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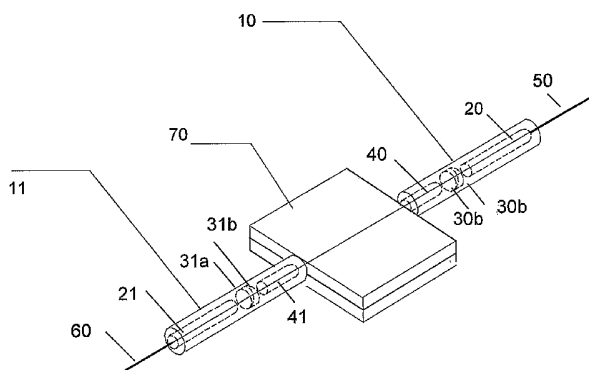
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[Continued on next page]

(54) Title: POLARIZATION DEVICE



(57) Abstract: A polarization device for implementing polarization diversity schemes in planar waveguide optical circuits is provided. A Polarization Beam Splitter (PBS) assembly comprises two birefringent wedges and a focusing lens. Advantageously, the birefringent wedges form a modified Wollaston prism. The PBS assembly divides a collimated input beam from the fiber collimator into vertically polarized and horizontally polarized collimated beams directed at slightly different angles. The focusing lens focuses the vertically polarized and horizontally polarized beams into two distinct spots located in substantially the same focal plane. The two focused spots are then coupled directly into the ends of two optical waveguides to propagate the two polarization states within a planar waveguide circuit. In a further embodiment of the invention, a Polarizing Beam Combiner device comprising a collimating lens and two birefringent wedges is provided. Advantageously, the birefringent wedges form a modified Wollaston prism. The collimating lens collimates light from a first source point having a first polarization and a second source point having a second polarization, the source points lying within the focal plane of the collimating lens. The source points are provided at the output face of a planar polarization diversity lightwave circuit where the output face coincides with the focal plane of the collimation lens. The birefringent wedges then combine the two orthogonally polarized collimated beams into an output collimated beam. In a yet further embodiment of the invention the PBS and PBC assemblies described above are combined in two channel polarization diversity waveguide device.

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- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE,

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- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations
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POLARIZATION DEVICE

This application claims the benefit of U.S. Provisional Patent Application No. 60/471,079 filed May 16, 2003.

5

BACKGROUND OF THE INVENTION

This invention relates to fiber optical communications components and more particularly to a polarization device for minimizing polarization dependent losses.

10 The performance of components for use in fiber optic communications systems must be essentially independent of the polarization state of the incident light in order to avoid variation in device insertion loss or attenuation. This condition is particularly difficult to achieve in any component incorporating an inherently birefringent material, such as a holographic polymer dispersed liquid crystal material or a nematic liquid crystal material.

15

One solution to achieving low PDL in liquid-crystal-based devices is to separate two orthogonal polarization states using a micro-optic Polarizing Beam Splitter (PBS), pass the resulting two beams of light through the liquid crystal device independently, and then recombine the two beams using a micro-optic Polarizing Beam Combiner (PBC). This approach is commonly
20 termed "polarization diversity". Several different technologies have been used to provide PBS or PBC devices. Birefringent polarizing "walk-off" crystals, such as those manufactured by Koncent Communication Inc. (China) or JDSU Casix Inc. (China), are the most commonly used devices.

25 One solution to providing polarization diversity for devices based on planar optical waveguides is to use a micro-optic polarization beam splitter to separate unpolarized light into two

orthogonally polarized components, and then couple these components from the beam splitter to the waveguide device by means of polarization maintaining fiber. Micro-optical polarization beam splitter/combiner components are available from a number of sources, including Wavesplitter Technologies Inc. (San Jose, CA) and Oplink Communications Inc. (San Jose, CA). However, this approach to polarization diversity suffers from poor performance due to the high polarization crosstalk of the available micro-optic polarization splitter components. This high polarization crosstalk is due to the difficulty of aligning the polarization maintaining fiber. Not only must the fiber be spatially aligned to accept the focused beam from the polarization splitter, but also the fiber must be rotationally aligned to match the polarization direction of the incident light. In addition, the polarization maintaining fiber will allow some light to convert from one polarization mode to the orthogonal mode, particularly if the fiber is bent or otherwise stressed.

Another approach to polarization diversity for a planar lightwave device would be to employ a planar waveguide polarization splitter, such as the one described by R.M. de Ridder et al in "An integrated optical adiabatic TE/TM mode splitter on silicon", IEEE Journal of Selected Topics in Quantum Electronics, Vol 4, No. 6, Nov/Dec 1998 pages 930-97. However, the planar waveguide polarization splitters reported in the literature generally require extremely tight manufacturing tolerances and are not suitable for volume production.

Thus there exists a need for an improved method of providing polarization diversity for optical devices based on planar optical waveguides.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a polarization device that minimizes the problems of size, cost and alignment arising from the implementation of polarization diversity schemes in planar waveguide optical circuits.

The objects of the invention are achieved in a first embodiment comprising a PBS assembly, a lens, and a planar waveguide optical circuit. The function of the PBS assembly is to divide a collimated beam, typically from a fiber collimator, into two orthogonally polarized collimated beams directed at slightly different angles. Advantageously, the PBS assembly is comprised of two birefringent wedges disposed in the form of a Wollaston prism. The lens focuses the two orthogonally polarized beams into two distinct spots located in substantially the same focal plane. The two focused spots are then coupled directly into the ends of two optical waveguides used to propagate the two polarization states within the planar waveguide circuit.

In a further embodiment of the invention the same basic components are configured in reverse to provide a PBC device. Advantageously, the birefringent wedges again form a modified Wollaston prism. A collimating lens collimates light from a first source point having a first polarization and a second source point having a second polarization, the source points lying within the focal plane of the collimating lens. The source points are provided at the output face of a planar lightwave circuit. The output face coincides with the focal plane of the collimation lens. The birefringent wedges then combine the two orthogonally polarized collimated beams into an output-collimated beam.

In a yet further embodiment of the invention the PBS and PBC assemblies described above are combined in a two-channel polarization diversity waveguide device.

A more complete understanding of the invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings, wherein like index numerals indicate like parts. For purposes of clarity, details relating to technical material that is known in the technical fields related to the invention have not been described in detail.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic perspective view of a Polarizing Beam Splitter (PBS) assembly.

FIG. 2 is a schematic perspective view of a waveguide polarization diversity device.

FIG. 3 is a table giving the specifications of a representative PBS assembly.

DETAILED DESCRIPTION OF THE INVENTION

The invention will now be further described by way of example only with reference to FIGS. 1-2.

A perspective view of a first embodiment of the invention is shown in FIG. 1 in which a Polarizing Beam Splitter assembly contained in a housing 1 is comprised of a fiber collimator 2, a PBC assembly comprised of two birefringent wedges 3a and 3b and a lens 4. An input beam is provided by an optical fiber 5. The housing 1 is shown as rectangular, but more commonly would be cylindrical.

Advantageously, the two birefringent wedges are cemented along their hypotenuse faces to form a Wollaston prism. The function of the Wollaston prism can be illustrated by example. Assume that the extraordinary (i.e. high refractive index) axis of wedge 3a is orientated in the vertical direction, and the extraordinary axis of wedge 3b is oriented in the horizontal direction. Thus vertically polarized light passing from wedge 3a into wedge 3b experiences a reduction in refractive index, while horizontally polarized light passing from wedge 3a into wedge 3b experiences an increase in refractive index. Thus the two orthogonally polarized components

will refract in opposite directions at the slanted interface. In this manner the pair of birefringent wedges function to divide the input beam from the fiber collimator into vertically polarized and horizontally polarized collimated beams directed at slightly different angles.

5 The lens 4 focuses the vertically polarized and horizontally polarized beams into two distinct spots 6a and 6b, said spots being located in substantially the same focal plane and separated by a precise distance. A conventional polarizing beam splitter/combiner can be formed by positioning the ends of two precisely aligned polarization maintaining fibers such that the cores of the fibers receive the two focused spots of light 6a and 6b. All of the components shown in
10 FIG.1 are commercially available from sources such as Koncent Communication Inc. (China) and JDSU Casix Inc. (China).

FIG.2 shows an optical schematic of an embodiment of the invention in which the two focused spots from the polarization beam splitter are directly coupled into a planar lightwave circuit. In
15 addition, the basic components previously shown in FIG.1 are operated in reverse to provide a Polarization Beam Combiner (PBC).

The optical path from input to output is comprised of the following elements:

- a) An input fiber 50;
- 20 b) An input Polarizing Beam Splitter (PBS) assembly 10 that divides the input from a single mode fiber into two focused beams of orthogonal polarization;
- c) A planar lightwave circuit 70 including a first optical path for the vertically polarized beam generated by the PBS a second optical path for the horizontally polarized;
- d) An output Polarizing Beam Combiner (PBC) assembly 11 that accepts the outputs from
25 the waveguide device and combines the orthogonally polarized beams into a single mode fiber;

- e) An output fiber 60.

The input PBS assembly 10 is comprised of a fiber collimator 20, a first Wollaston prism assembly, comprising two birefringent wedges 30a and 30b, and a lens 40 that focuses the
5 vertically-polarized and horizontally-polarized beams into two distinct spots located in essentially the same focal plane and separated by a precise distance. As in the embodiment of FIG.1 the Wollaston prism assembly divides the beam from the fiber collimator into vertically polarized and horizontally polarized collimated beams directed at slightly different angles. The components of the input PBS assembly would normally be pre-assembled and aligned in a housing.

10

The output PBS assembly 11 is comprised of a fiber collimator 21, a first Wollaston prism, comprising two birefringent wedges 31a and 31b and a lens 41. The construction of the output PBS assembly and in particular the fiber collimator focusing lens and prism pair is similar to that of the input PBS assembly. However, the components now operate in reverse fashion such that
15 the two beams emerging from the planar lightwave circuit are collimated by the lens 41, combined by the Wollaston prism assembly 31a, 31b and then focused to a focal point by the collimator lens 21.

The disposition of the optical waveguides on the planar lightwave circuit must be such that the
20 spacing between the ends of the waveguides is essentially the same as the spacing between the two focused spots formed by the polarizing beam splitter. In addition, the diameter of the focused spots must be essential the same as the mode field diameter of the optical waveguides. Note that focal lengths of the collimator 20 and focusing lens 40 within the polarizing beam splitter assembly 10 do not have to be the same. Thus the mode field diameter of the input
25 optical fiber can be converted to the mode field diameter of the planar optical waveguide by choosing the proper ratio for the focal lengths of the collimator and focusing lens.

In a typical application all of the optical components would be mounted in a hermetically sealed package, with the input and output fibers and the electrical connections to the waveguide device and connections for a thermoelectric cooler and temperature sensor penetrating the package.

5

Compared to the present art of employing a micro-optic polarization beam splitter coupled to a planar lightwave circuit by means of polarization maintaining fibers, the invention offers numerous advantages. Since the invention requires fewer components and precision alignment steps, the cost will be lower. Second, the insertion loss of the invention will be lower due to fewer interfaces (each of which introduces some loss from reflections and alignment errors). Third, since the invention does not employ polarization-maintaining fibers, the polarization purity of the light launched into the planar lightwave circuit will be much higher.

10

FIG.3 shows a table giving the specifications of one particular practical embodiment of the invention that was fabricated for experimental evaluation.

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Although the invention has been described in relation to what are presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not limited to the disclosed arrangements but rather is intended to cover various modifications and equivalent constructions include within the spirit and scope of the invention. In particular, the invention may be used with other types of birefringent prisms such as beam-splitting Glans Thompson prisms or beam displacing prisms. The invention may also be used with thin film polarizing beam splitter devices. In addition the invention may be used to provide the functions of PBC and PBS in more complex optical circuits. Although the invention has been discussed with regard to polarization diversity schemes for liquid crystal devices it could be used in polarization diversity schemes using other waveguide device technologies.

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The invention could be applied to Dynamic Gain Equalizers (DGEs) and other waveguide components based on Electrically Switchable Bragg Grating (ESBG) devices and Silicon Oxynitride (SiON) planar waveguide circuits. Specifically, the invention could be applied in the devices disclosed in US Provisional Patent Application 60/309,738 entitled "Electro-Optical Device with Parallel Sections for Orthogonal Polarization Modes" filed August 1, 2001 and US Patent Application No. 10/378,310 entitled "Planar Lightwave Filter Device" filed March 3, 2003.

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What is claimed is:

1. A optical assembly comprising:

polarization beam splitter means adapted to received a collimated optical input
5 beam and divide said input beam into first and second collimated beams, said first and
second collimated beams being directed at different angles and having orthogonal
polarization states;

a lens disposed to focus said first and second collimated beams into first and
second focused spots in the focal plane of said lens means; and

10 a planar lightwave circuit having a surface, a front face, and a first optical
waveguide and a second optical waveguide disposed on said surface and terminating at
said front face, wherein said lightwave circuit is disposed with said front face proximate
to the focal plane of said lens means such that light from said focused spots is coupled
into said first and second waveguides.

15 2. The optical assembly of claim 1, wherein the polarization beam splitter means is a pair of
birefringent wedges cemented together in the form of a Wollaston prism.

20 3. The optical assembly of claim 1, wherein the polarization beam splitter means is a
beam-splitting Glan Thompson prism.

4. The optical assembly of claim 1, wherein the polarization beam splitter means is a beam
displacing prism.

25 5. The optical assembly of claim 1, wherein the polarization beam splitter means is a thin
film device.

6. The optical assembly of claim 1, wherein the diameter of said focused spots is substantially the same as the mode field diameter of said optical waveguides.

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7. The optical assembly of claim 1, wherein the planar lightwave circuit is an Electrically Switchable Bragg Grating device.

8. The optical assembly of claim 1, wherein the planar lightwave circuit is a liquid crystal device.

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9. An optical assembly comprising:

a planar lightwave circuit having a surface, an exit face, and a first optical waveguide and a second optical waveguide disposed on said surface and terminating at said exit face, wherein the light propagating in said first and second optical waveguides exits said planar lightwave circuit at said exit face;

15

lens means disposed to accept light exiting said planar lightwave circuit and collimate said light into third and fourth collimated beams, said beams directed at different angles; and

20

polarization beam combiner means disposed to combine said third and fourth collimated beams into a single collimated output beam.

25

10. The optical assembly of claim 9, wherein the polarization beam combiner means is a pair of birefringent wedges cemented together in the form of a Wollaston prism.

11. The optical assembly of claim 9, wherein the polarization beam splitter means is a beam-splitting Glan Thompson prism.

12. The optical assembly of claim 9, wherein the polarization beam splitter means is a beam displacing prism.

13. The optical assembly of claim 9, wherein the polarization beam splitter means is a thin film device.

14. The optical assembly of claim 9, wherein the planar lightwave circuit is a liquid crystal device.

15. The optical assembly of claim 9, wherein the planar lightwave circuit is an Electrically Switchable Bragg Grating device.

16. An optical assembly comprising:

polarization beam splitter means adapted to receive a collimated optical input
5 beam and divide said input beam into first and second collimated beams, said first and second collimated beams having orthogonal polarization states and being directed at different angles;

first lens means disposed to focus said first and second collimated beams into
first and second focused spots in the focal plane of said lens means; and

10 a planar lightwave circuit having a surface, a front face, an exit face, and a first optical waveguide and a second optical waveguide disposed on said surface and terminating at said front face and said exit face, wherein said lightwave circuit is disposed with said front face proximate to the focal plane of said first lens means such that light from said first and second focused spots is coupled into said first and second
15 waveguides, said light propagating along said first and second optical waveguides and exiting said planar lightwave circuit at said exit face;

lens means disposed to accept light exiting said planar lightwave circuit and collimate said light into third and fourth collimated beams directed at different angles;
and

20 polarization beam combiner means disposed to combine said third and fourth collimated beams into a single collimated output beam.

17. The optical assembly of claim 16, wherein at least one of said polarization beam splitter
means and said polarization beam combiner means is a pair of birefringent wedges
25 cemented in the form of a Wollaston polarizer.

18. The optical assembly of claim 16, wherein at least one of said polarization beam splitter means and said polarization beam combiner means is a beam-splitting Glan Thompson prism.

5 19. The optical assembly of claim 16, wherein at least one of said polarization beam splitter means and said polarization beam combiner means is a beam displacing prism.

20. The optical assembly of claim 16, wherein at least one of said polarization beam splitter means and said polarization beam combiner means is a thin film device.

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21. The optical assembly of claim 16, wherein the planar lightwave circuit is a liquid crystal device.

22. The optical assembly of claim 16, wherein the planar lightwave circuit is an Electrically
15 Switchable Bragg Grating device.

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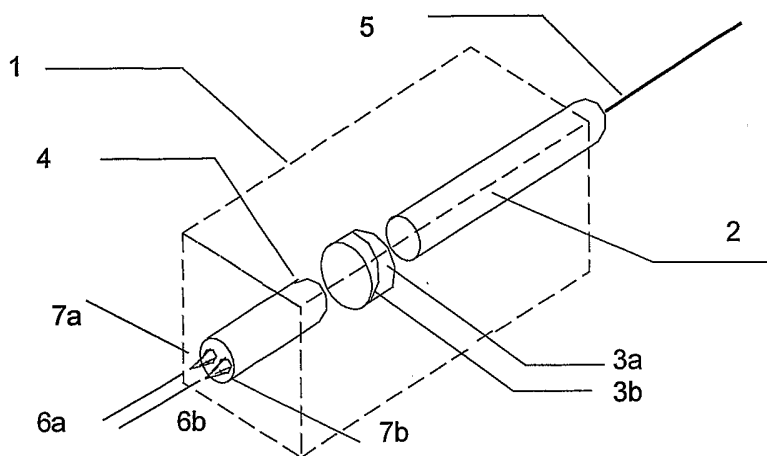


FIG. 1

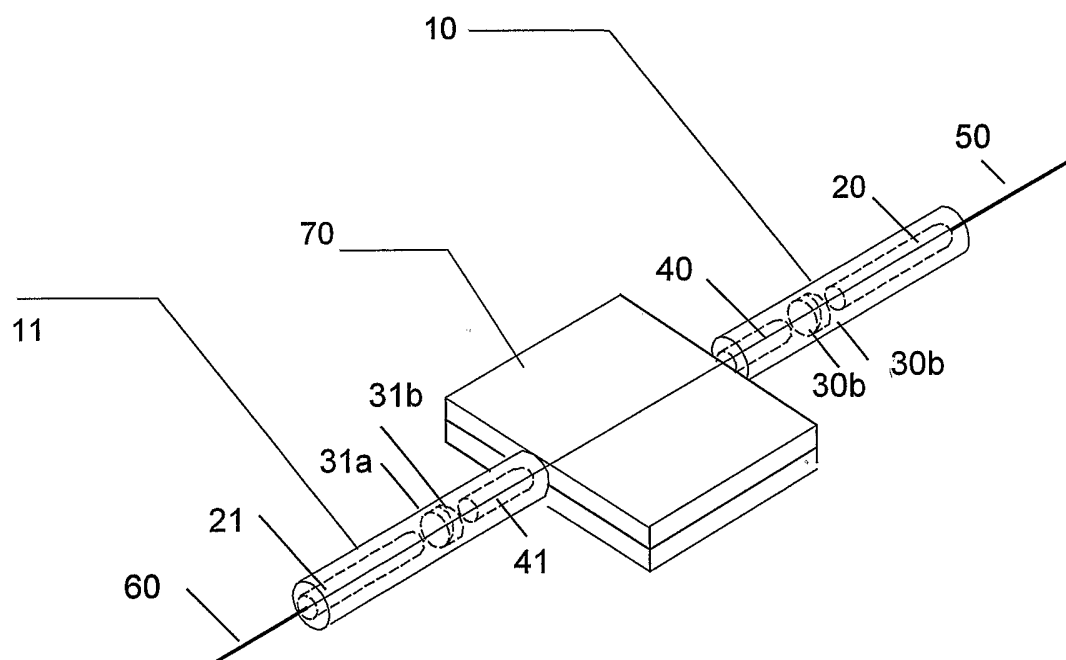


FIG. 2

PARAMETER		SPECIFICATION
Input Fiber	Type	SMF-28, 250u O.D.
	Length	1 meter minimum
Wavelength		1528 nm – 1564 nm
Critical dimensions	Working distance from output face of assembly to beam waists	Supplier-defined within range of 0.001 mm to 0.100 mm
	Working distance tolerance	$\pm 3\mu$ difference between focal plane of the two beams
	Mode field diameter at beam waist	$10.5\mu \pm 1.0\mu$
	Separation at working distance	$126\mu \pm 1.0\mu$
Optical Requirements	Insertion loss	≤ 0.4 dB at 1550 nm
	Insertion loss uniformity	≤ 0.2 dB difference between beams
	Wavelength dependent loss	0.2 dB, 1528 – 1564 nm
	Polarization crosstalk	> 27 dB (30 dB desired)
Housing	Design	Supplier defined cylindrical
	Cross section	4.0 mm - 5.5 mm diameter
	Length	As required. Focal plane of the two beams must be at least 1.0 mm past the end of the housing.

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/34 G02F1/1333 G02B27/28

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 G02B 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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	EP 1 176 451 A (JDS UNIPHASE INC ; JDS UNIPHASE CORP (US)) 30 January 2002 (2002-01-30) paragraph '0034! figure 8	1-22
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

International Application No

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