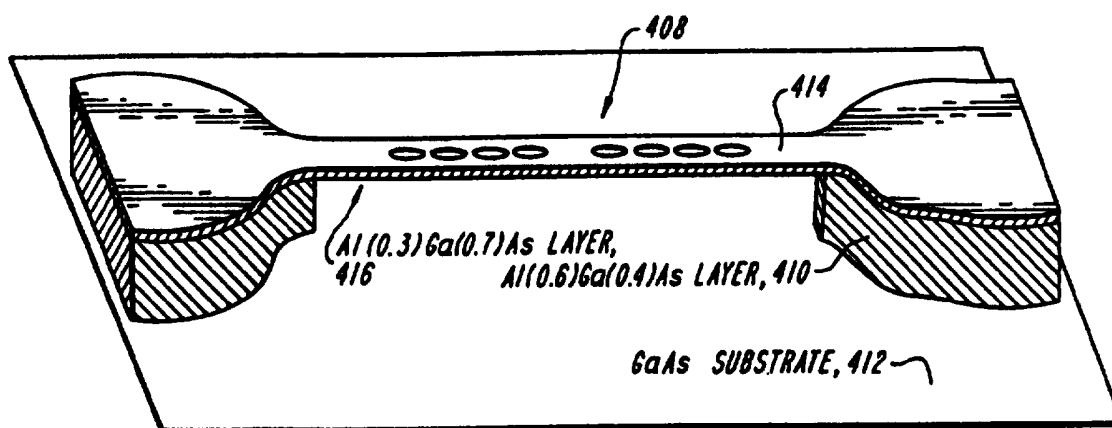
(57) Abstract

The present invention provides a resonant microcavity which includes a periodic dielectric waveguide, and a local defect in the periodic dielectric waveguide which accommodates spatial confinement of radiation generated within the waveguide around the defect. In an alternative embodiment, the present invention provides a method of enhancing radiation confinement within a resonant microcavity and minimizing radiation losses into an associated substrate, the microcavity configured within a periodic dielectric waveguide as a local defect which exhibits spacial radiation confinement, the method including the step of increasing the refractive index contrast between the microcavity and the substrate.

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RESONANT MICROCAVITIES EMPLOYING ONE-
DIMENSIONAL PERIODIC DIELECTRIC WAVEGUIDES
BACKGROUND OF THE INVENTION

In the past decades, the semiconductor laser has come
5 to play a critical role in numerous applications including
optical information storage and retrieval (e.g. CD players),
lightwave communication (e.g. optical fibers), and computer
input/output. Typical semiconductor lasers are nearly 200μm
in length and the lateral mode area is approximately a
10 square micron. This results in nearly 100 longitudinal
modes within the spectral bandwidth of the laser gain
medium. As a result, many modes can reach lasing threshold,
leading to multimode oscillations. In order to increase the
relative gain differences between the various modes, a
15 frequency-selective loss can be introduced by building a
corrugated structure inside the laser cavity. The modes
closest to the Bragg wavelength of the grating will have the
lowest losses and will build up. This is known as a
distributed feedback (DFB) laser.

20   Single-frequency lasing can be obtained by
incorporating a phase shift (or defect) in the grating of
the DFB laser, as shown in Fig. 1A. Fig. 1A shows a cross-
sectional view of a DFB laser 100 with a single phase slip
102 at the center. The DFB laser is configured with a
25 substrate 104 and a grating layer 106 made with two
dielectric materials. The grating pattern includes the
aforementioned single phase slip or defect. A gain region
108 with impurity atoms and a cladding layer 110 for
isolation are also provided. Although the phase shift has
30 the effect of confining the field around the defect, the
confinement is very weak, as shown in Fig. 1B. Fig. 1B
shows a plot of the intensity as a function of the axial
position in the DFB laser. The parameter κL is known as the
coupling parameter and increases as a function of the depth
35 of the corrugation. The intensity is in arbitrary units.

Mirrors of a DFB laser (or any semiconductor laser) are
normally formed simply by cleaving the end faces of the
crystal. The two faces are cleaved along the same

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crystallographic planes which results in a parallel-plane
resonator which is at the limit of the geometric stability
conditions of lasers. This partly accounts for the typical
lack of stability of the output mode in semiconductor
5   lasers.   Furthermore,   each   interface   between   the
semiconductor and air has roughly a 30% reflectivity. These
high losses, in conjunction with the large dimensions of the
laser, result in very large input thresholds required to
operate semiconductor lasers. In order to increase the
10 reflectivity at each interface, multilayer dielectric films
can be deposited on the end faces. However, this process
involves laborious and expensive manipulations since each
laser must be separated from the others and direct
integration on a substrate becomes impossible.
15   In order to solve most of these problems, researchers
have developed laser cavities whose dimensions are on the
order of the wavelength of the emitted light. These
microcavities have dimensions of microns or fractions of
microns. The first such device was introduced in the late
20 1980's. It is called the vertical cavity surface emitting
laser (VCSEL) 200 and is shown in Fig. 2A. It is made of
two multilayer dielectric quarterwave mirrors 202, 204
separated by a material 206 of index n and thickness λ/n.
The gain medium is often made of one or several quantum
25 wells 207 placed in the layer of index n at the peak of the
resonant mode electric field. For wavelengths around 1 and
1.5μm, typical dimensions are 5-10μm in diameter and several
microns in height. Although there is only one longitudinal
mode within the gain spectral bandwidth, there are other
30 modes in the plane of the gain region transverse to the axis
of the VCSEL. Furthermore, the overlap of the resonant mode
and the gain quantum layer is very low since the field
extends deeply into the multilayer mirrors. In spite of the
advantages of the VCSEL over typical semiconductor lasers,
35 the most significant drawback of these devices is their
vertical position and vertical emission 208 on the substrate
which   limits   significantly   their   usefulness   in
optoelectronic integrated circuits (OEICs).

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Another microlaser design was introduced in the early
1990's and is known as the microdisk laser 210 as shown in
Fig. 2B. As its name indicates, it is made of a small high-
index disk 212 supported by a post 214. The disk diameter
5 is typically between 2 and 10μm and its thickness is around
0.25μm. The gain medium is made of one or several quantum
layers 217 placed in the center of the disk. Since the
resonant mode 216 can be strongly confined in the disk, its
overlap with the gain material can be much larger than that
10 of the VCSEL. The dominant resonant mode is called a
whispering-gallery mode since it propagates around the edge
of the disk with low losses due to total internal
reflection. However, the resonant mode can "leak out"
anywhere along the edge of the disk. This limits
15 significantly the coupling efficiency of the microdisk since
only a small fraction of the output light can be coupled
into a waveguide.

Although the fabrication of the microdisk does not
require the growth of several dielectric layers, which
20 should make its fabrication easier than that of the VCSEL,
the resonant imperfections can significantly affect the
whispering-gallery mode and reduce the lasing efficiency of
the microdisk. The lasing efficiency is further reduced by:
the presence of two counter-propagating modes at the disk
25 edge which competes for spontaneous emission, by the
presence of external modes propagating orthogonally through
the disk which may overlap the emission spectrum and compete
with the lasing mode for spontaneous emission, and by the
emission from the central region of the disk.

30   **SUMMARY OF THE INVENTION**

The present invention provides a resonant microcavity
which includes a periodic dielectric waveguide, and a local
defect in the periodic dielectric waveguide which
accommodates spacial confinement of radiation around the
35 defect.

In an alternative embodiment, the present invention
provides a method of enhancing radiation confinement within

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a resonant microcavity and minimizing radiation losses into
an associated substrate, the microcavity configured within
a periodic dielectric waveguide as a local defect which
exhibits spacial radiation confinement, the method including
5 the step of increasing the refractive index contrast between
the microcavity and the substrate.

This present invention provides a new class of resonant
microcavities which combine the best features of all the
state-of-the-art integrated resonant cavities into one.
10 These new microcavities contain an electromagnetic mode
whose field is very strongly confined within the cavity.
They are integrated in the plane of the substrate which
allows for direct coupling into optoelectronic integrated
circuits without the need of any additional device. The
15 microcavities will allow for the fabrication of high density
and high speed optical interconnects, ultra-low threshold
microlasers and LED's, and will also allow for the
enhancement of spontaneous emission. They employ one-
dimensional periodic dielectric waveguides to confine light
20 along all three dimensions in space.

The microcavities of the present invention contain an
electromagnetic mode which can lead to very high quantum
efficiencies since all the spontaneous emission will be
funneled into just one mode. These new microcavities also
25 give rise to strong field confinement within the cavities.
The overlap of the resonant mode and the gain medium should
be very large and should lead to the enhancement of
spontaneous emission. By concentrating the electric field
fluctuations into a small volume, the recombination rate of
30 carriers is increased allowing the microcavities to be
modulated at very high speeds.

Furthermore, the microcavity design of the present
invention is very small, hence a large number of them can be
integrated onto a single optical chip. Their small size
35 combined with their high efficiency will allow them to be
operated at very low thresholds. Yet one of the most
significant advantages of the microcavities of the present
invention is their ability to be integrated directly into

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OEICs. The devices allow light to be coupled directly in and out of a waveguide with very high degrees of efficiency. In addition, deviations arising in the fabrication process should not affect significantly their efficiency. Finally, even without the presence of gain in these devices, they would still behave as single mode thresholdless light-emitting diodes. Either with or without gain, the devices could be pumped optically or electrically.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B respectively show a cross-sectional view of a conventional DFB laser with a single phase defect at the center, and a plot of the intensity as a function of the axial position in the DFB laser;

Figs. 2A and 2B respectively show a conventional vertical cavity surface emitting laser, and a conventional microdisk laser construction;

Fig. 3A shows a conventional rib waveguide on a substrate; Fig. 3B shows a one-dimensional periodic dielectric microcavity in accordance with the present invention; Fig. 3C shows the waveguide microcavity of Fig. 3B in a bridge configuration in accordance with the present invention;

Figs. 4A and 4B respectively show an alternative embodiment of a waveguide microcavity positioned on a substrate and in a bridge configuration in accordance with the present invention; Figs. 4C and 4D show two steps of fabrication process of the bridge configuration of Fig. 4B; Figs. 4C and 4D show computed power graphs as a function of position;

Figs. 5A and 5B respectively show a waveguide microcavity and substrate configured with a dielectric layer therebetween, the layer having a width which is greater than that of the microcavity, and a width which is smaller than that of the microcavity; Fig. 5C shows a microcavity fabricated by etching away part of the dielectric layer; and

Figs. 6A and 6B respectively show a waveguide microcavity configured from a periodic array of dielectric

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rods with an oversized intermediate rod, and a waveguide microcavity configured with a dielectric rib with holes disposed through the sides thereof.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

5   The resonant microcavities of the present invention are formed by using a conventional planar optical waveguide geometry with a strong periodic variation of the dielectric constant along the axial direction of the waveguide. As described above, the microcavities have dimensions of

10 microns or fractions of microns. The planar resonant microcavities allow for in-plane coupling along the surface of a substrate on which it is constructed.

For simplicity of illustration, a conventional rib waveguide 300 is shown in Fig. 3A. The waveguide is made of

15 one or more layers of a high-index of refraction material, which lies on a substrate 302 with a lower refractive index. The waveguide confines the radiation along both the y and z directions. Radiation can be further confined along the x direction by adding a periodic variation of the dielectric

20 constant along that axis. The microcavity is formed by breaking the perfect periodicity along the x-axis hence forming a local defect which can lead to strong spacial confinement of the radiation around the defect in order to generate a single electromagnetic mode. It will be

25 appreciated that multimode operations are possible with the same device configuration. The electromagnetic mode is localized around the defect within a few periodic distances. Local defects can be made, for example, by putting a phase shift in the periodic structure along the x-axis or by

30 adding a different material locally in the waveguide.

The waveguide microcavity 304 in accordance with the present invention is shown in Fig. 3B. The one-dimensional periodic structure is depicted by the alternating dielectric regions 306, 308 along the x-axis and the defect 310 is

35 shown in a central location. In order to get good radiation confinement into the microcavity (i.e. minimum leakage into the surrounding medium) it is essential that the index

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contrast between the waveguide 304 and the substrate 302 be
as large as possible. Si waveguides on a SiO_2 substrate
would offer excellent index contrasts. Other materials such
as GaAs and AlGaAs can be used in the fabrication of the
5 waveguides but they would need to be grown on a substrate
with a low dielectric constant. Ge waveguides on a GaAs
substrate could also be used but the index contrast would be
smaller.

    One particularly advantageous technique of increasing
10 the index contrast is to suspend a waveguide 312 with
alternating dielectric index materials in air in such a
manner that the microcavity is completely surrounded by air
as shown in Fig. 3C. The "air bridge" suspension can be
achieved by the use of fabricated support members 314, 316
15 described in more detail hereinafter. This suspension has
the effect of minimizing the radiation losses into the
substrate.

    More specific embodiments of the waveguide
microcavities of the present invention are now described.
20 An exemplary embodiment of a microcavity 400 is shown in
Fig. 4A. The microcavity is fabricated by creating a
periodic array of holes 404 into the top surface of a rib
waveguide 402. The rib waveguide can be made of one or more
layers of different materials. A local defect 406 is added
25 by separating two of the holes by a distance larger than
that which separates the other holes.

    In this exemplary embodiment, the cross-section of the
holes is circular, however, other configurations are
possible. The different parameters of this microcavity are:
30 the width w and height h of the rib waveguide, the radius r
of the holes, the distance a from center to center of each
hole, the size d of the defect, and the number of holes on
each side of the defect. Since the microcavity can be
scaled to any wavelength simply by scaling these parameters,
35 it is convenient to choose one of the parameters and scale
every other with respect to it. In the exemplary embodiment
illustrated, every parameter is chosen to be scaled with
respect to a.

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The waveguide of the present invention is grown directly onto a substrate, but the radiation leakage into this substrate will reduce the confinement efficiency of the microcavity. In order to minimize these losses, it is
5 desirable to reduce the contact area and increase the index contrast between the microcavity and the substrate. As mentioned above, one way of increasing the index contrast is to suspend the microcavity in air. A specific exemplary embodiment of a microcavity 408 is shown in Fig. 4B using
10 fabricated layers of GaAs and AlGaAs. A layer 410 of $Al_{0.6}Ga_{0.4}As$ is grown on a GaAs substrate 412, and thereafter a waveguide 414 is then grown over this layer using $Al_{0.3}Ga_{0.7}As$. By selectively etching away the $Al_{0.6}Ga_{0.4}As$ from under the microcavity leaving space 416, the microcavity
15 itself is suspended in air. One exemplary method of fabricating space 416 is shown in Figs. 4C and 4D. Layers 410 and 414 are grown on the substrate 412 and both layers are etched as shown in Fig. 4C where the ends are wider than the center. Layer 410 is selectively etched away until the
20 central part is entirely removed, leaving space 416 as shown in Fig. 4D. The ends of waveguide 414 can then be tapered down to any shape with an additional etching step. Although the illustrated example utilizes GaAs and AlGaAs in Fig. 4B, it will be appreciated by those of skill in the art that the
25 bridge configuration can alternatively be made with any material strong enough to support itself. For example, a Si waveguide on SiO_2 is another alternative material construction.

The bridge configuration accommodates very high degrees
30 of confinement within the microcavity along every direction. Figs. 4E and 4F respectively show exemplary graphs of the computed power of the resonant mode in the suspended microcavity as a function of position in the xy-plane (at $z = 0$) and the yz-plane (at $x = 0$). The coordinate system is
35 centered in the defect. The exemplary waveguide microcavity was assumed to be made of a material with a dielectric constant of 12.096 with the following parameters: $w = 1.1a$, $h = 0.4a$, $r = 0.3a$ and $d = 1.9a$, where d is the distance

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from center to center of the holes on either side of the defect. Furthermore, three and a half holes on either side of the defect were used in the illustrated computations. In the specific case where the microcavity is operated at a
5 wavelength of 1.5μm, the lattice constant a would be equal to 0.5μm.

    Another technique of the present invention to reduce the losses into the substrate is to grow an extra dielectric layer between the substrate and the microcavity. Several
10 exemplary embodiments of this design are shown in Figs. 5A-5C. The thickness H and the width W of the additional layer can be adjusted in order to minimize radiation leakage into the substrate. In Fig. 5A, a dielectric layer 500 is positioned between a waveguide microcavity 502 and substrate
15 504. The width of the layer 500 is greater than that of the waveguide, whereas the width of the layer 500' is smaller in the configuration of Fig. 5B.

    One technique of fabricating the microcavity shown in Fig. 5B is to grow the dielectric layer 500' onto the
20 substrate 504' and then grow the waveguide microcavity 502' onto the layer 500'. By selectively etching part of the dielectric layer from underneath the waveguide, the resulting device is shown in Fig. 5C. Although the dielectric layer 500" is preferably made out of a different
25 material (with a smaller dielectric constant) than that of the substrate 504", it can also be made of the same material. Since materials like Si and GaAs are often used as substrates and since these materials have high dielectric constants, it becomes necessary to separate the microcavity
30 from the substrate with a material of smaller dielectric constant.

    Another alternative technique of increasing the radiation confinement into the microcavity is to increase the depth of each hole 506 through the waveguide 502 and
35 into the dielectric layer 500 as shown in Fig. 5A. The holes can further be extended into the substrate 504. This approach can be applied to any embodiment, including the ones shown in Figs. 5B and 5C.

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Although the radiation confinement in the microcavity increases with the number of holes, the coupling efficiency into the waveguide decreases. When a large number of holes are used on either side of the defect, there is barely any

5 radiation leaking out into the waveguide. In order to couple light in and out of the microcavity, the number of holes on one side of the defect can be reduced without affecting significantly the confinement efficiency of the device. As a result, microcavities with both excellent

10 field confinement and excellent coupling into the waveguide are fabricated.

Fig. 6A shows another exemplary embodiment of a waveguide microcavity 600 which includes an array of long dielectric rods 602 fabricated on a substrate 604. The

15 array of rods behaves like a one-dimensional periodic waveguide. Although the rods are illustrated with a square cross-section, it will be appreciated by those of skill in the art that the rods can be of any shape. The local defect is made of a single oversized rod 606, shown positioned in

20 the center of the array. Radiation is strongly confined around this defect. However, stronger confinement can be achieved in the structure shown in Fig. 6B. The waveguide microcavity 608 of Fig. 6B is similar in structure to the embodiments shown in Figs. 4 and 5 with a substrate 610 and

25 dielectric layer 612, except that the waveguide dielectric rib 614 rests on its side at a 90° angle, with holes 616 going through parallel to the surface of the substrate. This structure is grown in stages by etching square grooves and by backfiling them with a material which is eventually

30 removed after having grown the top part of the structure. Therefore, instead of ending up with circular holes, the holes 616 are square.

Lasing is achieved in all of the described embodiments simply by adding a gain medium in or in the vicinity of the

35 defect. Since the field is very strongly confined around that area, the overlap of the resonant mode and the gain medium would be very large.

The waveguide microcavities described herein combine

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the best properties of microlasers while having the ability of being coupled directly into planar waveguides. The devices are interesting candidates for high-density high-speed planar integrated optical interconnects and could play
5 a very significant role in systems such as optical computers.

The foregoing description has been set forth to illustrate the invention and is not intended to be limiting. Since modifications of the described embodiments
10 incorporating the spirit and substance of the invention may occur to persons skilled in the art, the scope of the invention should be limited solely with reference to the appended claims and equivalents thereof.

What is claimed is:

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CLAIMS

1   1. A resonant microcavity comprising:
2   a planar periodic dielectric waveguide; and
3   a defect in said periodic dielectric waveguide which
4 accommodates spacial confinement of radiation generated
5 within said waveguide around said defect.

1   2. The microcavity of claim 1, wherein said waveguide
2 is supported by a substrate, said substrate providing a
3 refractive index contrast with said waveguide.

1   3. The microcavity of claim 2, wherein a dielectric
2 layer is disposed between said waveguide and said substrate
3 in order to minimize radiation losses into said substrate.

1   4. The microcavity of claim 1, wherein said waveguide
2 is suspended in air in a bridge configuration between
3 substrate supports such that said defect is surrounded by
4 air.

1   5. The microcavity of claim 2, wherein said waveguide
2 comprises   an   array   of   holes   provided   therein   for
3 periodicity.

1   6. The microcavity of claim 5, wherein said local
2 defect comprises a separation of two of said holes by a
3 distance larger than that which separates the remaining
4 holes in said array.

1   7. The microcavity of claim 6, wherein said holes are
2 disposed perpendicular with respect to the surface of said
3 substrate so as to produce an electromagnetic mode localized
4 around said defect.

1   8. The microcavity of claim 7, wherein a dielectric
2 layer is disposed between said waveguide and said substrate,

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3 said holes extending through said waveguide and into said
4 dielectric layer in order to minimize radiation losses into
5 said substrate.

1   9.   The microcavity of claim 5, wherein said holes are
2 disposed parallel with respect to the surface of said
3 substrate so as to produce an electromagnetic mode localized
4 around said defect.

1   10. The microcavity of claim 2, wherein said waveguide
2 comprises an array of rods extending therefrom for
3 periodicity.

1   11. The microcavity of claim 10, wherein said local
2 defect comprises a rod of a different size or dielectric
3 constant in said array which produces an electromagnetic
4 mode localized around said defect.

1   12. A resonant microcavity which exhibits an
2 electromagnetic mode for use in a microlaser, comprising:
3   a planar one-dimensional periodic dielectric waveguide
4 which confines radiation generated therewithin along all
5 three dimensions in space, said waveguide having a periodic
6 variation of dielectric constant along its axial direction;
7 and
8   a local defect disposed in said periodic dielectric
9 waveguide which accommodates spacial confinement of
10 radiation around said defect.

1   13. The microcavity of claim 12, wherein said
2 waveguide is supported by a substrate, said substrate
3 providing a refractive index contrast with said waveguide.

1   14. The microcavity of claim 13, wherein a dielectric
2 layer is disposed between said waveguide and said substrate
3 in order to minimize radiation losses into said substrate.

1   15. The microcavity of claim 12, wherein said

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2 waveguide is suspended in air in a bridge configuration
3 between substrate supports such that said local defect is
4 surrounded by air.

1   16.   The microcavity of claim 13, wherein said
2 waveguide comprises an array of holes provided therein for
3 periodicity.

1   17.   The microcavity of claim 16, wherein said local
2 defect comprises a separation of two of said holes by a
3 distance larger than that which separates the remaining
4 holes in said array.

1   18.   The microcavity of claim 17, wherein said holes
2 are disposed perpendicular with respect to the surface of
3 said substrate so as to produce said electromagnetic mode
4 localized around said local defect.

1   19.   The microcavity of claim 18, wherein a dielectric
2 layer is disposed between said waveguide and said substrate,
3 said holes extending through said waveguide and into said
4 dielectric layer in order to minimize radiation losses into
5 said substrate.

1   20.   The microcavity of claim 16, wherein said holes
2 are disposed parallel with respect to the surface of said
3 substrate so as to produce said electromagnetic mode
4 localized around said local defect.

1   21.   The microcavity of claim 13, wherein said
2 waveguide comprises an array of rods extending therefrom for
3 periodicity.

1   22.   The microcavity of claim 21, wherein said local
2 defect comprises a rod of different size or dielectric
3 constant in said array which produces said electromagnetic
4 mode localized around said local defect.

1   23. A method of enhancing radiation confinement within
2 a resonant microcavity and minimizing radiation losses into
3 an associated substrate, said microcavity configured within
4 a planar periodic dielectric waveguide including a local
5 defect which exhibits spacial radiation confinement, said
6 method comprising:
7   increasing the refractive index contrast between said
8 microcavity and said substrate.

1   24. The method of claim 23, wherein said step of
2 increasing comprises suspending said microcavity in air in
3 a bridge configuration so that said microcavity is
4 surrounded by air.

1   25. The method of claim 23, wherein said step of
2 increasing comprises providing a dielectric layer between
3 said waveguide and said substrate.

1   26. The method of claim 23, wherein said waveguide
2 comprises an array of holes therein for periodicity.

1   27. The method of claim 26, wherein said step of
2 increasing comprises increasing the number of holes in said
3 array.

1   28. The method of claim 23, wherein said step of
2 increasing comprises increasing the depth of each hole of an
3 array of holes provided in said substrate for periodicity
4 into said dielectric layer.

1   29. A method of producing a resonant microcavity with
2 enhanced radiation confinement, comprising:
3   providing a substrate;
4   forming a periodic waveguide on and parallel to the
5 plane of said substrate;
6   forming a local defect in said periodic waveguide which
7 accommodates spacial confinement of radiation generated
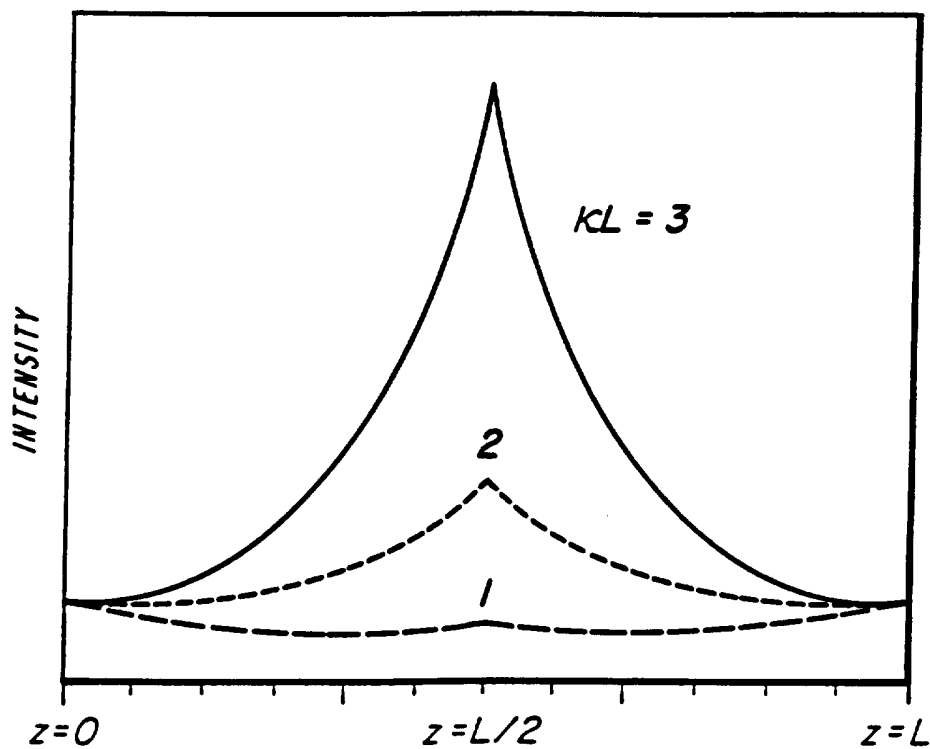8 within said waveguide around said defect;

- 16 -

9   removing said substrate from beneath said local defect
10 so as to produce a bridge configuration in which said defect
11 is surrounded by air.
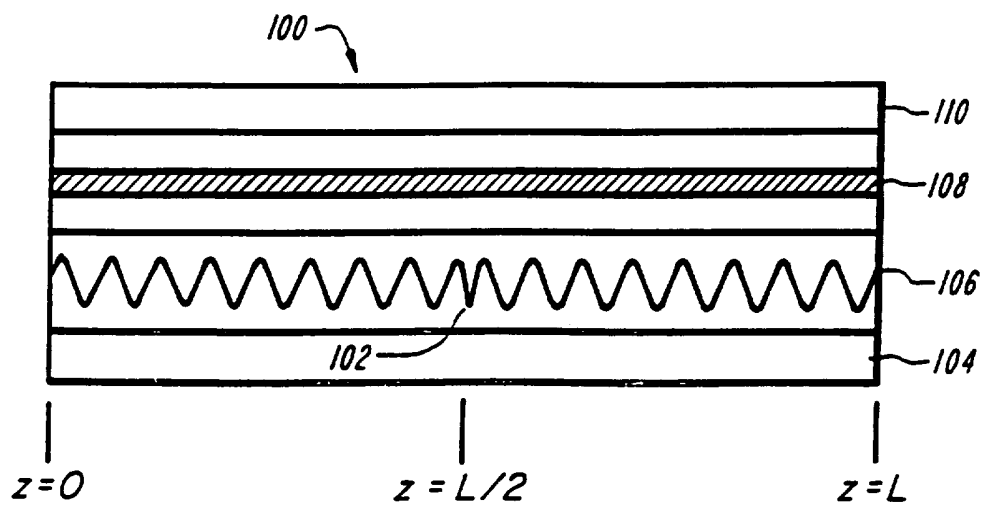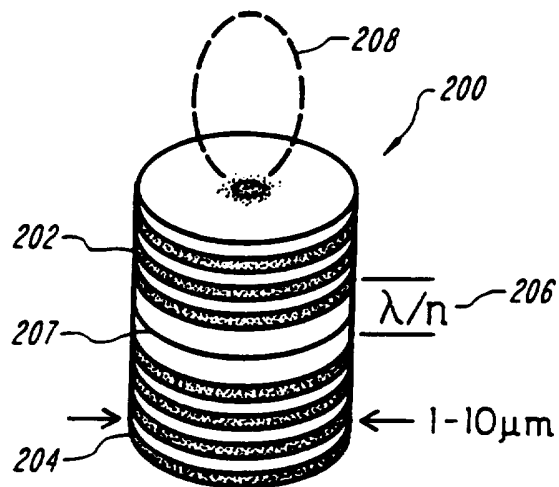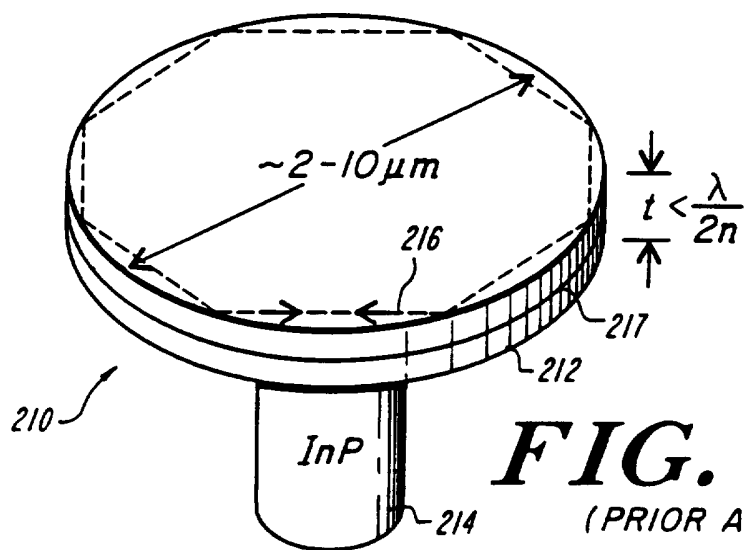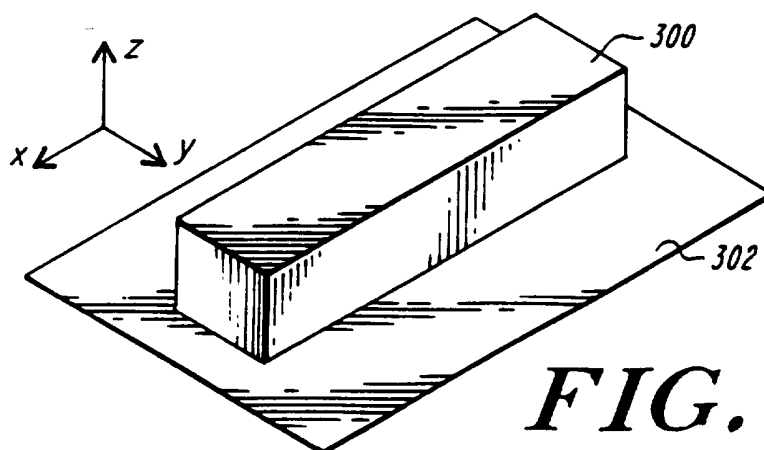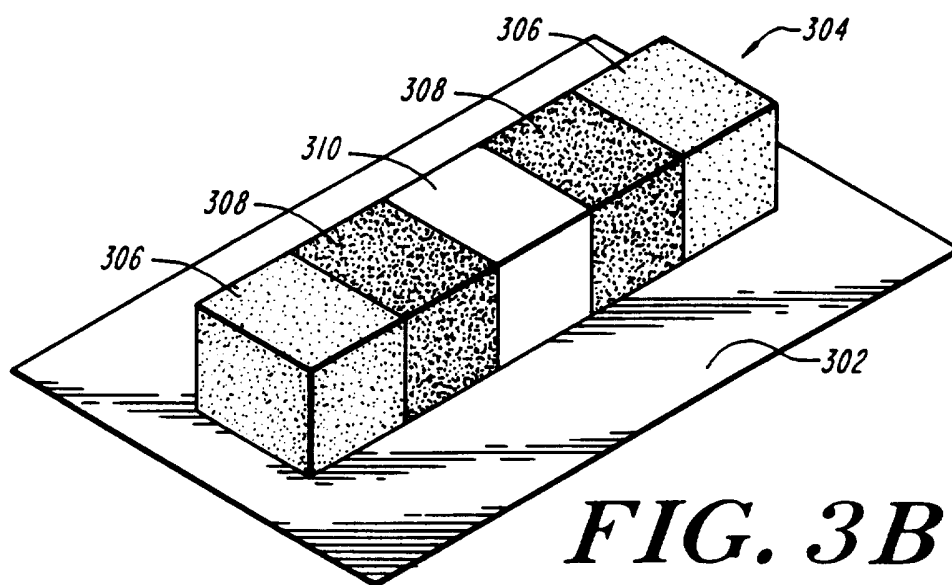
FIG. 1A
(PRIOR ART)

FIG. 1B
(PRIOR ART)

FIG. 2B

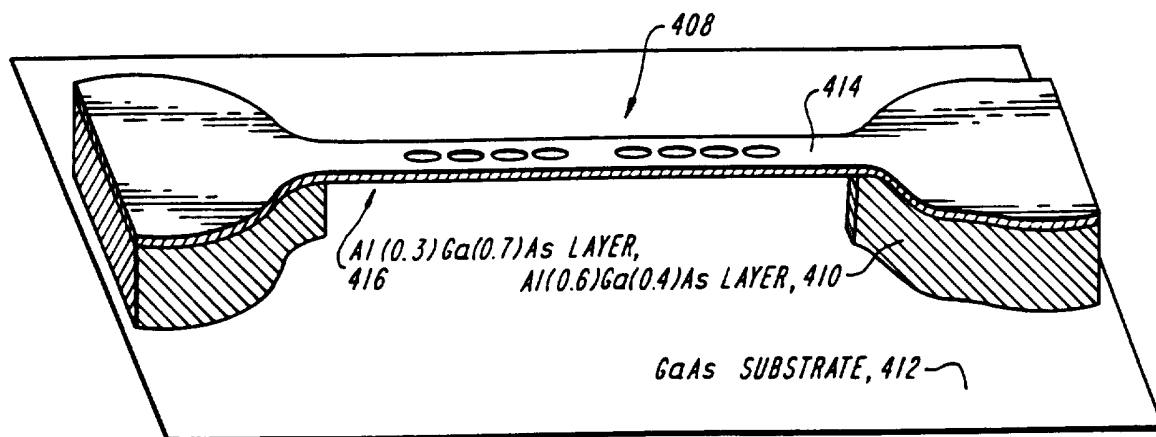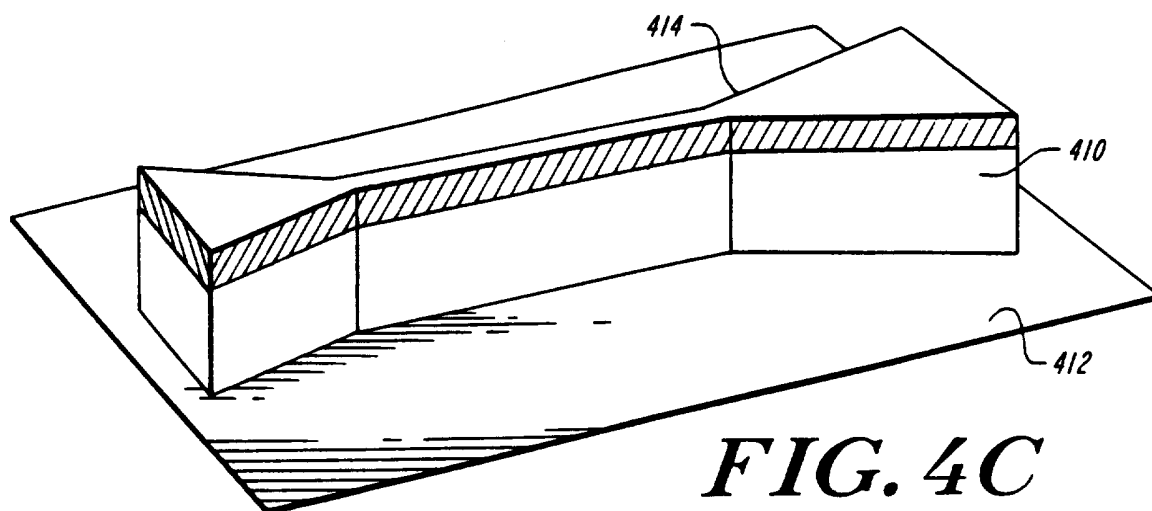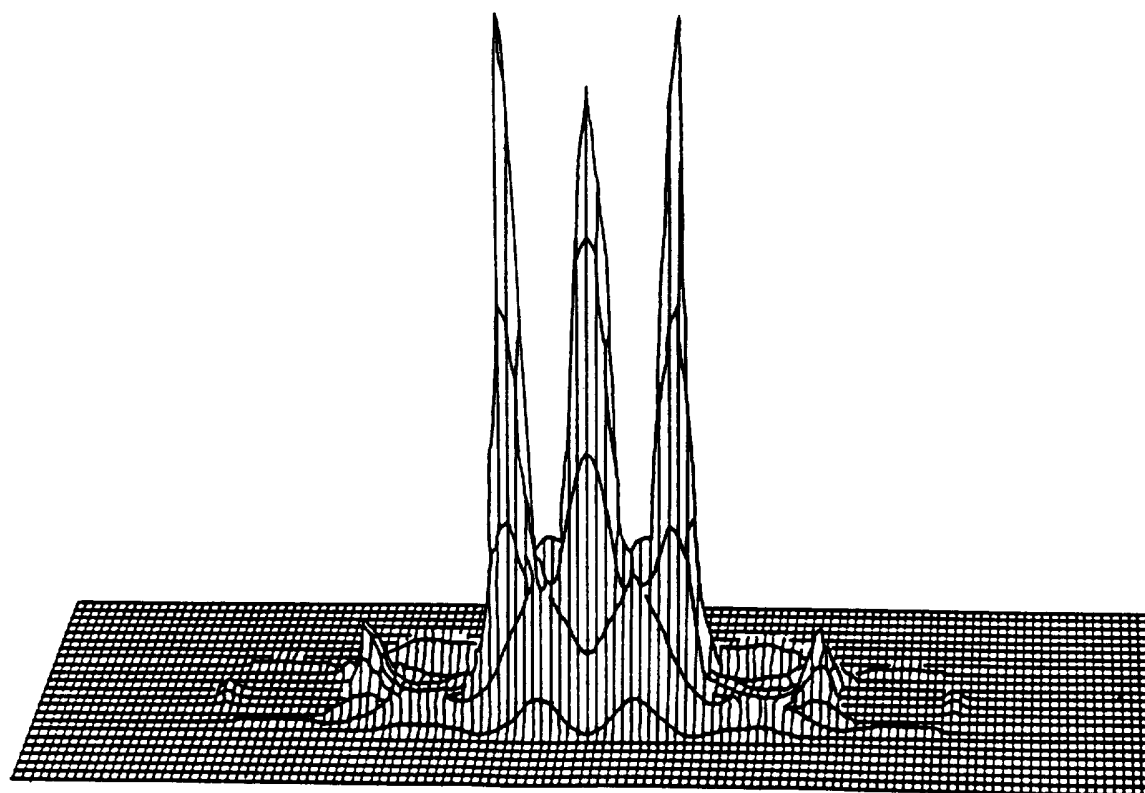**FIG. 2B**
(PRIOR ART)

FIG. 3A

FIG. 3B

FIG. 3C

4/8
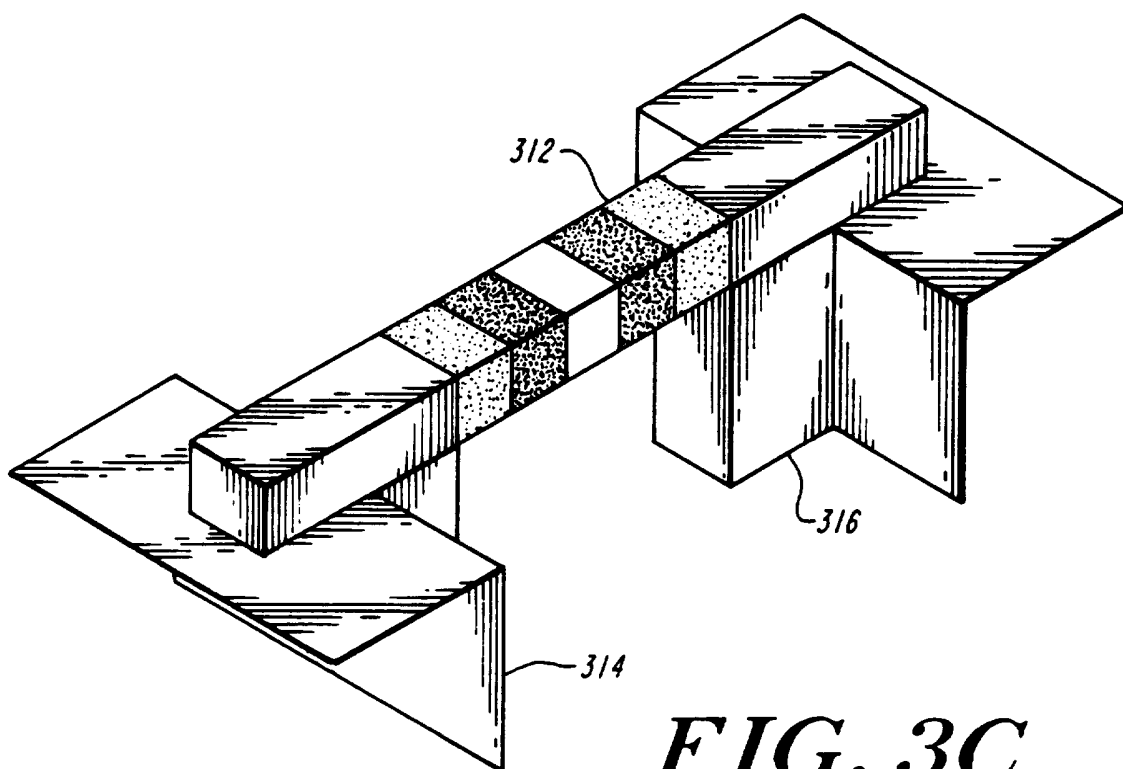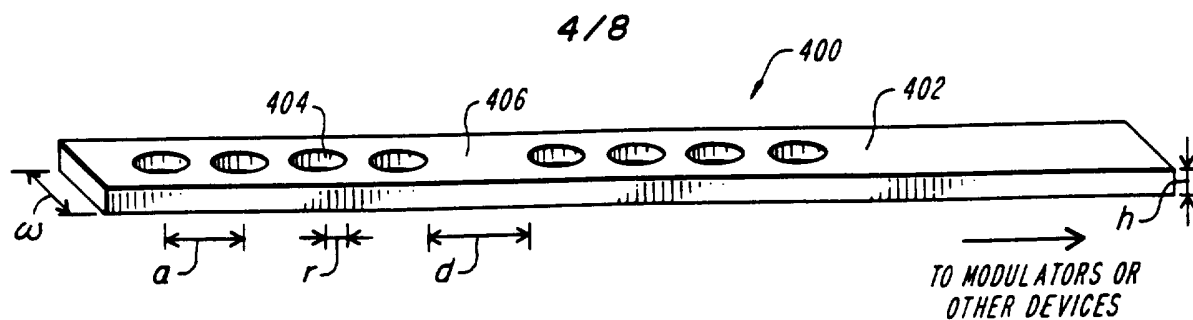
FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D

FIG. 4E

6/8

FIG. 4F

FIG. 5A

7/8

502'

500'

504'

$W < \omega$

FIG. 5B

502"

500"

504"
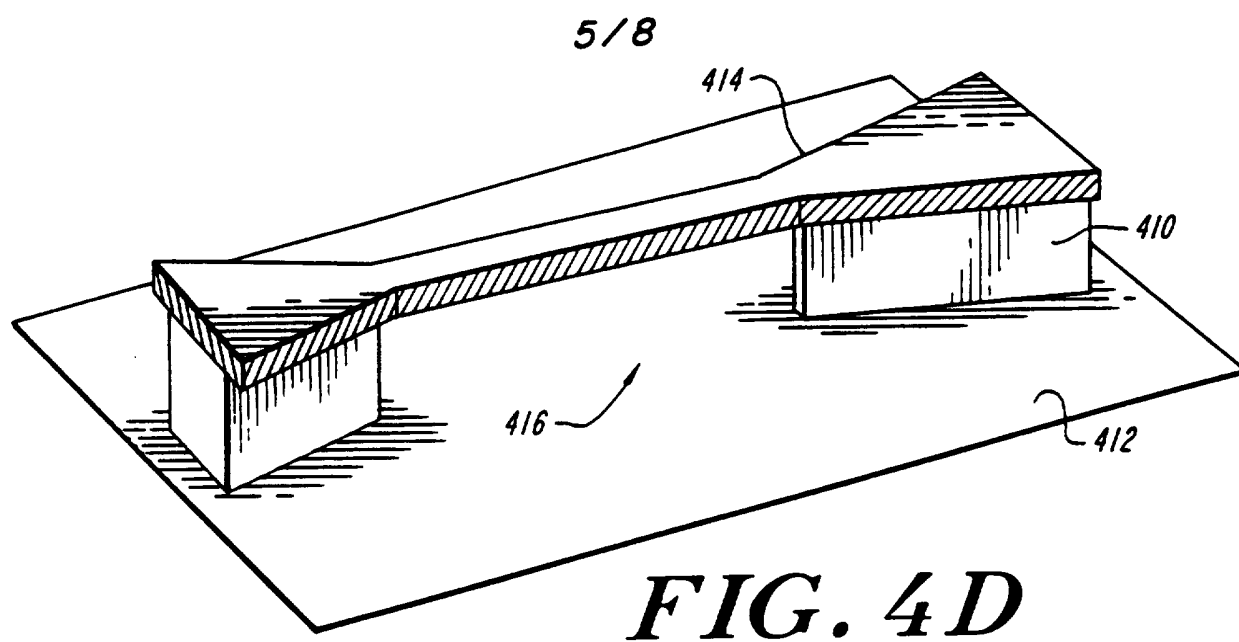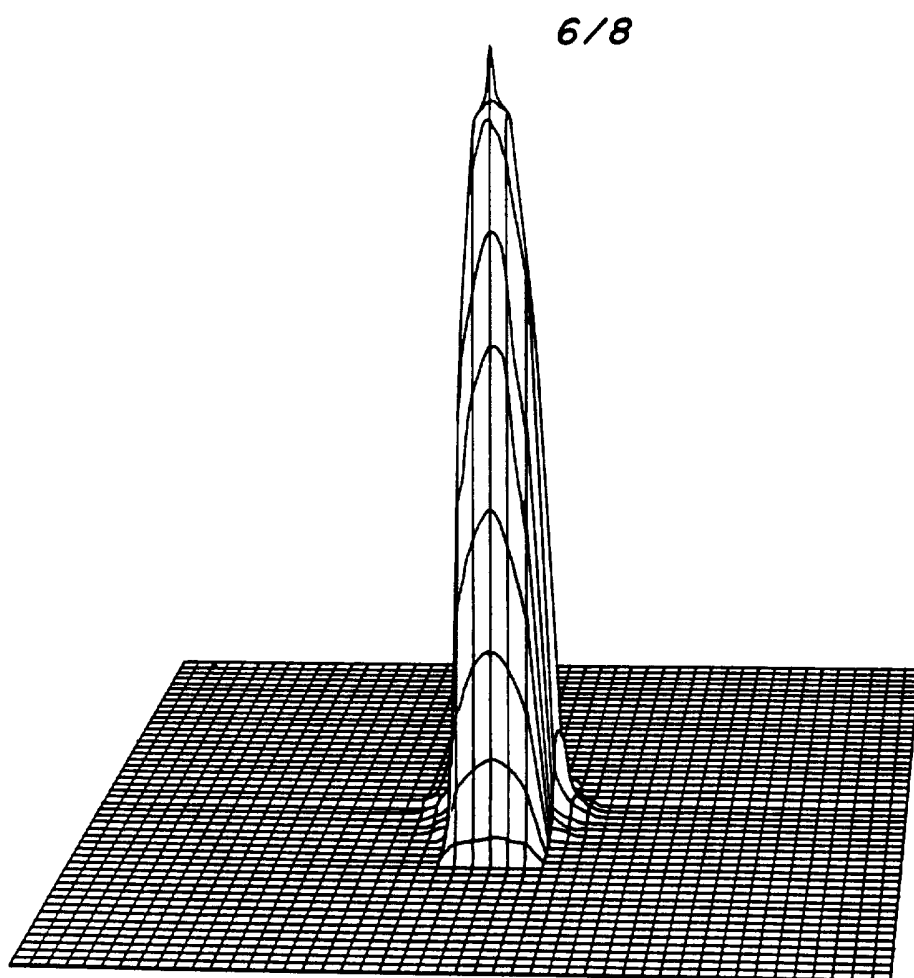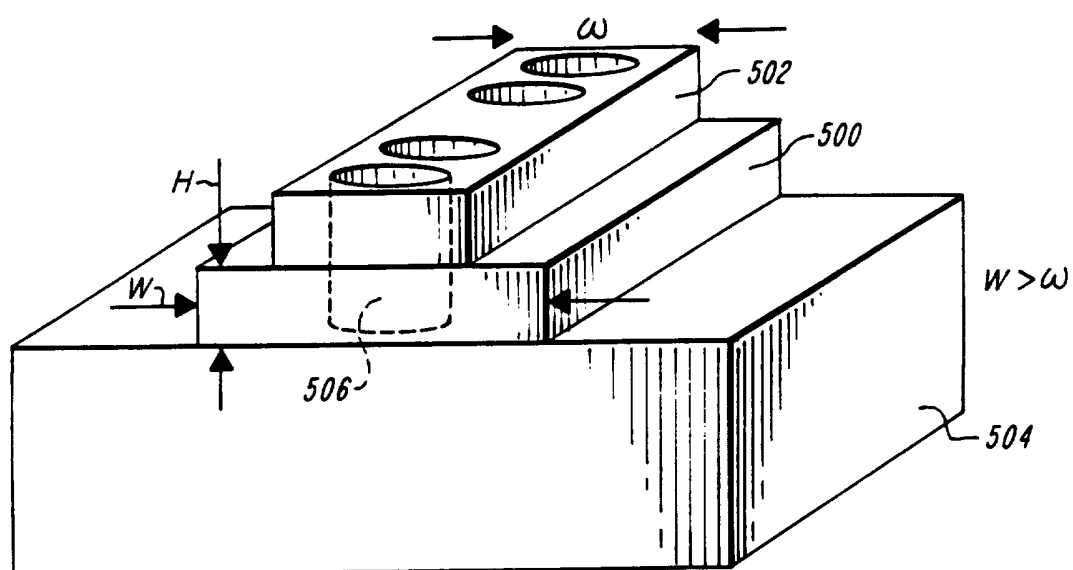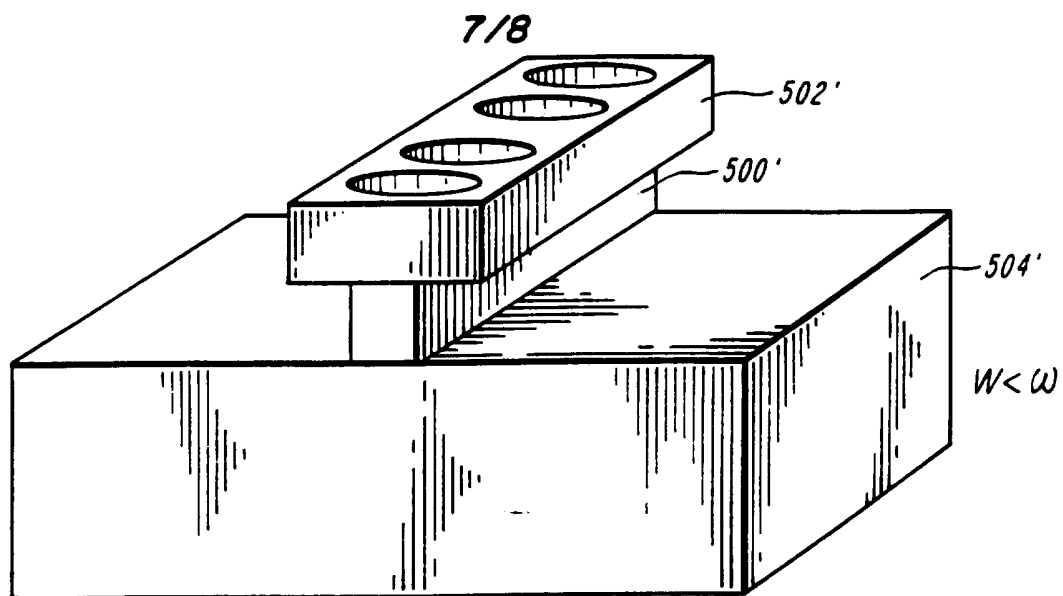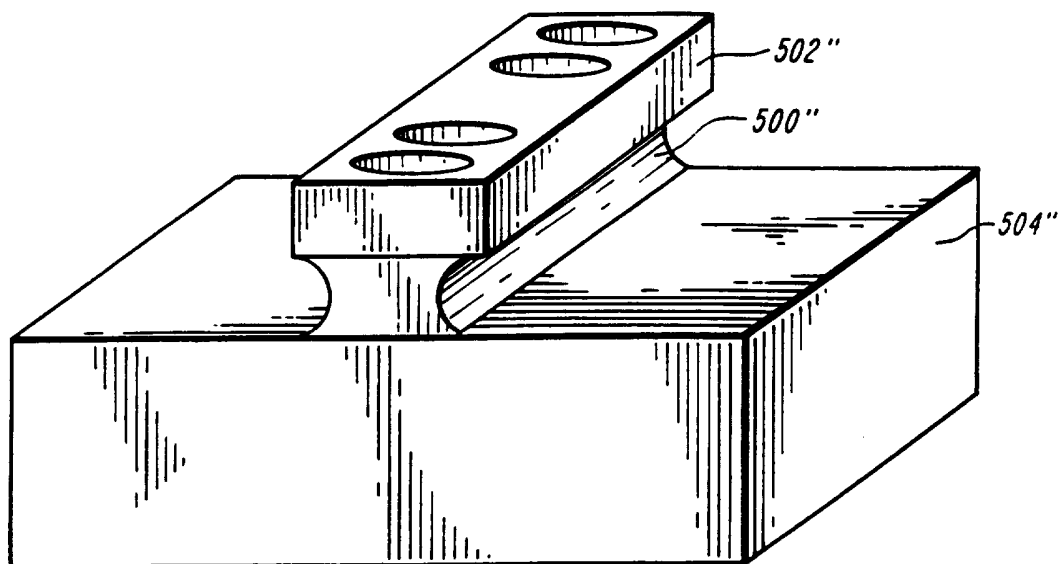
FIG. 5C
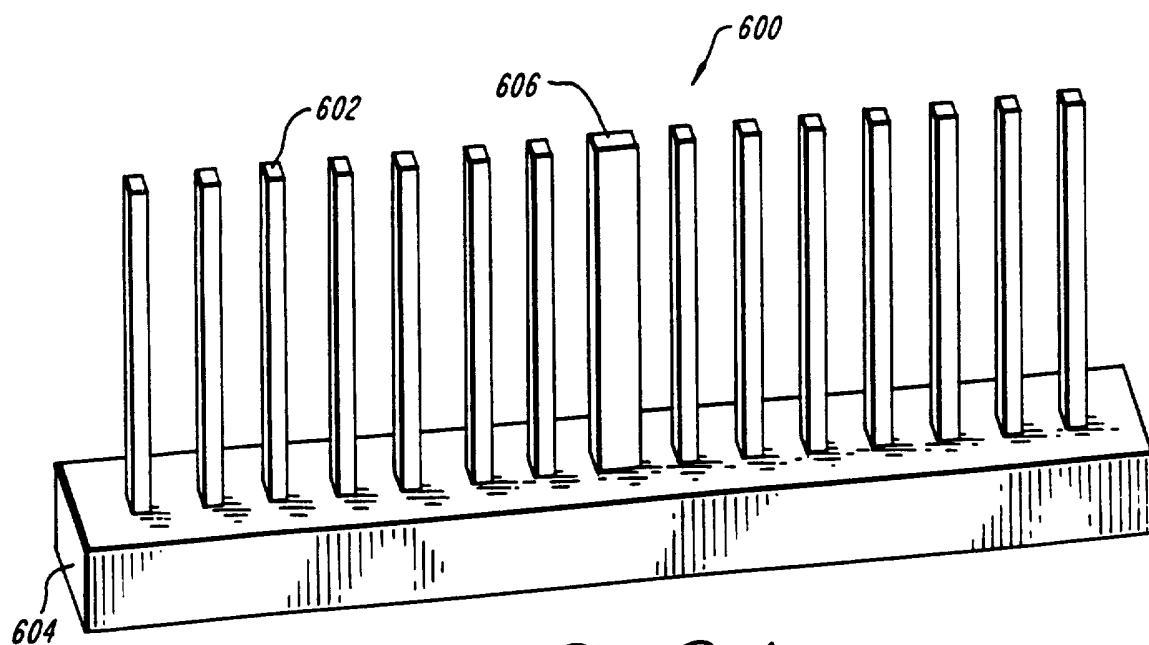
FIG. 6A
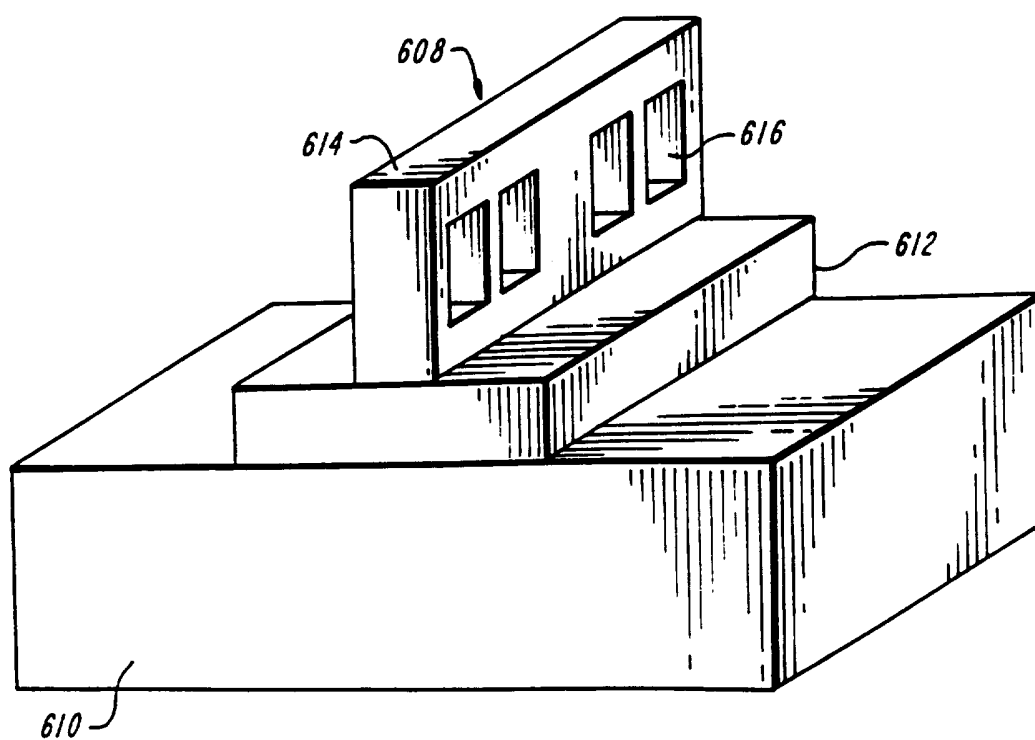
FIG. 6B

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   H01S3/085   H01S3/06   G02B6/10   G02B6/12   H01Q15/00
H01P1/207

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)

IPC 6   H01S   G02B   H01Q   H01P

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JOURNAL OF APPLIED PHYSICS, vol. 75, no. 9, 1 May 1994 NEW YORK US, pages 4753-4755, XP 000562393 R.D. MEADE ET AL 'Novel applications of photonic band gap materials: Low-loss bends and high Q cavities'	1-3, 5-14, 16-23, 25-28
A	see page 4753, right column, paragraph 4 - page 4755; figure 2A ---	4,15,24, 29
Y	WO,A,94 16345 (MASSACHUSETTS INST TECHNOLOGY) 21 July 1994	1-3, 5-14, 16-23, 25-28
A	see the whole document ---	29

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[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 February 1996	16. 02. 96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Claessen, L

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PHYSICAL REVIEW LETTERS, vol. 67, no. 24, 9 December 1991 NEW YORK US, pages 3380-3383, XP 000561904 E. YABLONOVITCH ET AL 'Donor and acceptor modes in Photonic band structure' see the whole document	1,12,29
A	PHYSICAL REVIEW A, vol. 48, no. 3, September 1993 NEW YORK US, page 2246 R.P STANLEY ET AL 'impurity modes in one-dimensional periodic systems: The transistion from photonic band gaps to microcavities' see the whole document	1,12,29
A	WO,A,92 15124 (MASSACHUSETTS INST TECHNOLOGY ;LOCKHEED SANDERS INC (US)) 3 September 1992 see abstract; figures 1-12	1,12,29
A	PATENT ABSTRACTS OF JAPAN vol. 012 no. 072 (E-588) ,5 March 1988 & JP,A,62 213288 (OKI ELECTRIC IND CO LTD) 19 September 1987, see abstract	1,4,15, 24,29
A	APPLIED PHYSICS LETTERS, vol. 56, no. 11, 12 March 1990 pages 990-992, XP 000133445 SETO M ET AL 'GAAS/ALGAAS SINGLE-MODE OPTICAL WAVEGUIDES WITH LOW PROPAGATION LOSS AND STRONG OPTICAL CONFINEMENT' see the whole document	1-29
P,X	APPLIED PHYSICS LETTERS, vol. 67, no. 2, 10 July 1995 NEW YORK US, pages 167-169, XP 000518681 P.R. VILLENEUVE ET AL 'Air-bridge microcavities' see the whole document	1-29
P,X	JOURNAL OF THE OPTICAL SOCIETY OF AMERICA - B, vol. 12, no. 7, July 1995 NEW YORK US, pages 1267-1271, S. FAN ET AL 'Guided and defect modes in periodic dielectric waveguides' see the whole document	1,2,29

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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		EP-A-	0678196	25-10-95
WO-A-9215124	03-09-92	US-A-	5187461	16-02-93
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		US-A-	5471180	28-11-95
		US-A-	5389943	14-02-95