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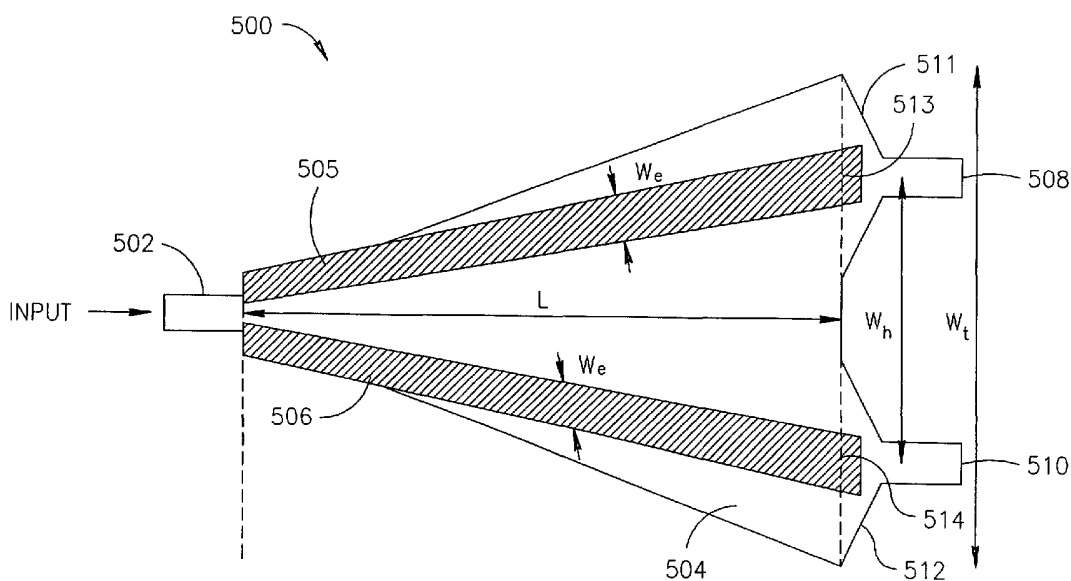
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(54) Title: DEVICE AND METHOD OF DYNAMIC OPTICAL SPOT CONVERSION



(57) Abstract: A dynamic adiabatic spot converter, including an adiabatic waveguide adapted to adiabatically direct at least a fraction of at least one mode of an input signal to propagate through at least one, respective, region of the waveguide and to exit from at least one, respective, output location of the waveguide.

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DEVICE AND METHOD OF DYNAMIC OPTICAL SPOT CONVERSION**FIELD OF THE INVENTION**

[001] The present invention relates generally to the field of optical devices and, more specifically, to localization of a signal of light.

5 BACKGROUND OF THE INVENTION

[002] In the field of integrated optics, there may be a need to use a spot-size converter for converting the shape, e.g. the size and physical location, of a light signal within a waveguide.

[003] U.S. Patent No. 5,623,566 to Hyung J. Lee et al describes a device using
10 a thin film heating element to create a thermally induced light-guide. When the heating element is inactive, a light signal may not propagate through the light-guide. When the heating element is activated, the heat induced in the light-guide changes its optical properties, i.e. its index of refraction, such that the light signal may propagate through the heat-induced waveguide. A device including N
15 heating elements associated with N light-guides connected to N outputs may allow directing a light signal to a desired output by activating the heating element corresponding to the desired output. A drawback of this device is the high heating element temperature required in order to achieve even a low power extinction ratio between the signals at the output ports.

SUMMARY OF EMBODIMENTS OF THE INVENTION

[004] According to embodiments of the invention, there is provided a dynamic, adiabatic optical spot converter, which may include an adiabatically shaped, e.g., tapered, waveguide associated with at least one control element, e.g., a heating element in thermal communication with at least one, respective, region of the waveguide. The waveguide may have a cross-sectional structure including a core surrounded by a cladding, and an optional base substrate to support the waveguide and/or to assist in maintaining a desired waveguide temperature.

[005] According to embodiments of the invention, the spot converter may include at least two states of operation, e.g., at least one "On" state, and an "Off" state. When the spot converter is at the "Off" state, a light signal with a wavelength, λ , entering the input may propagate through the waveguide and exit the waveguide without undergoing any conversion. When the spot converter is at the "On" state, at least one of the control elements may be activated to localize at least a fraction of at least one mode of the light signal to at least one, respective, region of the waveguide, respectively, and the at least one localized signal may exit the waveguide from at least one, respective, output location at an output of the spot converter. The at least one control element may be positioned such that different localized signals may exit the spot converter from different output locations.

[006] According to embodiments of the invention, the at least one heating element may be selectively and/or controllably activated to localize a predetermined fraction of the signal to predetermined output locations. For

example, the more electrical power is supplied to the at least one heating element, the higher temperature increase is produced, and the more localized the converted signal may be, i.e., the signal may be directed to a narrower region of the waveguide and, thus, a narrower output location.

- 5 [007] According to embodiments of the invention, the waveguide may have a tapered structure including an output width, w_t , and a length, L , such that:

$$L > w_t^2 / \lambda$$

[008] According to further embodiments of the invention, the spot converter may be implemented as a switching device.

- 10 [009] According to some exemplary embodiments of the invention, there is provided a 1X2 switch. The switch may include two states of operation, e.g., "first output" and "second output". When the switch is at the "first output" state, a first control element may be activated to localize at least a fraction of a first mode of the input signal to a first region determined by the position of the first control element. The at least partially localized first mode of the input signal may exit the waveguide at a first output location determined by the position of the first control element.
- 15

- [0010] When the switch is set to the "second output" state, a second control element may be activated to localize at least a fraction of a second mode of the input signal to a second region determined by the position of the second control element. The at least partially localized second mode of the input signal may exit the waveguide at a second output location determined by the position of the second control element. According to exemplary embodiments of the invention,
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the first and second control elements may be controllably and/or selectively activated such that a desired fraction of either or both modes of the input signal may be localized to either or both the first and second output locations.

[0011] According to some embodiments of the invention, the 1X2 switch may be implemented as a variable optical attenuator (VOA) by using only one of the switch output locations and both of the control elements. According to these embodiments, in order to produce a desired attenuation of the signal at the output location being used, the control element corresponding to the unused output location may be activated to localize a predetermined fraction of the input signal to the unused output location.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanied drawings in which:

[0013] Fig. 1 is a schematic, front-view cross-sectional, illustration of a waveguide in accordance with exemplary embodiments of the invention;

[0014] Fig. 2 is a schematic illustration of a graph depicting effective refractive index versus horizontal location and heating element temperature, respectively, in the waveguide of Fig. 1;

[0015] Fig. 3 is a schematic illustration of a graph depicting lowest order signal power versus horizontal location and heating element temperature, respectively, in the waveguide of Fig. 1;

[0016] Fig. 4 is a schematic, top view, illustration of a spot converter in accordance with exemplary embodiments of the invention;

[0017] Fig. 5 is a schematic, top view, illustration of a 1X2 switch in accordance with exemplary implementations of the present invention; and

[0018] Fig. 6 is a schematic illustration of a graph depicting extinction ratio versus temperature increase for the device of Fig. 5.

[0019] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn accurately or to scale.

For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity or several physical components included in one element. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous
5 elements. It will be appreciated that these figures present examples of embodiments of the present invention and are not intended to limit the scope of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0020] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits may not have been described in detail so as not to obscure the present invention.

[0021] Reference is made to Fig. 1, which schematically illustrates a cross-section of a waveguide 100 in accordance with exemplary embodiments of the invention.

[0022] Waveguide 100 may include a core 102 surrounded by a cladding 104. Waveguide 100 may also include a base substrate 106 attached to a surface, e.g., a bottom surface, of cladding 104, and a control element, e.g., a heating element 108, in thermal communication with a surface, e.g., a top surface, of cladding 106.

[0023] According to some exemplary embodiments of the invention, core 102 may be formed of a silica-based material having a core refractive index, n_{core} , of about 1.455. Further, in exemplary embodiments of the invention, cladding 104 may be formed of a silica-based material having a cladding refractive index, $n_{cladding}$, of about 1.445. According to these exemplary embodiments, core 102 may have a core height, h , of between $2\mu\text{m}$ and $15\mu\text{m}$, for example, about $6\mu\text{m}$, and a width, w , of between $10\mu\text{m}$ and $200\mu\text{m}$, for example, $100\mu\text{m}$. Further, in accordance with these exemplary embodiments, heating element 108 may have

a width, w_e , of between $10\mu\text{m}$ and $50\mu\text{m}$, for example, between $11\mu\text{m}$ and $17\mu\text{m}$. Furthermore, according to exemplary embodiments of the invention, a distance, H , between core 102 and heating element 108 may be between $10\mu\text{m}$ and $30\mu\text{m}$, for example, $16\mu\text{m}$. Base substrate 106 may be formed of any suitable material known in the art, for example, silicon. Base substrate 106 may be maintained at a substantially constant temperature by use of a Thermo-Electric Cooler (TEC) or any other device adapted to keep the substrate at a substantially constant temperature, e.g., room temperature. Heating element 108 may be implemented in the form of an electrode, for example, a strip of material having a suitable electrical resistance capable of producing a predetermined increase in temperature in response to electrical power supplied thereto.

[0024] According to exemplary embodiments of the invention, waveguide 100 may have a cross-section aspect ratio such that the width, w , of the waveguide may be much larger than the height, h , of the waveguide. This cross-section may result in a waveguide that is sufficiently narrow in height to support only one mode order in the vertical, y , dimension and sufficiently wide to support several mode orders in a horizontal, x , dimension. These dimensions may be calculated using approximation methods, for example, the approximation described in paragraph 2.4 of chapter two of *K. Okamoto "Fundamentals of Optical Waveguides", San Diego, Academic Press (1992)*, which is incorporated herein by reference in its entirety. In this context, the aspect ratio of the spot converter, AR , may be defined by the following equation:

$$[0025] AR \equiv h/w \quad (1)$$

[0026] The approximation method, as described above, may be further used to compute an effective refractive index, $n_{\text{eff}}(x, \Delta T)$, as a function of horizontal location in the waveguide, x , and temperature increase, ΔT , between heating element 108 and ambient temperature.

5 [0027] According to embodiments of the invention, the effective refractive index approximation may depend on two assumptions. The first assumption is that a temperature-induced refractive index change, which may be defined by the difference between $n_{\text{eff}}(x, \Delta T)$ and n_{core} , is significantly smaller than the difference, Δn , between n_{core} and n_{cladding} , such that the light signal may be
10 confined in the y direction, as described above.

[0028] The second assumption is that the temperature-induced refractive index does not vary substantially along the waveguide height. For example, the thermo-optical coefficient, dn/dT , for glass is about $1.15 \cdot 10^{-5}$. Therefore, the difference between $n(\Delta T=100)$ and $n(\Delta T=0)$ is about $1.15 \cdot 10^{-3}$, which is
15 significantly smaller than Δn , which may be equal to about 0.01.

[0029] According to embodiments of the invention, a temperature distribution in waveguide 100 resulting from activation of heating element 108 may be calculated as a stationary solution of a two-dimensional heat equation with a boundary condition, e.g., requiring a zero temperature increase at the surface of
20 the base substrate. For example, the following equation may be used:

$$[0030] \partial_x(\kappa \partial_x T) + \partial_y(\kappa \partial_y T) + p = 0 \quad (2)$$

[0031] Equation 2 may be applied to a waveguide having the dimensions H and w_e and a thermal conductivity of the core and the cladding in accordance with

embodiments of the invention, for example, a thermal conductivity of approximately $\kappa_{\text{glass}}=1.4\text{W}/(\text{mK})$ for silica. Parameter p in Equation 2 is the electric power density that may be supplied to the at least one heating element of the device.

5 [0032] The temperature distribution in waveguide 100 may be used to calculate the refractive index, $n_{\text{eff}}(x, \Delta T)$, as a function of x and ΔT , for example, using the thermo-optical coefficient dn/dT described above, i.e. multiplying dn/dT with each one of the ΔT values, respectively, to obtain a variation of n_{eff} created by each one of the ΔT values, respectively.

10 [0033] Fig. 2 is a schematic illustration of a graph depicting $n_{\text{eff}}(x, \Delta T)$ versus x and ΔT for the waveguide of Fig. 1. In Fig. 2, an isothermal line 202 depicts $n_{\text{eff}}(x, \Delta T=0)$, an isothermal line 204 depicts $n_{\text{eff}}(x, \Delta T=100^\circ\text{C})$, and an isothermal line 206 depicts $n_{\text{eff}}(x, \Delta T=200^\circ\text{C})$.

[0034] According to exemplary embodiments of the invention, electric power of
15 about 0 Watts (W), 2.6W, and 5.1W, respectively, may be supplied to the heating element, in order to produce isothermal lines 202, 204 and 206 of Fig. 2, respectively.

[0035] According to embodiments of the invention, a maximum effective refractive index, $N(\Delta T)$, may be defined for each temperature increase value,
20 ΔT , as follows:

$$[0036] N(\Delta T) \equiv \text{Max}(n_{\text{eff}}(x, \Delta T)) \quad (3)$$

[0037] As shown in Fig. 2, $n_{\text{eff}}(x, \Delta T)$ reaches a maximum substantially underneath the center of heating element 108, i.e., where x is equal to zero.

Therefore, in this embodiment of the invention, $N(\Delta T)$ may alternatively be defined by:

$$[0038] N(\Delta T) \equiv n_{\text{eff}}(x=0, \Delta T) \quad (4)$$

[0039] In order to allow a given mode to propagate through a given material, the material should have a modal effective refractive index, n_{efm} , as follows:

$$[0040] N(\Delta T = 0) - n_{\text{efm}} = \frac{\pi^2}{2w^2 k^2 n_{\text{efm}}} \quad (5)$$

[0041] for the limit of:

$$[0042] N(\Delta T=0) - n_{\text{efm}} \ll \Delta n \quad (6)$$

[0043] wherein a free space wave vector, k , may be defined by:

$$10 \quad [0044] k = 2\pi/\lambda \quad (7)$$

[0045] As shown in Fig. 2, n_{efm} may be significantly closer to $N(\Delta T=0)$ as the waveguide becomes wider.

[0046] Different modal effective refractive indices may be required to allow propagation of different modes. As demonstrated by Equation 7, the modal effective refractive index may also depend on attributes of the waveguide, e.g., waveguide geometry and/or refractive indices, as well as on signal attributes, e.g., wavelength.

[0047] According to embodiments of the invention, in order to “trap” and localize a mode, e.g., to allow propagation of the localized mode substantially under heating element 108, the value of ΔT may be calculated from the following equation:

[0048] $N(\Delta T) - N(\Delta T=0) \gg N(\Delta T=0) - n_{\text{efm}}$ (8)

[0049] for the limit of:

[0050] $N(\Delta T) - N(\Delta T=0) \ll \Delta n$ (9)

[0051] Equation 8 may be rewritten as follows:

5 [0052] $\delta n(\Delta T) \gg N(\Delta T=0) - n_{\text{efm}}$ (10)

[0053] wherein $\delta n(\Delta T)$ is a temperature-induced change, which may be defined by:

[0054] $\delta n(\Delta T) \equiv N(\Delta T) - N(\Delta T=0)$ (11)

10 [0055] Substituting Equation 10 in Equation 5 results in the following new equation:

[0056] $\delta n(\Delta T) \gg \frac{\pi^2}{2w^2k^2n_{\text{efm}}}$ (12)

[0057] Substituting Equation 7 in Equation 12 and re-arranging equation 12 yields the following equation:

[0058] $\frac{\lambda^2}{8w^2n_{\text{efm}}\delta n(\Delta T)} \ll 1$ (13)

15 [0059] According to exemplary embodiments of the invention, Equation 13 may be used to calculate a minimum required temperature-induced change. Based on the calculated minimum temperature-induced change, the relationship illustrated by the graph of Fig. 2 may be used to find a corresponding minimal ΔT allowing to localize a mode, e.g., a lowest order mode, i.e., the eigenmode of
20 the waveguide, to a region of the waveguide, as described herein. A

combination of ΔT and w satisfying Equation 13 may be chosen to allow localization of the eigenmode to a predetermined region of the waveguide. If, for example, a given combination of ΔT and w does not satisfy Equation 13, then the eigenmode may not be localized.

5 [0060] According to exemplary embodiments of the invention, applying the values $\Delta T=100$, $w=100\mu\text{m}$, $\lambda=1.55\mu\text{m}$ and $n_{\text{eff}}\sim 1.45$, may yield a value of approximately 0.05 on the left-hand side of Equation 13, thus satisfying Equation 13. It should be appreciated that, since the left-hand side of Equation 13 increases quadratically with core width, w , Equation 13 may not be satisfied for
10 a realistic value of ΔT if the waveguide is not sufficiently wide, for example, for a waveguide width of $w=25\mu\text{m}$. In such case, the eigenmode of the waveguide may not be localized to a region of the waveguide at a realistic temperature increase ΔT of the heating element.

[0061] According to embodiments of the invention, $n_{\text{eff}}(x, \Delta T)$ may be used to
15 numerically compute the signal power of the lowest-order mode along the x -axis of the waveguide, for example, by substituting $n_{\text{eff}}(x, \Delta T)$ and solving for E in the following modal equation:

$$[0062] \partial_x^2 E + \frac{(2\pi)^2}{\lambda^2} (n_{\text{eff}}(x, \Delta T)^2 - n_{\text{eff}}^2) E = 0 \quad (14)$$

wherein E is an amplitude of a modal signal field, and wherein the power of the
20 signal may be proportional to E^2 .

[0063] Fig. 3 is a schematic illustration of a graph depicting eigenmode signal power versus horizontal location and heating element temperature, respectively, in the waveguide of Fig. 1.

[0064] As shown in Fig. 3, a temperature increase $\Delta T=100$ may yield a confined eigenmode 302 which may be significantly narrower and may have a higher signal power compared with a basic eigenmode 304 provided by, e.g., $\Delta T=0$. As also shown in Fig. 3, a higher temperature increase, for example, $\Delta T=200$, may
5 yield another eigenmode 306 substantially similar to confined eigenmode 302.

[0065] According to embodiments of the invention, a predetermined temperature increase, which may be produced as described above, may be used to localize a mode of a signal to a region of the waveguide substantially underneath heating element 108 (Fig. 1).

10 [0066] According to embodiments of the invention, heating element 108 (Fig. 1) may be controllably activated to localize the signal. The more electrical power is supplied to the heating element, the higher temperature increase is produced, and the more localized the signal may be, i.e., the signal may be localized to a narrower region of the waveguide.

15 [0067] Fig. 4 schematically illustrates a top view of a dynamic, adiabatic spot converter 400 in accordance with exemplary embodiments of the invention.

[0068] According to exemplary embodiments of the invention, spot converter 400 may include an adiabatic waveguide 410, having an input 402 and an output 404, and at least one control element, e.g., heating element 408, in thermal
20 communication with a top surface of waveguide 410. The parameters for designing the tapered structure of waveguide 410 may be selected as described in detail herein.

[0069] In exemplary embodiments of the invention, adiabatic waveguide 410 may have a cross-sectional structure similar to the one illustrated in Fig. 1 and as described above.

[0070] According to embodiments of the invention, spot converter 400 may have at least two states of operation, e.g., at least one "On" state, and an "Off" state. When the spot converter is at the "Off" state, a light signal entering input 402 may propagate through adiabatic waveguide 410 and exit output 404 without undergoing any conversion. When the spot converter is at the "On" states, by controllably activating the at least one heating element 408, at least a fraction of a mode of the light signal may be localized to a region substantially underneath heating element 408. The localized light signal may propagate through output 404 at an output spot 406. Consequently, the at least partly localized mode of the light signal may exit spot converter 400 at an output location 412 of output 404.

[0071] According to some exemplary embodiments of the invention, spot converter 400 may include several heating elements 408, which may be used to localize at least a fraction of predetermined modes of the light signal to regions substantially underneath several respective heating elements, which localized signal fractions may exit spot converter 400 at several desired output locations of output 404, as described above.

[0072] According to embodiments of the invention, waveguide 410 may be adapted to adiabatically localize at least the fraction of the signal, as described below. In this context, adiabatic localizing means a substantially small part of the signal power is lost during the localization by virtue of a gradual, controlled,

conversion process. The adiabatic localization in accordance with embodiments of the invention is achieved, inter alia, by the specific tapered structure of the waveguide as described herein.

[0073] According to exemplary embodiments of the invention, a minimum waveguide tapering length, L , may be required in order to significantly reduce the transfer of signal power between the localized mode and other modes of the waveguide, i.e., to avoid cross talk between different channels. According to embodiments of the invention, a minimal length L may be required to allow a gradual increase in the waveguide width such that the signal power loss would be minimal.

[0074] According to an exemplary embodiment of the invention, the required tapered section length may be computed for a taper end-width, w_t , by the following equation:

$$[0075] L > w_t^2 / \lambda \quad (15)$$

[0076] In exemplary embodiments of the invention, Equation 15 may be valid for the same limit as that of Equation 6 above.

[0077] According to exemplary embodiments of the invention, waveguide 410 may have a width, w_t , of between $60\mu\text{m}$ and $150\mu\text{m}$, for example, $100\mu\text{m}$, for a wavelength, λ , of about $1.55\mu\text{m}$. According to these embodiments, in order to satisfy equation 15, waveguide 410 may have a length of at least $6452\mu\text{m}$, for example, 10mm .

[0078] Fig. 5 schematically illustrates a top view of a 1X2 switch 500 in accordance with exemplary implementations of the present invention.

[0079] According to exemplary embodiments of the invention, switch 500 may include an adiabatic waveguide 504 having an input 502, a first output port 508, and a second output port 510. Switch 500 may further include a first control element, e.g., a heating element 505, and a second control element, e.g., a heating element 506. Switch 500 may also include a first output taper 511 and a second output taper 512 connecting portions of waveguide 504 to output ports 508 and 510, respectively. According to exemplary embodiments of the invention, waveguide 504 may be adapted to adiabatically localize at least a fraction of at least one mode of an input signal to at least one region of the waveguide, respectively, as described above.

[0080] According to exemplary embodiments of the invention, switch 500 may have two states of operation, e.g., a "first output" state and "second output" state. When the switch is at the "first output" state, first heating element 505 may be activated to localize at least a fraction of a first mode of the input signal to a first region substantially underneath heating element 505, in analogy to device 400 described above with reference to Fig. 4. This first localized signal may propagate through a first output spot 513 of waveguide 504, substantially underneath first heating element 505, and may be coupled by first output taper 511 to output port 508.

[0081] When the switch is set to the "second output" state, second heating element 506 may be activated to localize at least a fraction of a second mode of the input signal to a second region substantially underneath heating element 506, in analogy to device 400 described above with reference to Fig. 4. This second localized signal may propagate through a second output spot 514 of the

waveguide, substantially underneath the second heating element, and may be coupled by second output taper 512 to output port 510.

[0082] According to embodiments of the invention, the first and second heating elements may be controllably activated such that a desired fraction of a desired mode of the input signal may be localized to either output ports 508 or 510, as described above. If neither of the heating elements is activated, all modes of the input signal may exit both output ports.

[0083] According to exemplary embodiments of the invention, waveguide 504 may have a tapered structure with a length, L , of between 5mm and 15mm, for example 10mm, a distance, W_h , between centers of outputs 508 and 510 of between 55 μ m and 65 μ m, for example 60 μ m, an output taper length of between 0.5mm and 2mm, for example, 1 mm, a heating element width, w_e , of between 10 μ m and 20 μ m, for example, 10 μ m, and taper width, w_t , of between 50 μ m and 150 μ m, for example, 100 μ m.

[0084] According to some embodiments of the invention, switch 500 may be implemented as a variable optical attenuator (VOA) by using only one of the switch outputs, for example, output port 508, and both of heating elements 505 and 506. According to these embodiments, in order to produce a desired attenuation of the signal at the output port being used, e.g., output port 508, control element 506 may be activated to localize a predetermined fraction of the input signal to the unused output port 510, which may be disconnected. It will be appreciated by persons skilled in the art that the localization of a controllable fraction of the input signal to output port 510 produces a controllable attenuation of the light signal which may exit output port 508, thereby providing variable

optical attenuation at output port 508. Reference is now made also to Fig. 6, which schematically illustrates a graph depicting extinction ratio versus ΔT for the device of Fig. 5.

[0085] The extinction ratio may be defined as the ratio between signal power in first output port 508 and signal power in second output 510 when switch 500 is set to the "first output" state, as described above. For example, an extinction ratio of about 35dB may be achieved by activating first heating element 505 to produce a ΔT of about 100 degrees, as shown in Fig. 6. It will be appreciated by persons skilled in the art that this extinction ratio is significantly higher than the extinction ratio that may be achieved by prior art switches and spot converters under comparable operational conditions.

[0086] While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made. Embodiments of the present invention may include other apparatuses for performing the operations herein. Such apparatuses may integrate the elements discussed, or may comprise alternative components to carry out the same purpose. It will be appreciated by persons skilled in the art that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

CLAIMS

1. A dynamic adiabatic spot converter, comprising an adiabatic waveguide adapted to adiabatically direct at least a fraction of at least one mode of an input signal to propagate through at least one, respective, region of said waveguide and to exit from at least one, respective, output location of said waveguide.
5
2. The spot converter of claim 1 comprising at least one control element associated with said at least one region, respectively, wherein said at least one control element, when activated, causes said waveguide to localize at least said fraction of said mode to said at least one region, respectively.
10
3. The spot converter of claim 2 wherein said at least control element comprises at least one heating element that, when activated, produces an increase in temperature in at least a portion of said at least one region, respectively.
15
4. The spot converter of claim 3 wherein said at least one heating element comprises at least one electrode adapted to produce a predetermined increase in temperature in said at least one region, respectively, in response to electrical power supplied thereto.
- 20 5. The spot converter of any of claims 2-4 wherein said control element is controllably activated to cause localization of a desired fraction of said mode of said signal.

6. The spot converter of any of claims 2-5 wherein said at least one region comprises at least one elongated region in proximity with said at least one control element, respectively.
7. The spot converter of any of the above claims wherein said waveguide is
5 adiabatically tapered.
8. The spot converter of any of the above claims wherein said waveguide comprises a length, L , and an output width, w_t , such that $L > w_t^2/\lambda$.
9. The spot converter of any of the above claims, further comprising at least one output taper associated with said at least one output location of said
10 waveguide, respectively.
10. The spot converter according to any of claims 2-9 wherein said at least one control element comprises at least first and second control elements, wherein said at least one region comprises at least first and second regions, respectively, and wherein said at least one output location
15 comprises at least first and second, respective, output locations.
11. A variable optical attenuator comprising a spot converter as in claim 10, wherein the light output at said second output location is controllably attenuated by controllably directing a desired fraction of said input light signal to propagate through said second region.
- 20 12. A method of adiabatically localizing a signal, comprising adiabatically directing at least a fraction of a mode of an input signal to propagate through a respective region of an adiabatic waveguide and to exit from a respective output location of said waveguide.

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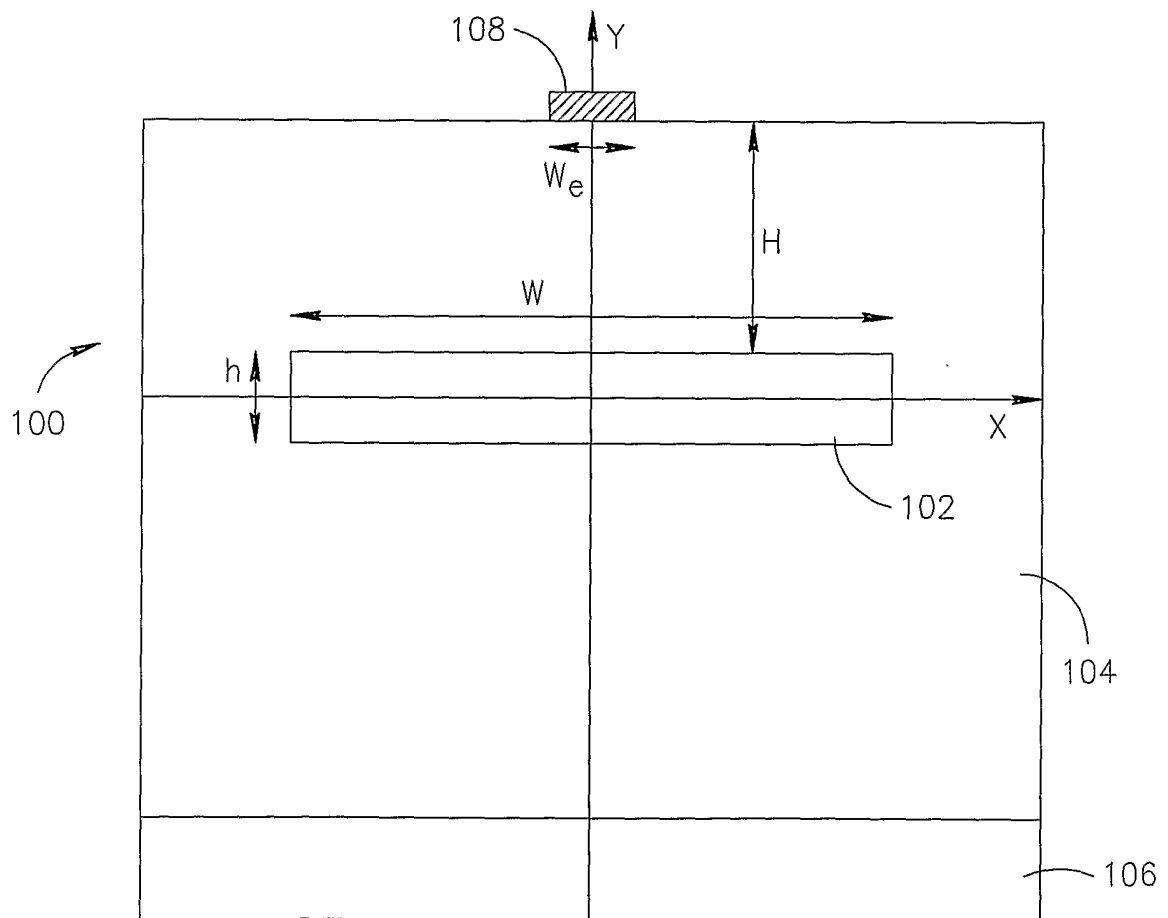


FIG.1

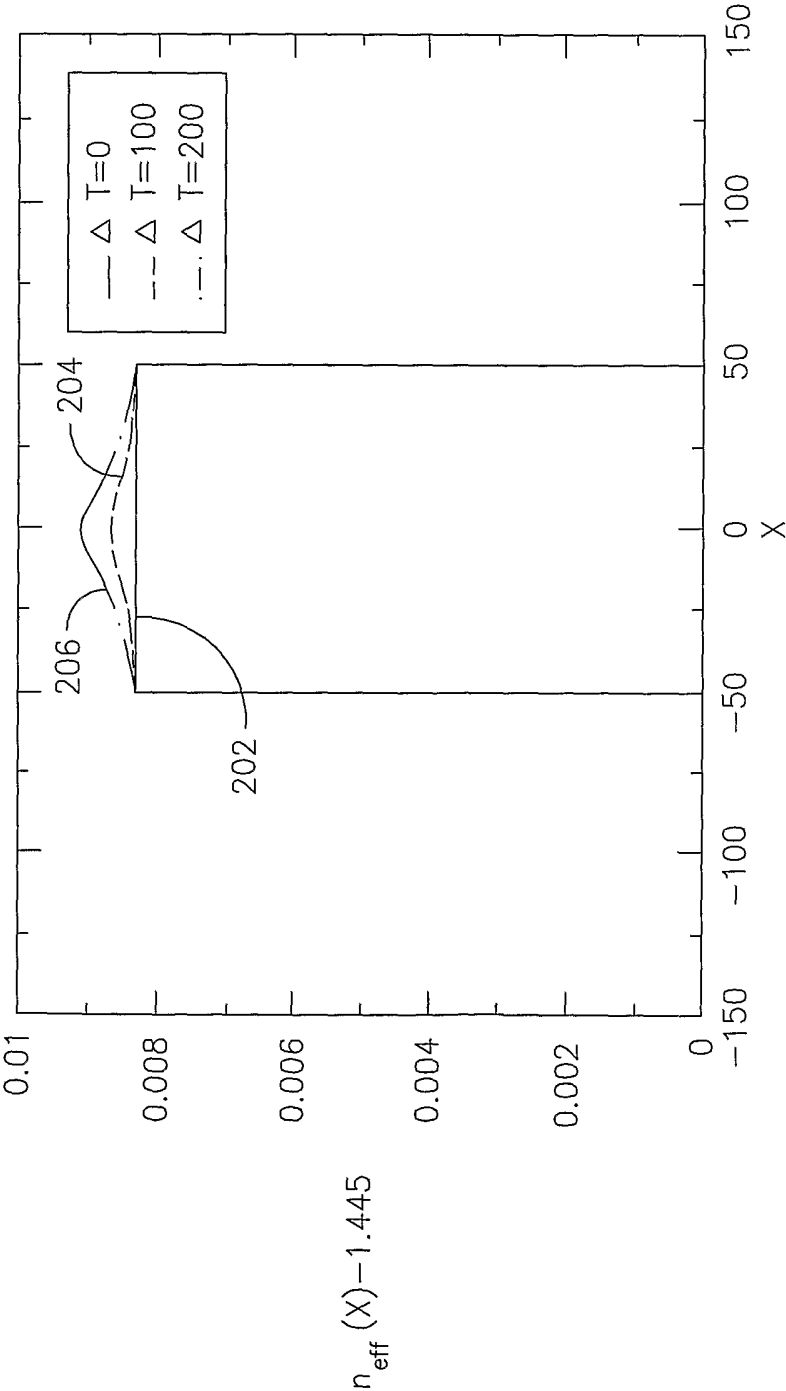


FIG.2

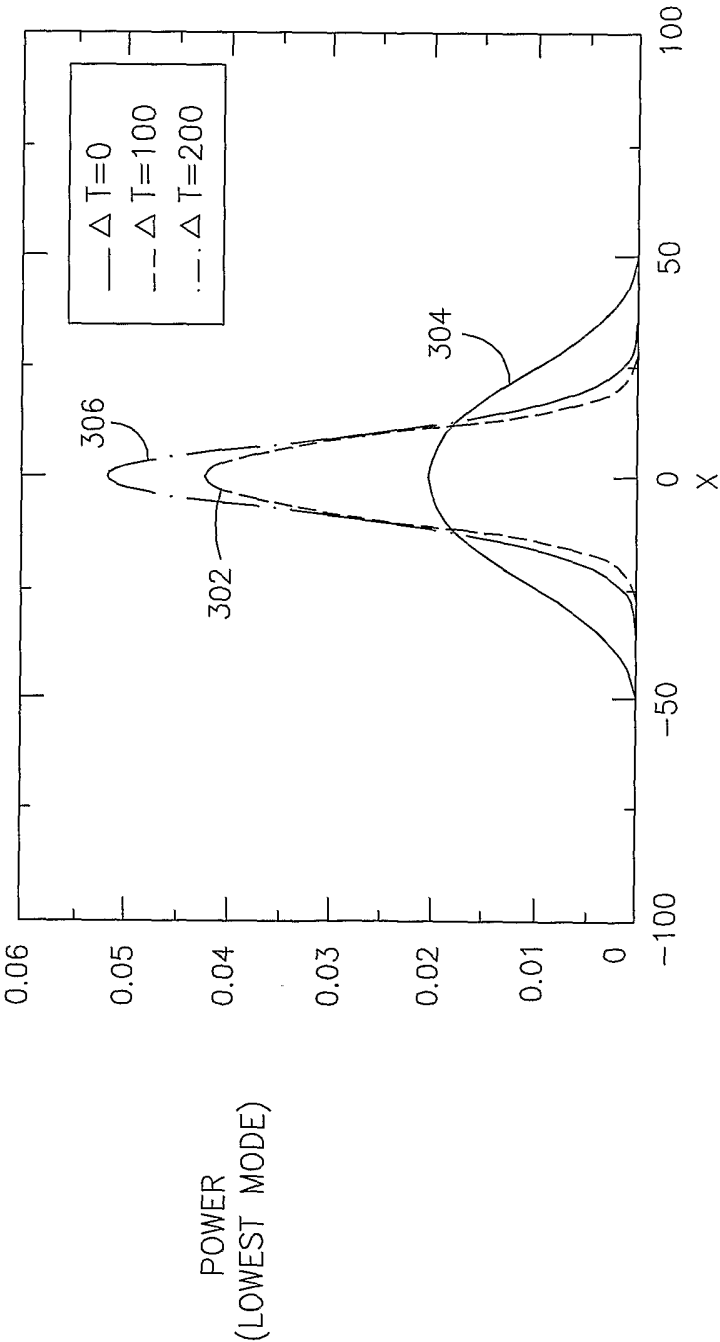


FIG.3

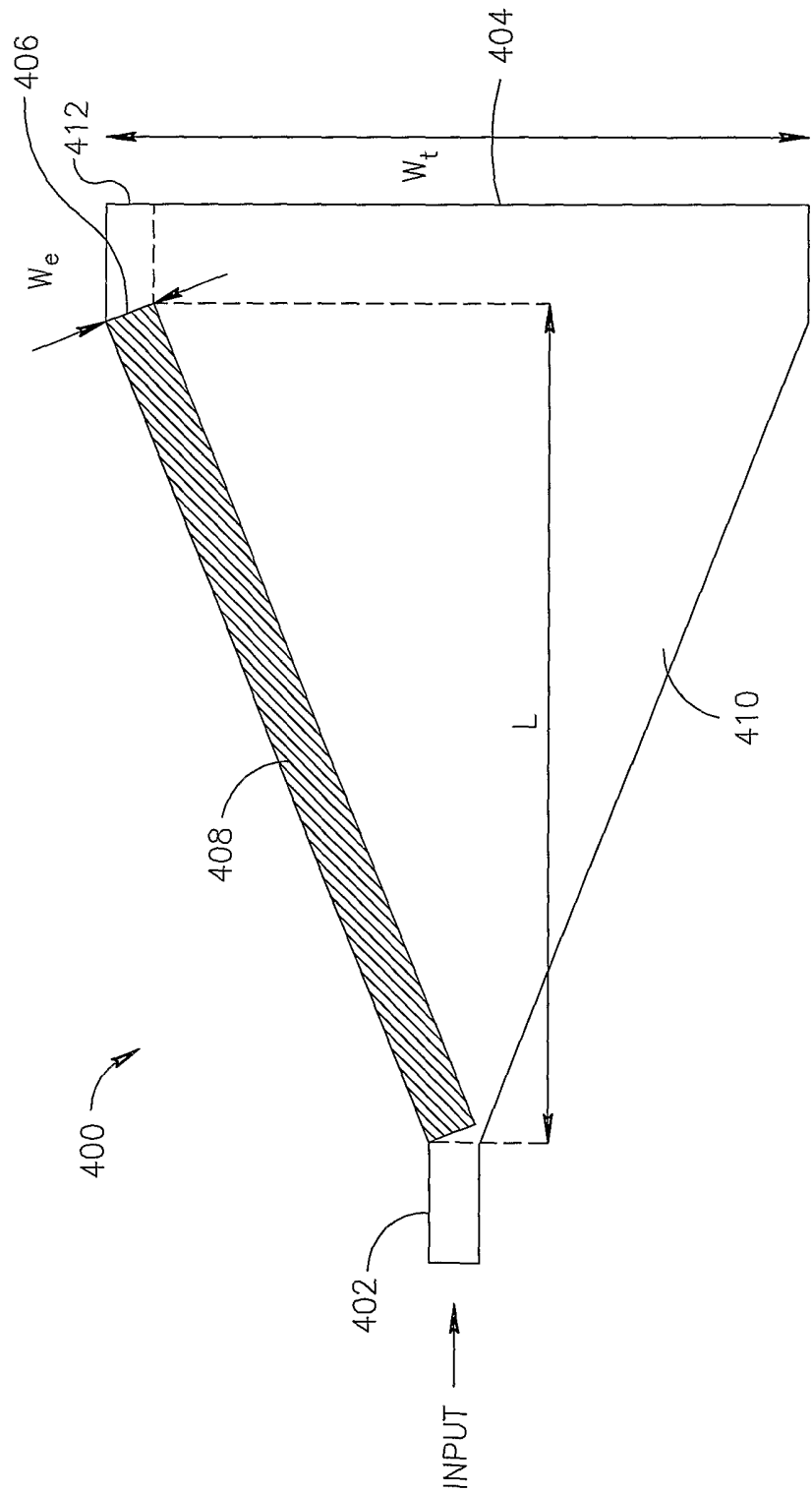


FIG.4

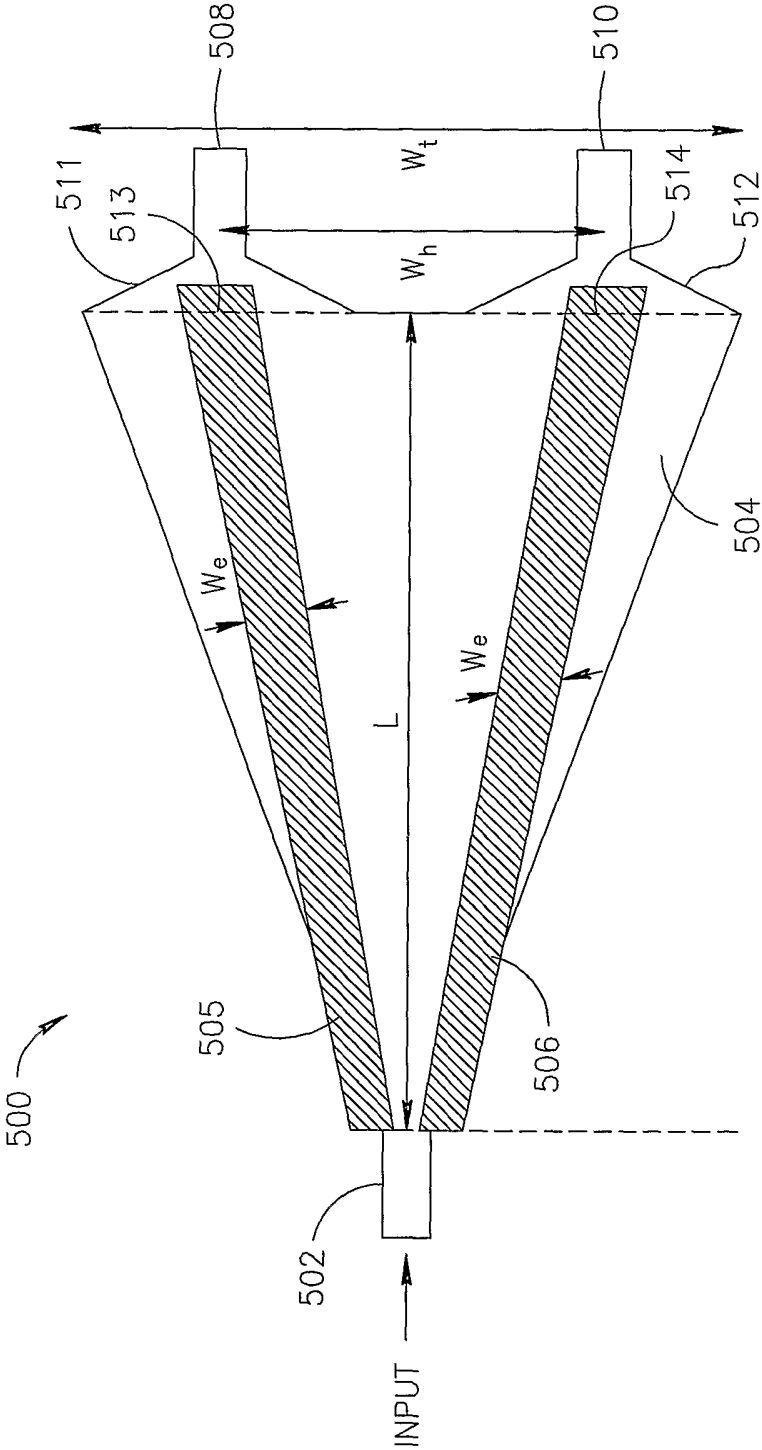


FIG. 5

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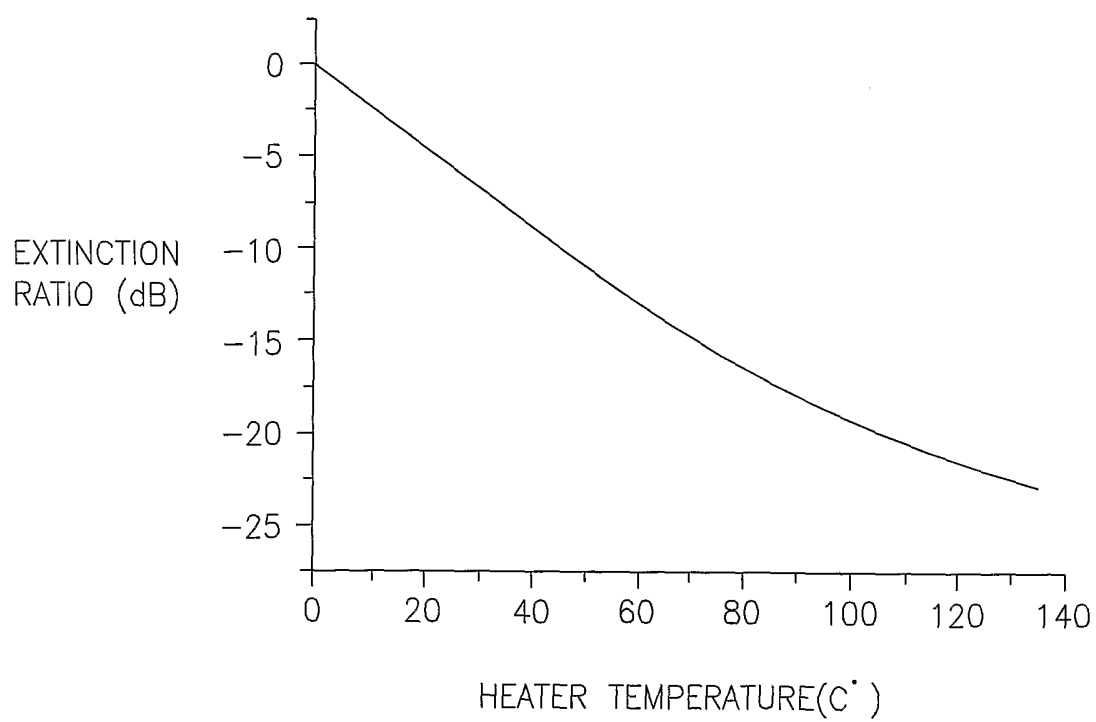


FIG.6

INTERNATIONAL SEARCH REPORT

PCT/IL 03/00446

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02F1/313 G02F1/01

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 7 G02F

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, PAJ, WPI Data, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 623 566 A (LEE HYUNG J ET AL) 22 April 1997 (1997-04-22) column 2, line 25 -column 2, line 55; figures 5A,5B,5C column 3, line 12 -column 8, line 49; claims	1-12
Y	US 6 222 953 B1 (PROPSTRA KORNELIS ET AL) 24 April 2001 (2001-04-24) column 1, line 50 -column 1, line 54; figures 1,3-5 column 3, line 12 -column 7, line 8; claims	1-12

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

16 September 2003

Date of mailing of the international search report

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SEKERKA-BAJBUS M A ET AL: "Design optimization and implementation of an optical Ti:LiNbO3 3-branch switch by the beam propagation method" INTEGRATED OPTICS & OPTOELECTRONICS PROCEEDINGS, 5-8 SEPT. 1989, BOSTON, BELLINGHAM, WA, US, vol. 1177, 5 September 1989 (1989-09-05), pages 216-227, XP000391618 figures 1,3 ---	1-12
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A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 12, 3 January 2001 (2001-01-03) & JP 2000 241838 A (NIPPON TELEGR & TELEPH CORP), 8 September 2000 (2000-09-08) abstract ---	1-12
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