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(54) Title: SPATIALLY RESOLVED SPECTROMETER

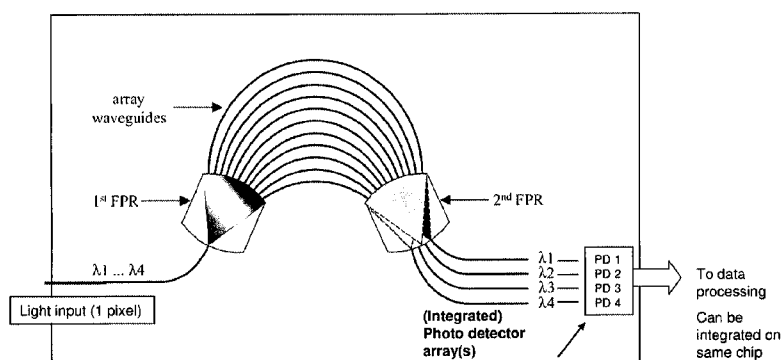


Fig. 1

(57) Abstract: A spatially resolved spectrometer has a line of pixel positions, each optically coupled to a first free propagation region of a respective one pixel spectrometer, wherein each one pixel spectrometer comprises - a grating optically coupling the first free propagation region of the one pixel spectrometer, and a second free propagation region of the one pixel spectrometer; - a photodetector array, optically coupled to the second free propagation region of the one pixel spectrometer.

Title: Spatially resolved spectrometer

Field of the invention

The invention relates to a spatially resolved spectrometer.

5 Background

Position dependent spectrometry may be used for example to investigate tissue. The position dependent spectrum can be used to detect a transition between two types of tissue, such as a border between tissue with
10 and without cancer or between tissue with good and bad cholesterol. This will enhance accurate operation removing all and only the desired tissue. Position dependent spectrometry may also be used for earth observation, e.g. for pollution detection, COS, NOX etc.

Current spectrometers systems resolve an incoming light beam into
15 parallel light at different wavelengths that can be detected in parallel, but information about the spatial distribution is lost. Another type of spectrometer uses a tunable filter that passes light at a selectable wavelength. In this case and image formed with the filtered light can be used to detect spectral content as a function of spatial position. In this case time dependent scanning of the
20 selected wavelength is needed to obtain spectra at the different image positions. Thus, current spectrometers systems provide for spatially resolved or real-time parallel readout. Combinations of the two are only possible by scanning, or by using a light source which scans over λ .

From the art of telecommunication, multiplexing of optical signals it
25 is known to perform spectral separation of optical communication signals using arrayed waveguide gratings (AWG) and a free propagation region (FPR).

Arrayed waveguide gratings (AWG) are commonly used as optical (de)multiplexers in wavelength division multiplexed systems. These devices are capable of multiplexing a large number of wavelengths into a single optical

fiber. The AWGs may be used to multiplex channels of several wavelengths onto a single optical fibre at the transmission end and are also used to retrieve individual channels of different wavelengths at a demultiplexer of an optical communication network.

5 The arrayed waveguide grating comprises a series of optical waveguides that provide for functionally parallel optical paths, successive waveguides providing optical paths of successively longer optical lengths, for example with a fixed length step from each waveguide to the next. A planar array with a series of successively adjacent waveguides may be used, with
10 inputs of the successive waveguides along a first row and outputs of the successive waveguides along a second row. Conventional silica-based AWGs are planar lightwave circuits fabricated by depositing doped and undoped layers of silica on a silicon substrate. An optical fiber is connected to an input port that faces inputs of the waveguides with a first free propagation region in
15 between. Inputs of output fibres face outputs of the waveguides with a second free propagation region in between.

 In the operation of such a device light is coupled into the device via an optical fiber connected to the input port. Light radiating from the input port propagates through a free propagation region and illuminates the inputs of the
20 grating waveguides. In each waveguide light components of different wavelength components undergoes a change of phase associated with the optical length of the waveguide. Light output from the waveguides passes through another free propagation region.

 Light from the input port reaches the input of each output fibre via a
25 plurality of parallel paths, via the first free propagation region, the optical waveguides and the second free propagation region. Each optical waveguide provides for a respective path between the input port and the input of each output fibre. The input of each output fibre lies at a location where light from the paths at a respective wavelength interferes constructively and light from
30 other wavelengths does not interfere constructively. As a result each output

channel substantially inputs only light of the wavelength at which the light interferes constructively.

Summary

5

It is an object to provide for a spectrometer with parallel readout over a plurality of pixels without using scanning elements.

According to one aspect a spatially resolved spectrometer is provided that comprises a plurality of one pixel spectrometers integrated on a substrate,
10 arranged to measure spectra at a plurality of pixel positions in an image, each spectrometer comprising an integrated grating optically coupling a first free propagation region of the one pixel spectrometer, and a second free propagation region of the one pixel spectrometer.

According to another aspect a spatially resolved spectrometer is
15 provided that comprises

- a line of pixel positions, each optically coupled to a first free propagation region of a respective one pixel spectrometer, wherein each one pixel spectrometer comprises;
- a grating optically coupling the first free propagation region of the one pixel
20 spectrometer, and a second free propagation region of the one pixel spectrometer;
- a photodetector array, optically coupled to the second free propagation region of the one pixel spectrometer. In an embodiment, the line may be part of a two dimensional array containing a plurality of lines. In an embodiment a spectral
25 resolution of 1pm to 1 nm may be provided, optionally by using cascaded gratings.

In an embodiment the grating may be an arrayed waveguide grating, comprising waveguides with inputs facing the first free propagation region of the one pixel spectrometer, and outputs facing the second free
30 propagation region of the one pixel spectrometer. With such a device it is

possible to integrate all one pixel spectrometers and their input and output waveguides on a common substrate.

The input of each one pixel spectrometer may be coupled to a respective pixel position in an input image surface (e.g. an image plane), the
5 pixel positions lying continuously along a line or in a 2-dimensional array, i.e. substantially at the minimum distance afforded by optical fibres or waveguides with their inputs at the pixel positions.

Brief description of the drawing

10

Figure 1 shows a one pixel spectrometer layout

Figure 2 shows an N pixel line spectrometer

Figure 3 and 4 show a spectroscopic imaging device

15 Detailed description of exemplary embodiments

Figure 1 shows a one pixel spectrometer layout comprising an input, a first free propagation region (FPR), an arrayed waveguide grating (AWG), a second free propagation region (FPR), a plurality of output connections and a
20 photodetector array. The input is coupled to inputs of waveguides in the arrayed waveguide gratings (AWG) via the first propagation region (FPR). The output connections are coupled to outputs of waveguides in the arrayed waveguide gratings (AWG) via the second propagation region (FPR). The
25 outputs connection are coupled between the second propagation region (FPR) and the photodetector array. The photodetector array has an output coupled to data processing electronics, which may be located on a same chip as photodetector array.

The arrayed waveguide grating (AWG) may be of a type known per se from optical telecommunication systems, comprising a series of waveguides
30 of successively larger length, with inputs at successive positions along a first

row on one side of the first free propagation region (FPR), and with output at successive positions along a second row on one side of the second free propagation region (FPR). In an arrayed waveguide grating (AWG) each different output position of the second free propagation region lies at a position
5 where light from a respective different wavelength interferes constructively. Light from the respective output positions is fed to respective the detectors of the photodetector array.

Instead of an arrayed waveguide grating a planar concave grating (PCG) may be used. Planar concave gratings are known per se from
10 Brouckaert et al, Journal of Light wave Technology, Vol 25, no. 5 May 2007

In a further embodiment, for higher resolution, a cascaded system may be used, wherein another set of FPR's and an AWG is placed behind each output. Higher resolution can also be obtained by combining the AWG or PCG with other wavelength selective elements like Ring Resonators and
15 interferometers. Separating accuracy up to 1 pm may be realized. A typical operating range of the spectrometer may be 200 nm to 4000 nm, but no fundamental limitation exists for the range.

Figure 2 shows an N pixel line spectrometer with a plurality of one pixel spectrometers and a line of pixels, each pixel coupled to a respective one
20 pixel spectrometer. Each pixel is attached to its own one pixel spectrometer (of cascade of AWGs) which in turn is attached to its own detector array. Hence each detector detects information about light for a specific combination of wavelength (which λ) and pixel position.

In a further embodiment a continuous, 2D spatially resolved version
25 of the spectrometer is provided. In this further embodiment a fibre beam is used with a beam of fibres. An image is projected on the other end of the fibre beam. Each fibre is attached to its own pixel.

In an embodiment n times y vertical grating couplers (VGC) are used, each VGC being attached to its own on chip spectrometer. Similar
30 couplings to a C-mos detector array may be used. Each VGC corresponds to a

pixel. A pixel size of 25 μm is possible (spatial resolution). The image may be projected directly on to the VGC array. A vertical stacking of y 1D chips (n -pixel line spectrometer as described in the preceding) is used.

In an embodiment an on-Chip reference source may be included for auto calibration (mainly temperature and deformation drift). An (on-chip) Erbium ion laser may be included as reference, for example.

In this way a spatially resolved spectrometer with continuous read out per pixel can be realized. A 1D spectrometer may be realized, using n pixels on one line, or a 2D spectrometer may be realized using y lines of n pixels (n times y pixel array). There is no fundamental limit for the working range. Typical wavelength range is 200 nm to 4000 nm with 1 nm resolution. 1 pm resolution is possible. Resolutions up to 1 pm can be obtained using further cascading with AWGs and /or by combining with other wave length selective elements such as ring resonators, or interferometers. Electronics and/or detectors can be integrated on-chip. In an embodiment vertical stacking of the chips (1D version and or detector arrays and or electronics) is used.

A spectrometer is provided with continuous parallel read out over as many pixels as desired (providing the spatial information). The pixels can be located along a line of pixels (1D) or a 2D array of pixels. Preferably, the spectrometer has no scanning elements. The spectrometer combines C-Mos technology, (cascaded) AWG (array wave guides) or PCG (planar concave grating), detector arrays (can be on chip) and electronics (can be on chip).

Light may be coupled in by fibres (one per pixel), or by shining directly on to the chip and using technologies like VGC's (vertical grating couplers).

In an embodiment the spatially resolved spectrometer device is integrated it in a cellular phone (for example to enable local pollution detection) or a digital camera (as next step after night vision where the IR spectrum is used).

The spectrometer may be used to investigate tissue by means of position dependent spectrometry. Light from successive positions in the tissue may be fed to respective one pixel spectrometers. In this case a position dependent spectrum may be obtained from the photodetectors and processed
5 by data processing electronics to detect a transition between tissue regions with mutually different spectral properties. A transition between tissue with and without cancer or between tissue with good and bad cholesterol may be detected for example. This may be used for operations aimed at removing all and only the desired tissue. Position dependent spectrometry may also be used
10 for earth observation, e.g. for pollution detection, COS, NOX etc.

In an embodiment the device may be used in an endoscope, comprising a flexible tube. In one embodiment the tube may comprise a set of optical fibres coupled to a light source and the spatially resolved spectrometer device on one end of the tube and ending at the other end, in order to light
15 tissue and to capture light at the other end. In another embodiment the spatially resolved spectrometer device may be mounted at the tip of the endoscope tube. This reduces losses in the optical path to the spatially resolved spectrometer device. Optionally a light source may be included at the tip as well, or an optical fiber may be used to supply light to the tip from the other
20 end of the tube. In another embodiment the spatially resolved spectrometer device may be provided in an ingestible pill, with the inputs directed to capture light from outside the pill. Optionally, the pill may comprise a light source as well, configured to illuminate a region from which the light is captured.

25 Figure 3 shows a spectroscopic imaging device 100 comprising a lens 102 and an optoelectronic device 120. Optoelectronic device 120 comprises a plurality input optical waveguides 120 with a row of inputs in an image plane 104 of lens 102. In an embodiment, a plurality of optical fibres (not shown) is provided between the image plane 104 and the inputs of input optical
30 waveguides 120. Each of these optical fibres may have a diameter that is

larger than that of an input optical waveguides 120. In this embodiment, the inputs of the optical fibres lie in a row, and the outputs of the fibres are coupled to the inputs of input optical waveguides 120, which need not lie in a row in this case, or in a row with distances corresponding to the distances
5 between the centers of the optical fibres.

Optoelectronic device 120 comprises an array of one pixel spectrometers 124 and a data processing circuit 126. By way of example two rows and three columns of the array are shown, but different numbers of rows and columns may be used. A one column N-row arrangement may be used for
10 example. Input optical waveguides 120 run from the row of inputs of the optical waveguides 120 (or from the outputs of the optical fibers) to inputs of one pixel spectrometers 124. In the example of figure 3, the output optical waveguides and photodetectors (not shown separately) of the one pixel spectrometers 124 have been included in the one pixel spectrometers 124.
15 Electronic outputs of the photodetectors (not shown) are coupled to data processing circuit 126. In an embodiment input optical waveguides 120, one pixel spectrometers 124 and output optical waveguides may be integrated on a common substrate and an array of photodetectors may be manufactured separately and mounted on outputs of the output optical waveguides.

20 Figure 4 shows an embodiment wherein an integrated electronic circuit 130 with a data processing circuit 132 and a photodetector array 134 is mounted on outputs of output optical waveguides 136, over the substrate with the integrated optics. In an alternative embodiment, the photodetectors may be mounted adjacent the substrate next to outputs of the output waveguides
25 136 on an edge of the substrate. Although an embodiment is shown wherein a linear photodetector array 134 is shown, it should be appreciated that instead a two dimensional array may be used, in which case the outputs of the output waveguides 136 need not all lie in one row.

In stead of using a lens an image may be formed by moving the
30 inputs close to the surface that has to be imaged.

Claims

1. A spatially resolved spectrometer comprising a plurality of one pixel spectrometers integrated on a substrate, arranged to measure spectra at a plurality of pixel positions in an image, each spectrometer comprising an integrated grating optically coupling a first free propagation region of the one
5 pixel spectrometer, and a second free propagation region of the one pixel spectrometer.
2. A spatially resolved spectrometer according to claim 1, comprising
- a line of pixel positions, each optically coupled to a first free propagation region of a respective one pixel spectrometer, wherein each one pixel
10 spectrometer comprises
- a grating optically coupling the first free propagation region of the one pixel spectrometer, and a second free propagation region of the one pixel spectrometer;
- a photodetector array, optically coupled to the second free propagation region
15 of the one pixel spectrometer.
3. A spatially resolved spectrometer according to claim 2, wherein the grating is an arrayed waveguide grating, comprising waveguides with inputs facing the first free propagation region of the one pixel spectrometer, and outputs facing the second free propagation region of the one pixel
20 spectrometer.
4. A spatially resolved spectrometer according to claim 2, wherein the grating is a planar concave grating.
5. A spatially resolved spectrometer according to any one of the preceding claims, wherein each one pixel spectrometer comprises a cascade
25 wherein a further combination of further free propagation regions and a further arrayed waveguide grating is placed between the second free propagation region in each one pixel spectrometer and the photodetector array.

- 6 A spatially resolved spectrometer according to any one of the
preceding claims, comprising optical fibres and/or optical waveguides each
coupled between a respective one of the pixels to a respective one of the first
free propagation regions.
- 5 7 A spatially resolved spectrometer according to any one of the
preceding claims, wherein said line of pixel positions is part of a 2D array of
pixel positions, comprising a plurality of lines of pixel positions and a fibre
bundle, each of the pixel positions being coupled to a respective one pixel
spectrometer via a respective fibre from the fibre bundle.
- 10 8. A spatially resolved spectrometer according to any one of the
preceding claims, wherein said line of pixel positions is part of a 2D array of
pixel positions, comprising a stack of 1D spatially resolved sub-spectrometers,
each with a line of pixel positions and a subset of said one pixel spectrometers.
9. A spatially resolved spectrometer according to claim 7 or 8, wherein
15 the pixel positions in the 2D array are continuously located.
10. A spatially resolved spectrometer according to any one of the
preceding claims, wherein the pixel positions on the line of pixel positions are
continuously located.
11. A spatially resolved spectrometer according to any one of the
20 preceding claims, having no scanning elements.
- 12 A mobile telephone comprising a spatially resolved spectrometer as
claimed in any one of the preceding claims.
- 13 A digital camera comprising a spatially resolved spectrometer as
claimed in any one of the preceding claims.
- 25 14. A method of performing spectrometry comprising using a plurality of
one pixel spectrometers integrated on a substrate to measure spectra at a
plurality of pixel positions in an image.
15. A method according to claim 14, the method comprising

- feeding light from respective pixel positions along a line of pixel positions each to a first free propagation region of a respective one pixel spectrometer for the pixel position, wherein each one pixel spectrometer comprises
- a grating optically coupling the first free propagation region of the one pixel spectrometer, and a second free propagation region of the one pixel spectrometer;
- a photodetector array, optically coupled to the second free propagation region of the one pixel spectrometer.

16. A method according to claim 14, comprising detecting a transition between regions along the line that have mutually different spectral properties.

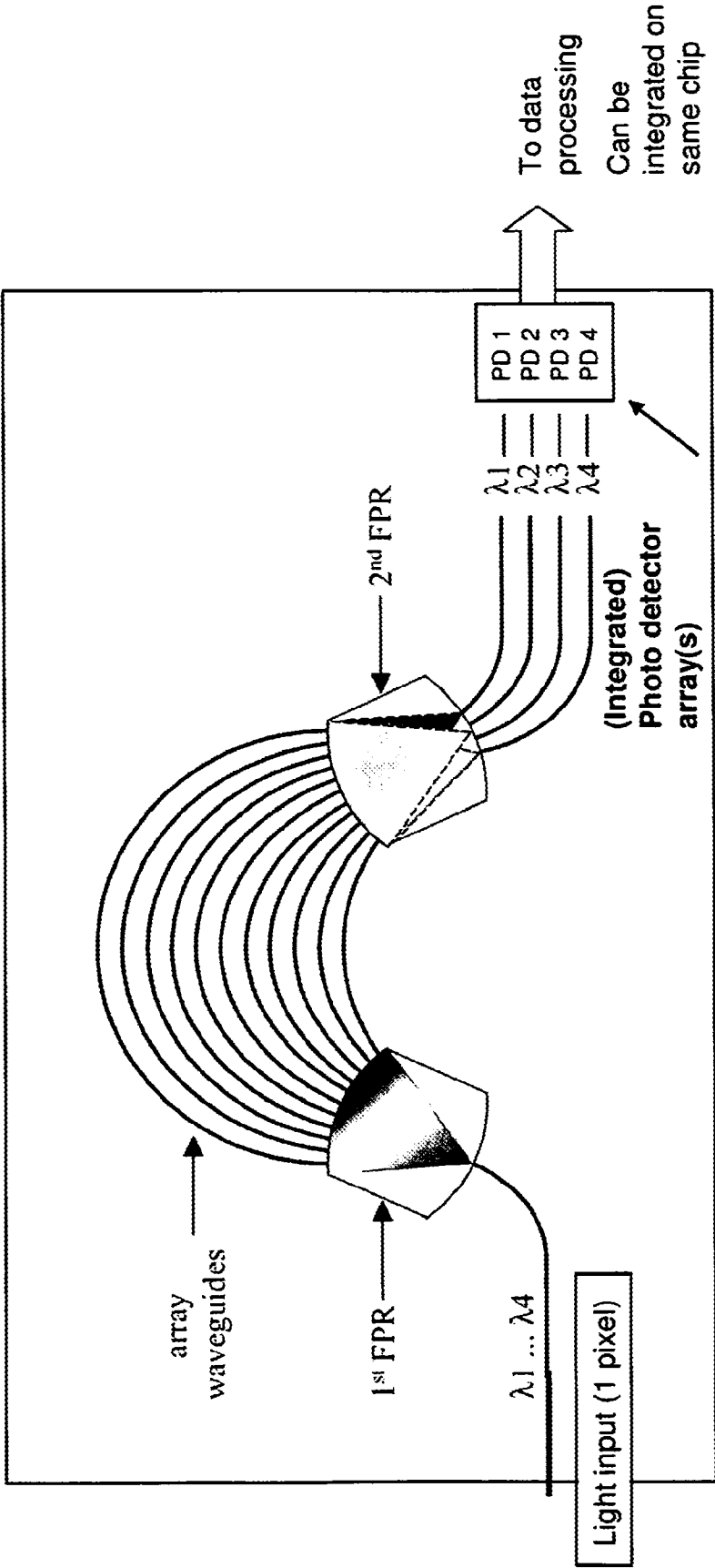


Fig. 1

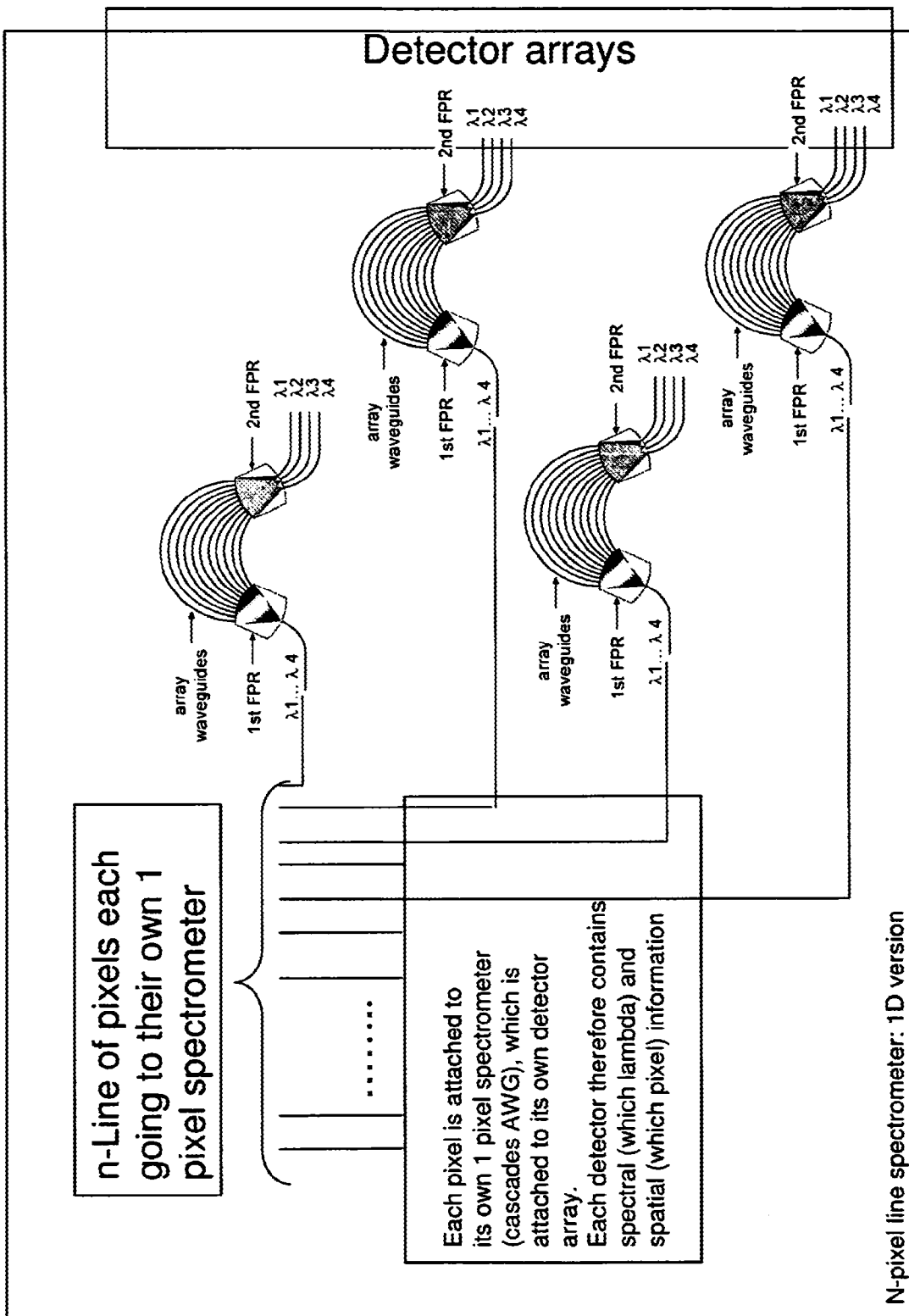


Fig. 2

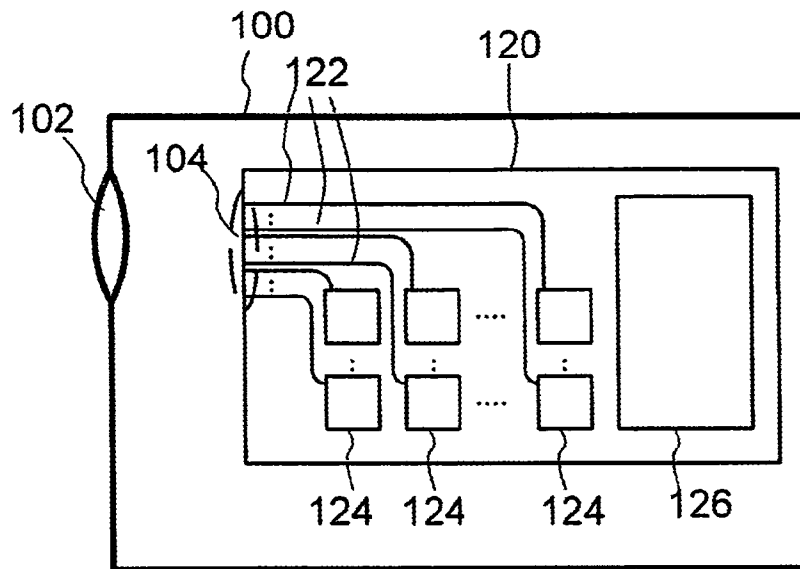


Fig. 3

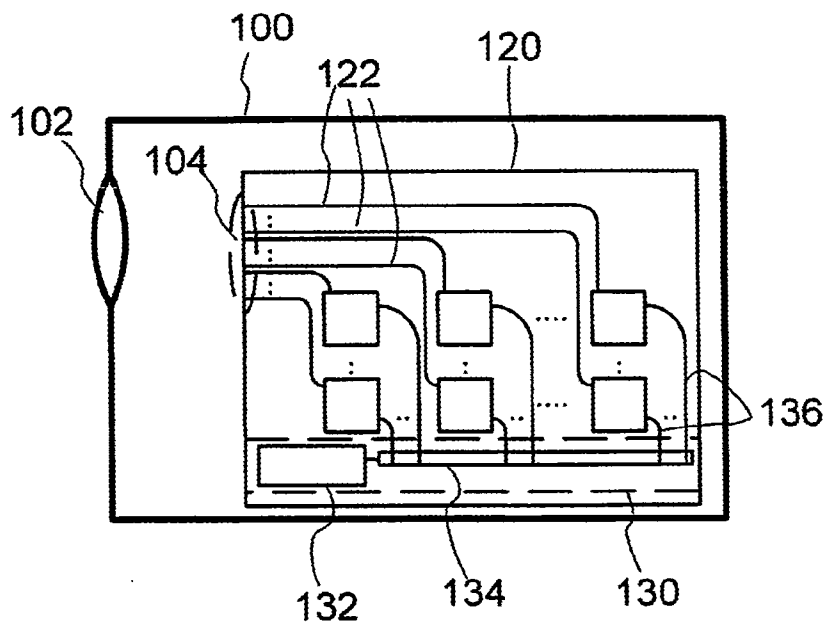


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2011/050246

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01J3/28 G01J3/02
ADD.

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)
G01J

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DZIUDA L ET AL: "Interrogation of extrinsic Fabry-Perot interferometric sensors using arrayed waveguide grating devices", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 52, no. 4, 1 August 2003 (2003-08-01), pages 1092-1096, XP011101092, ISSN: 0018-9456, DOI: DOI:10.1109/TIM.2003.814828 abstract; figures 1, 2 page 1092, right-hand column, paragraph second - page 1093, right-hand column, paragraph second ----- -/--	1-16

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

☐ See patent family annex.

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Date of the actual completion of the international search

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06/07/2011

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2011/050246

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CREMER C ET AL: "GRATING SPECTROGRAPH IN INGAASP/INP FOR DENSE WAVELENGTH DIVISION MULTIPLEXING", APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, vol. 59, no. 6, 5 August 1991 (1991-08-05), pages 627-629, XP000233514, ISSN: 0003-6951, DOI: DOI:10.1063/1.105405 abstract; figures 1,2 page 627, left-hand column, paragraph second - page 628, left-hand column, paragraph second	1-16
A	----- ZIRNGIBL M ET AL: "DEMONSTRATION OF A 15 X 15 ARRAYED WAVEGUIDE MULTIPLEXER ON INP", IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 4, no. 11, 1 November 1992 (1992-11-01), pages 1250-1253, XP000328571, ISSN: 1041-1135, DOI: DOI:10.1109/68.166958 the whole document -----	1-16