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(54) Title: ADDITIVE MANUFACTURING APPARATUS AND METHOD

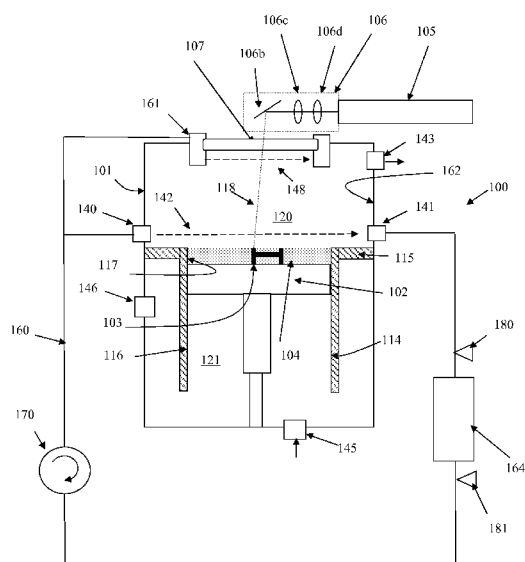


Fig. 1

(57) Abstract: This invention concerns an additive manufacturing apparatus for building a part by selectively consolidating flowable material in a layer-by-layer building process. The apparatus comprises an inert gas vessel (100) comprising a build chamber (101), a layering device (108, 109) for depositing layers of flowable material in the build chamber (101), a scanner (106) for delivering an energy beam (118) to selected areas of each layer to consolidate the flowable material of the layer, and an electrostatic device (164) for generating an electric field in the inert gas vessel (100) to cause movement of gas-borne particles in a desired direction. The electrostatic device may be an electrostatic precipitator.

ADDITIVE MANUFACTURING APPARATUS AND METHOD

Field of Invention

5 This invention concerns additive manufacturing apparatus and methods in which layers of material are consolidated in a layer-by-layer manner to form a part. The invention has particular, but not exclusive application, to selective laser solidification apparatus, such as selective laser melting (SLM) and selective laser sintering (SLS) apparatus.

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Background

Selective laser melting (SLM) and selective laser sintering (SLS) apparatus produce parts through layer-by-layer solidification of a material, such as a metal powder material, using a high energy beam, such as a laser beam. A powder layer is formed across a powder bed in a build chamber by depositing a heap of powder adjacent to the powder bed and spreading the heap of powder with a wiper across (from one side to another side of) the powder bed to form the layer. A laser beam, introduced through a window in the top of the build chamber, is then scanned across areas of the powder layer that correspond to a cross-section of the part being constructed. The laser beam melts or sinters the powder to form a solidified layer. After selective solidification of a layer, the powder bed is lowered by a thickness of the newly solidified layer and a further layer of powder is spread over the surface and solidified, as required. An example of such a device is disclosed in US6042774.

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The solidification process is carried out in an inert gas atmosphere, such as an argon or nitrogen atmosphere, as the metal powder is highly reactive. Melting of the powder results in formation of gas-borne particles in the build chamber. These particles include a cloud or fog of nanometre sized particulates (which are soot like in appearance) formed by material that has re-solidified in the inert atmosphere after being vaporised by the laser. It is undesirable for the gas-borne particles to resettle on the powder bed as this can affect the accuracy of the build. To remove such

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matter a gas knife of inert gas is generated across the powder bed between a nozzle and an exhaust. The gas collected by the exhaust is passed through a filter to remove the gas-borne particles, the filtered gas recirculated through a gas circuit back to the nozzle.

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WO2010/007394 discloses a parallel filter arrangement in which the gas flow through the circuit can be switched between either one of two filter assemblies such that the filter element in the other filter assembly can be replaced during a build. The filter elements are typically HEPA filters. Such filter elements may remove
10 the majority of particles having a size of microns or above but typically, are poor at removing nanoparticles from a gas stream. As described above, an additive manufacturing process will typically produce a large volume of nanometre sized particles and it is desirable to remove these particles from the gas flow.

15 **Summary of Invention**

According to a first aspect of the invention there is provided an additive manufacturing apparatus for building a part by selectively consolidating flowable material in a layer-by-layer building process comprising an inert gas vessel
20 comprising a build chamber, a layering device for depositing layers of flowable material in the build chamber; a scanner for delivering an energy beam to selected areas of each layer to consolidate flowable material of the layer, and an electrostatic device for generating an electric field in the inert gas vessel to cause movement of charged gas-borne particles in a desired direction (so called electrophoresis).

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The invention may advantageously allow the movement of charged gas-borne particles to be directed by the application of the electric field to ensure that the particles do not remain in undesired locations, such as above a working surface where the flowable material is consolidated, or settle on an undesired surface, such
30 as a window through which the energy beam is directed. For example, the electrostatic device may be used to filter, separate or direct the gas-borne particles.

The additive manufacturing apparatus may be apparatus for melting or sintering metal containing powder.

5 The electrostatic device may be arranged to generate an electric field across the build chamber to cause gas-borne particles to move away from a working surface where the flowable material is consolidated. For example, the electric field may cause the gas-borne particles to move towards an outlet in the build chamber. The electrostatic device may comprise electrodes, such as (curved or flat) plates, spaced apart either side of the working surface, the electrodes connected or connectable to
10 a power source for applying a voltage across the electrodes. Solidification of the flowable material may generate a plasma above the location being solidified. The electric field generated by the electrostatic device may cause positively charged particles of the plasma/generated by the plasma to move in a direction as dictated by the electric field.

15 The apparatus may comprise a gas circuit for generating a gas flow through the build chamber, the electrostatic device arranged to generate an electric field to cause movement of particles in the gas flow. The electrostatic device may be arranged in the gas circuit (outside of the build chamber).

20 The electrostatic device may be an electrostatic precipitator for filtering particles out of the gas flow. For example, an electrostatic precipitator may be used in combination with a semi-permeable filter element, such as a HEPA filter, which removes particles by blocking particles and allowing gas to flow therethrough. The
25 electrostatic precipitator may be used in combination with a recirculator and/or a cyclone. The electrostatic precipitator may cause movement of the particles within cyclonic gas flow such that the particles move to an outside of the cyclone and are carried away through a separate outlet to clean air formed at a centre of the cyclone.

30 The electrostatic precipitator may comprise (curved or flat) plates spaced apart such that the gas can flow therebetween, the plates connected or connectable to a power source for charging the plates to an opposite polarity to a charge of the particles.

The electrostatic precipitator may comprise an ionisation member for charging gas-borne particles before the particles flow between the plates. The electrostatic precipitator may comprise a repulsion plate on a downstream side (based on the direction of the gas flow) of the plates for repelling charged gas-borne particles. The repulsion plate may be charged to the same polarity as the charged particles.

The electrostatic precipitator may comprise an outlet for particles that have collected on charged surfaces of the electrostatic precipitator and subsequently released when the surfaces are discharged. The electrostatic precipitator may comprise a vibrator for vibrating the plates to aid in the release of the particles from the surfaces.

The apparatus may comprise a detector for detecting a pressure drop across the electrostatic precipitator. The apparatus may comprise an indicator for indicating that particles trapped by the electrostatic precipitator should be cleaned from the electrostatic precipitator. The apparatus may be arranged to activate the indicator based upon the detected pressure drop. The apparatus may comprise a controller for controlling a voltage applied between surfaces of the electrostatic precipitator, the controller arranged to discharge the surfaces based upon the detected pressure drop.

The electrostatic device may be an electrostatic separator for separating particles in the gas flow based on particle size. For example, the electrostatic separator may direct different sized particles to different filter elements, each filter element being suitable for filtering particles of different sizes.

According to a second aspect of the invention there is provided a method of removing particles from an inert gas atmosphere provided in a vessel in a layer-by-layer additive manufacturing process, wherein a part is built by selectively consolidating flowable material in layers, the method comprising generating an electric field in the inert gas vessel to cause movement of charged gas-borne

particles in a desired direction.

The vessel may comprise a build chamber in which a part is formed using the layer-by-layer additive manufacturing process, wherein the method may comprise
5 forming a gas flow through the build chamber and applying an electric field across the gas flow to filter particles from the gas flow.

The flowable material may comprise metal material.

10 Description of the Drawings

Figure 1 is a schematic diagram of an additive manufacturing apparatus according to one embodiment of the invention;

15 **Figure 2** is a schematic diagram of the additive manufacturing apparatus from another side;

Figure 3 is a cut-away perspective view of an electrostatic precipitator according to an embodiment of the invention; and

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Figure 4 is a schematic diagram of an additive manufacturing apparatus according to another embodiment of the invention.

Description of Embodiments

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Referring to Figures 1 and 2, an additive manufacturing apparatus according to an embodiment of the invention comprises an inert gas vessel 100 comprising build chamber 101 and a gas circuit 160.

30 The build chamber 101 has partitions 115, 116 therein that define a build cylinder 117 and a surface onto which powder can be deposited. A build platform 102 is provided for supporting a powder bed 104 and a part 103 built by selective laser

melting powder 104. The platform 102 can be lowered within the build cylinder 117 as successive layers of the part 103 are formed. A build volume available is defined by the extent to which the build platform 102 can be lowered into the build cylinder 117. The build cylinder 117 and build platform 102 may have any suitable cross-sectional shape, such as circular, rectangular and square.

Partitions 115, 116 and the build platform 102 split the build chamber 101 into an upper chamber 120 and a lower chamber 121. Seals (not shown) around the build platform 102 prevent powder from entering into the lower chamber 121. A gas connection, such as a one-way valve, may be provided between the upper and lower chambers 120, 121 to allow gas to flow from the lower chamber 121 to the upper chamber 120. The lower chamber 121 may be kept at a slight over-pressure relative to the upper chamber 120.

Layers of powder 104 are formed as the part 103 is built by dispensing apparatus 108 and an elongate wiper 109. For example, the dispensing apparatus 108 may be apparatus as described in WO2010/007396.

A laser module 105 generates a laser 118 for melting the powder 104, the laser directed as required by optical scanner 106 under the control of a computer 130. The laser enters the chamber 101 via a window 107, which is held in place in a ceiling of the build chamber 101 by a retainer ring 161.

The optical scanner 106 comprises steering optics, in this embodiment, two movable mirrors 106a, 106b for directing the laser beam to the desired location on the powder bed 104 and focussing optics, in this embodiment a pair of movable lenses 106c, 106d, for adjusting a focal length of the laser beam. Motors (not shown) drive movement of the mirrors 106a and lenses 106b, 106c, the motors controlled by processor 131.

A computer 130 controls modules of the additive manufacturing apparatus. Computer 130 comprises the processor unit 131, memory 132, display 133, user

input device 134, such as a keyboard, touch screen, etc., a data connection to the modules. Stored on memory 132 is a computer program that instructs the processing unit to carry out the method as described below.

- 5 The gas circuit 160 comprises a gas nozzle 140 and a gas exhaust 141 for generating a gas flow 142 through the chamber 101 across the working surface of the powder bed 104. The gas flow 142 acts as a gas knife carrying gas-borne particles, created by the melting of the powder with the laser, away from the build area. The gas circuit comprises a further gas nozzle integrated into the retainer ring 161 for
10 generating a gas flow 148 across the laser window 107. This gas flow may help to prevent particulates from collecting on the laser window 107, which in turn could affect the quality of the laser beam 118 delivered through the laser window 107.

A pump 170 drives the circulation of inert gas through gas circuit 160.

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A vent 143 provides a means for venting/removing gas from the chambers 120, 121. A backfill inlet 145 provides an inlet for backfilling the chambers 120, 121 with inert gas. The lower chamber 121 may comprise a further inlet 146 for maintaining the lower chamber 121 at an overpressure relative to the upper chamber 120.

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- The gas circuit further comprises an electrostatic device 164. Referring to Figure 3, the electrostatic device 164 comprises a housing 165 having a gas inlet 166, a gas outlet 167, a first particle outlet 168 and a second particle outlet 169. The housing 165 further comprises a removable cap 180 that can be removed to provide access to
25 an inside of the housing 164.

- The housing 165 contains first and second slatted members 170, 171. The slats of the member 170, 171 are angled to a direction, d, of the gas flow to provide a tortuous path for the gas flow. The openings between the slats are in
30 communication with the first particle outlet 168 such that particles that are captured by the slats can fall into the outlet 168. The slatted members 170 and 172 and particle outlet 168 together form an inertial filter for filtering larger particles from

the inert gas stream as a result of the larger particles having too much inertia to follow the tight curves of the gas path defined by the slats. Particles trapped by the slats can then drop through outlet 168 for collection in a container, such as a bottle, connected to outlet 168. The inertial filter filters larger particles from the gas stream before the gas flows through the electrostatic precipitator, as described below. The inertial filter is optional and in another embodiment, the electrostatic device 164 does not comprise an inertial filter.

The housing 165 further comprises an ionisation member 172 through which the gas flows. The ionisation member 172 is held within the housing 165 and electrically isolated from other components contained in the housing 165 by two electrical insulators, in this embodiment insulating rings 173, 174. The ionisation member 172 comprises a series of electrical conductors, in this embodiment concentric electrically conductive rings, between which the gas can flow. Downstream and electrically isolated from ionisation member 172 is a plurality of spaced apart collection plates 175. The collection plates 175 are aligned such that the gas can flow between the plates 175. The plates 175 are held in the housing 165 by a tubular electrically insulating member 176. A high voltage is applied between the ionisation member 172 and the collection plates 175 such that the ionisation member 172 is held at a high negative voltage, such as -10,000V, and the collection plates 175 are held at ground or a high positive voltage, such as +10,000V.

The ionisation member 172, collection plates 175 and particle outlet 169 form an electrostatic precipitator for filtering particles from the gas stream. In particular, the ionisation member ionises metal particles within the gas that flows through the ionisation member 172 and the negative ions, such as the metal gas-borne particles, move to the collection plates 175 following the electric field generated between the ionisation member 172 and the collection plates 175. As a result, the metal particles collect on the collection plates 175.

The voltage applied between the ionisation member 172 and the collection plates 175 may be controlled to release the particles from the collection plates at

appropriate times. For example, the voltage may be switched off when the gas flow is switched off to release the particles collected on the plates 175 so that the particles fall under gravity into outlet 169. Outlet 169 may be connected to a bottle (not shown) for the collection of particles.

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This embodiment of the electrostatic precipitator further comprises a repulsion member 177. The repulsion member 177 comprises openings to allow gas to flow to gas outlet 167 and is held in the housing 165 between tubular insulting member 176 and a further insulator, in this embodiment, a third insulation ring 178. The repulsion member 177 is connected or connectable to be held at a negative voltage to repel particles ionised by the ionisation member 172. The repulsion member 178 may help to ensure that metal particles collect on the collection plates 175.

In this embodiment, the electrostatic device 164 comprises an integral semi-permeable filter 179 that allows the gas to pass therethrough but blocks gas-borne particulates. However, in another embodiment, the semi-permeable filter is separate from the electrostatic device 164.

Pressure sensors 180, 181 monitor the pressure drop across the electrostatic device 164. The measured pressure drop 130 is reported to computer 130.

During a build, the particles formed during the selective laser melting process that are entrained in the gas knife 142 are carried to the outlet 142 and through the gas circuit 100. On entering the electrostatic device 164, the direction of the gas flow changes suddenly as the gas flows through the slats of the slatted member 170 such that larger particles that have a larger inertia collide with the slats and drop under gravity through the outlet 168.

On entering the ionisation member 172, the remaining gas borne particles are ionised, the ionised particles being attracted to collection plates 175. Ionised particles that are carried by the gas flow towards an end of the collection plates 175 are repelled back into the plates 175 by repulsion member 177, whilst the gas is

allowed to flow through the repulsion member and through filter 179.

During a period in which the gas flow is stopped, for example at the end of the build or during spreading of powder with the wiper 109, the voltage between the ionisation member 172 and collection members 175 may be removed, for example
5 under the control of computer 130, to release particles from the collection plates 175 such that the particles drop into the outlet 169 under gravity. The computer 130 may remove the voltage when the pressure drop detected by pressure sensors 180, 181 increases above a predetermined threshold.

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The housing 164 containing the filter elements may be sealable by valves (not shown) and removable from the gas circuit 100 such that the housing 164 can be flooded with a fluid, such as water, to wash out particles from the filter elements and neutralise particles trapped in filter element 179. After flooding, filter element
15 179 can then be removed and replaced by removing cap 180. Flooding of non-electrostatic filters is described in WO2010/026396 and it is envisaged that a similar process could be used with the electrostatic device 164 disclosed herein.

The electrostatic device 164 may remove enough particles from the gas stream to
20 significantly extend the life of the semi-permeable filter 179. This may provide for longer build times before the filter element 179 requires replacement. Furthermore, the electrostatic precipitator may capture nanometre sized particulates that are likely to pass through semi-permeable filters 179. Accordingly, fewer nanometre sized particulates may be recirculated back into the build chamber.

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In a further embodiment, the electrostatic precipitator comprises a vibrator or knocker, which is activated to knock-off particles from the collection plates 175 for collection in outlet 167. The vibrator or knocker may be used in conjunction with switching off the voltage.

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A further embodiment of the invention is shown in Figure 4. In Figure 4 the same reference numerals but in the series 200 are used for features of this embodiment

that are the same or similar to features of the embodiment shown in Figures 1 to 3. This embodiment differs from the previous embodiment in that a large voltage is applied between the gas inlet 240 and the gas outlet 241. This generates an electric field across the working/build surface.

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During melting of the powder with the laser, a plasma is formed above the working surface. The electric field applied across the working surface will cause the charged particles of the plasma to migrate towards the gas outlet 241 and be repelled from the gas inlet 240. Accordingly, the electric field supplements the gas flow in forcing
10 the particles generated during the melting process towards outlet 241.

Other surfaces of the build chamber may also be held at a high negative voltage to repel positively charged particles of the plasma/formed out of the plasma. For example, the retaining ring 261 for the window 207 may be held at a large negative
15 voltage to repel particles away from the window 207.

It will be understood that alterations and modifications may be made to the embodiments as described herein without departing from the invention as defined in the claims.

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CLAIMS

1. An additive manufacturing apparatus for building a part by selectively consolidating flowable material in a layer-by-layer building process comprising an inert gas vessel comprising a build chamber, a layering device for depositing layers of flowable material in the build chamber; a scanner for delivering an energy beam to selected areas of each layer to consolidate the flowable material of the layer, and an electrostatic device for generating an electric field in the inert gas vessel to cause movement of gas-borne particles in a desired direction.
2. An additive manufacturing apparatus according to claim 1, for melting or sintering metal containing powder.
3. An additive manufacturing apparatus according to claim 1 or claim 2, wherein the electrostatic device is arranged to generate an electric field across the build chamber to cause gas-borne particles to move away from a working surface where the flowable material is consolidated.
4. An additive manufacturing apparatus according to claim 3, wherein the electric field is formed to cause the gas-borne particles to move towards an outlet in the build chamber.
5. An additive manufacturing apparatus according to claim 3 or 4, wherein the electrostatic device comprises electrodes spaced apart either side of the working surface, the electrodes connected or connectable to a power source for applying a voltage between the electrodes.
6. An additive manufacturing apparatus according to claim 1 or claim 2 comprising a gas circuit for generating a gas flow through the build chamber, the electrostatic device arranged to generate an electric field to cause movement of particles in the gas flow.
7. An additive manufacturing apparatus according to claim 6, wherein the

electrostatic device is arranged in the gas circuit.

8. An additive manufacturing apparatus according to claim 7, wherein the electrostatic device is an electrostatic precipitator for filtering particles out of the gas flow.

9. An additive manufacturing apparatus according to claim 8, wherein the electrostatic precipitator is used in combination with a semi-permeable filter element, which removes particles by blocking particles and allowing the gas to flow therethrough.

10. An additive manufacturing apparatus according to claim 8 or claim 9, wherein the electrostatic precipitator comprises plates spaced apart such that the gas can flow therebetween, the plates connected or connectable to a power source for charging the plates to an opposite polarity to a charge of the particles.

11. An additive manufacturing apparatus according to claim 10, wherein the electrostatic precipitator comprises an ionisation member for charging gas-borne particles before the particles flow between the plates.

12. An additive manufacturing apparatus according to claim 10 or claim 11, wherein the electrostatic precipitator comprises a repulsion plate on a downstream side of the plates for repelling charged gas-borne particles.

13. An additive manufacturing apparatus according to any one of claims 8 to 12, wherein the electrostatic precipitator comprises an outlet for particles that have collected on charged surfaces of the electrostatic precipitator and are subsequently released from the surfaces when discharged.

14. An additive manufacturing apparatus according to claim 13, wherein the electrostatic precipitator comprises a vibrator for vibrating the surfaces to aid in the release of the particles from the surfaces.

15. An additive manufacturing apparatus according to any one of claims 8 to

14, comprising a detector for detecting a pressure drop across the electrostatic precipitator and an indicator for indicating that particles trapped by the electrostatic precipitator should be cleaned from the electrostatic precipitator, the indicator activated based upon the detected pressure drop.

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16. A method of removing particles from an inert gas atmosphere provided in a vessel in a layer-by layer additive manufacturing process, wherein a part is built by selectively consolidating flowable material in layers, the method comprising generating an electric field in the inert gas vessel to cause movement of gas-borne particles in a desired direction.

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17. A method according to claim 16, wherein the vessel comprises a build chamber in which a part is formed using the layer-by-layer additive manufacturing process, wherein the method comprises forming a gas flow through the build chamber and applying an electric field across the gas flow to filter particles from the gas flow.

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18. A method according to claim 16 to claim 17, wherein the flowable material comprises metal material.

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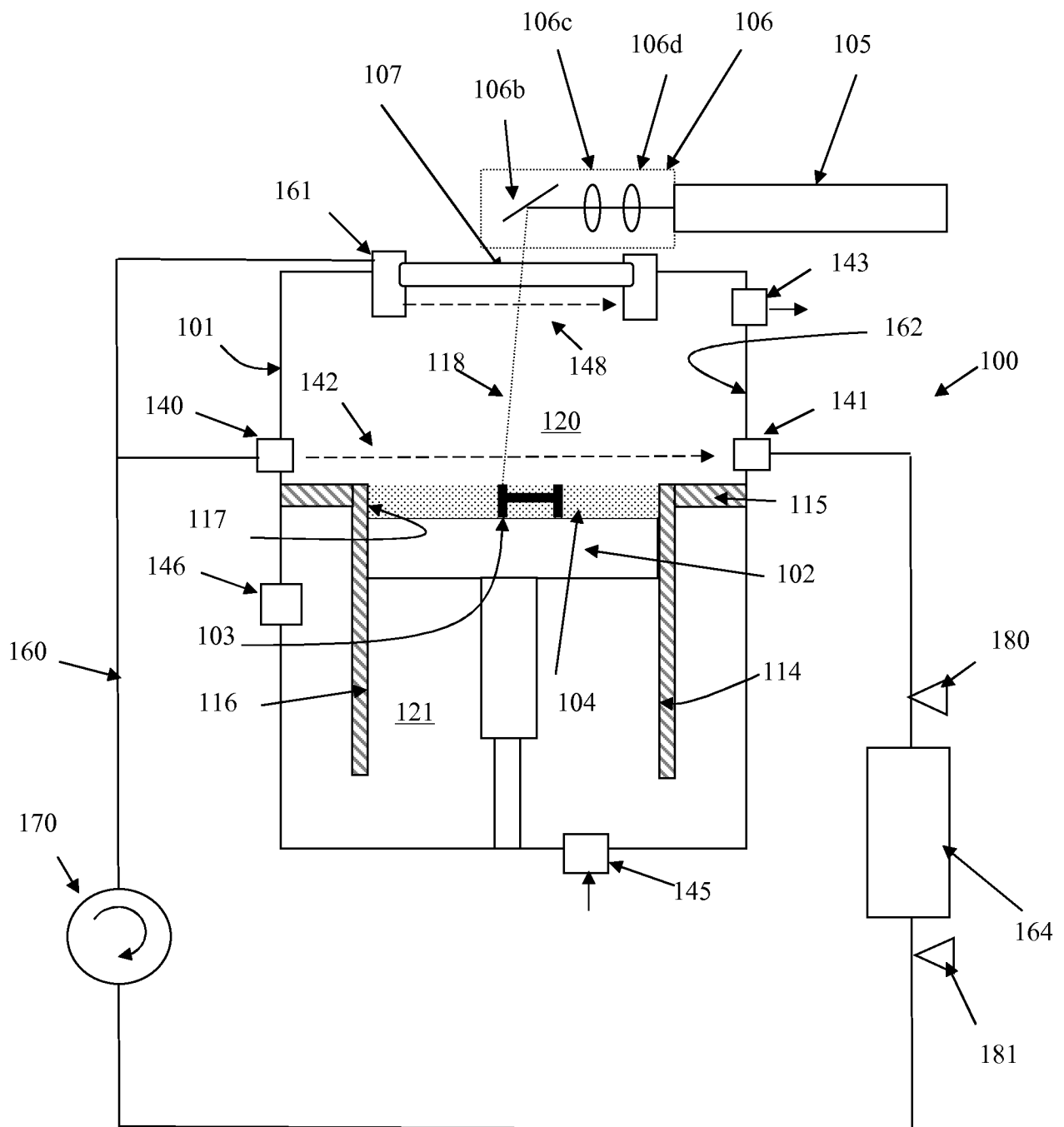
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Fig. 1

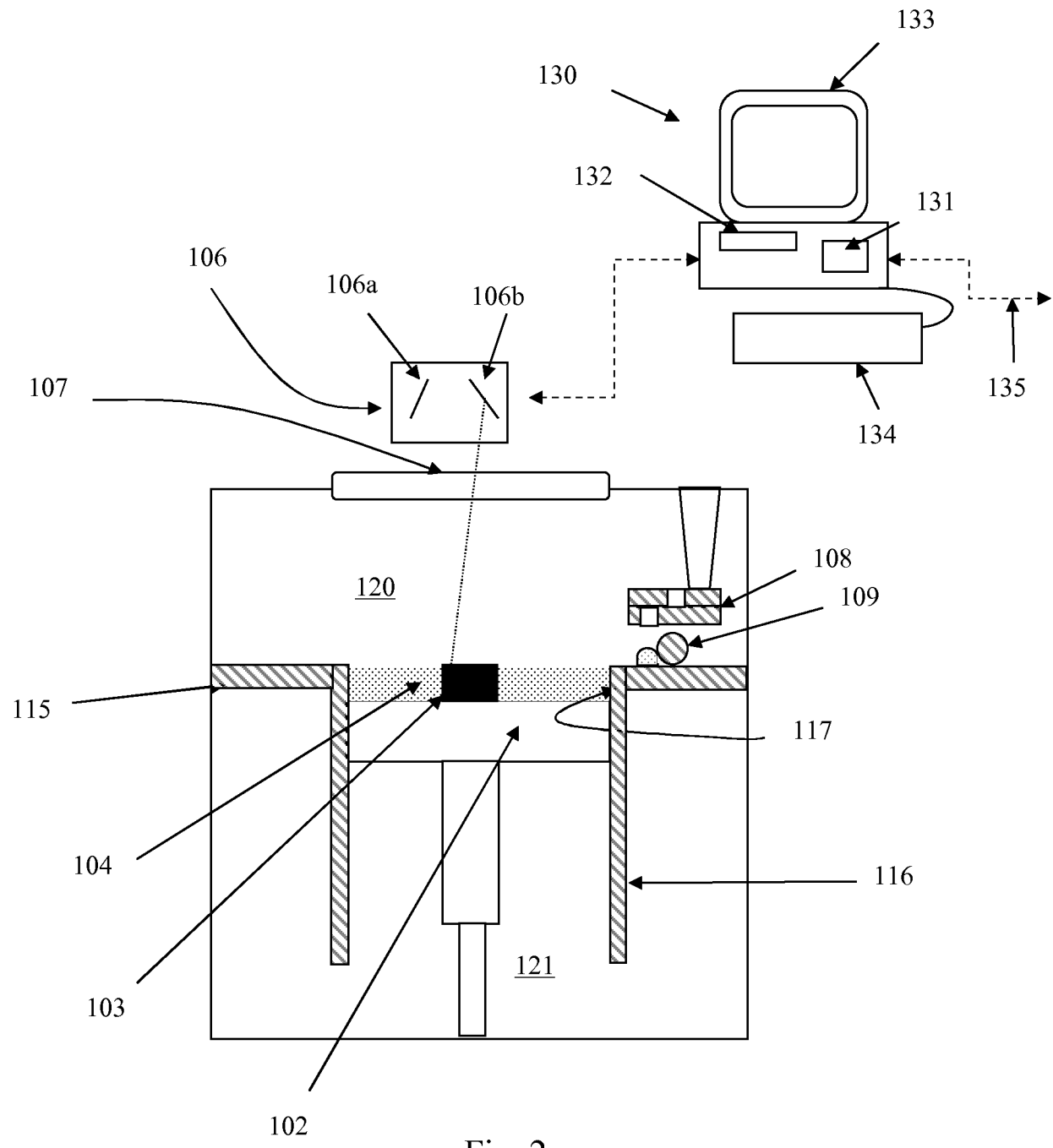
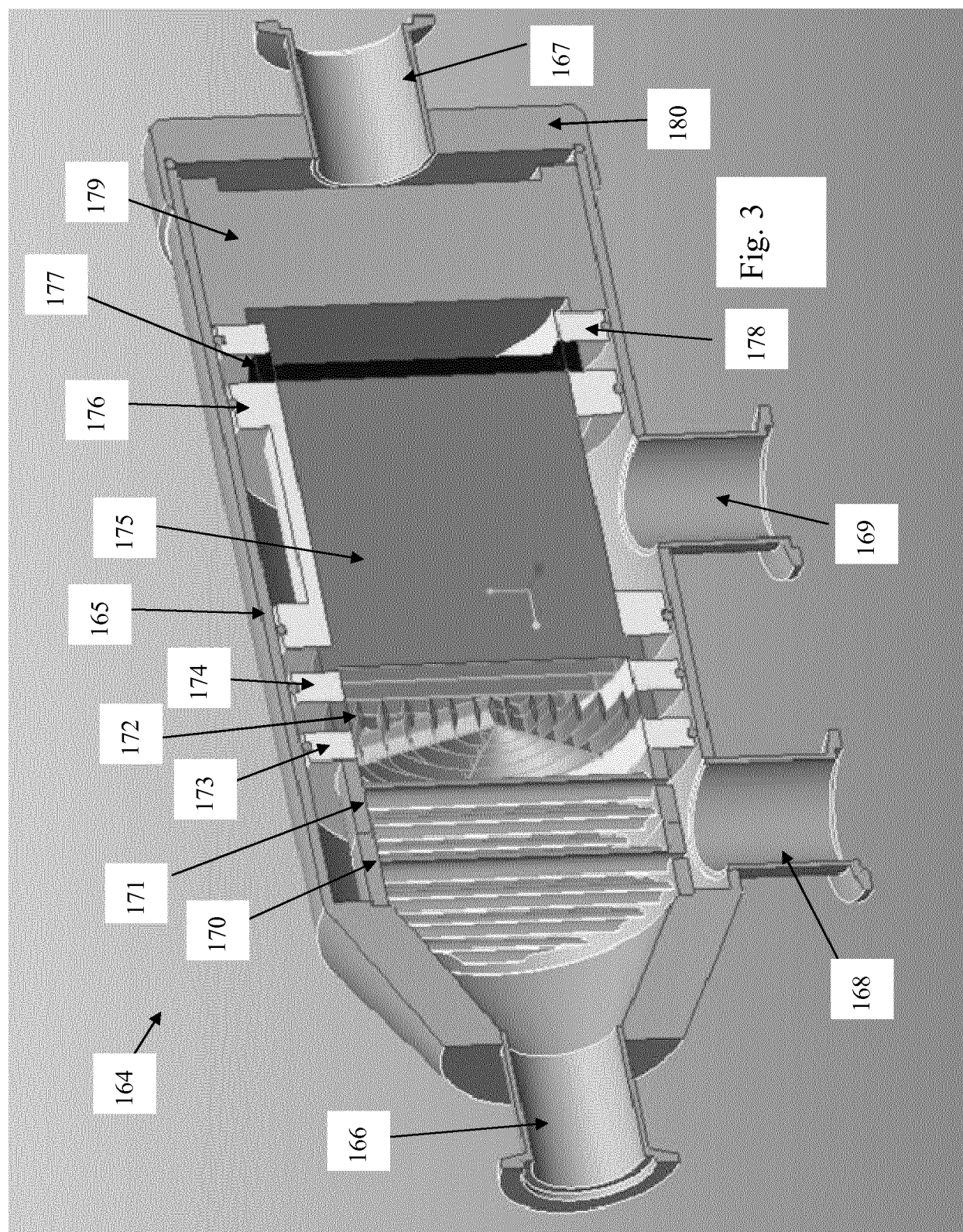


Fig. 2



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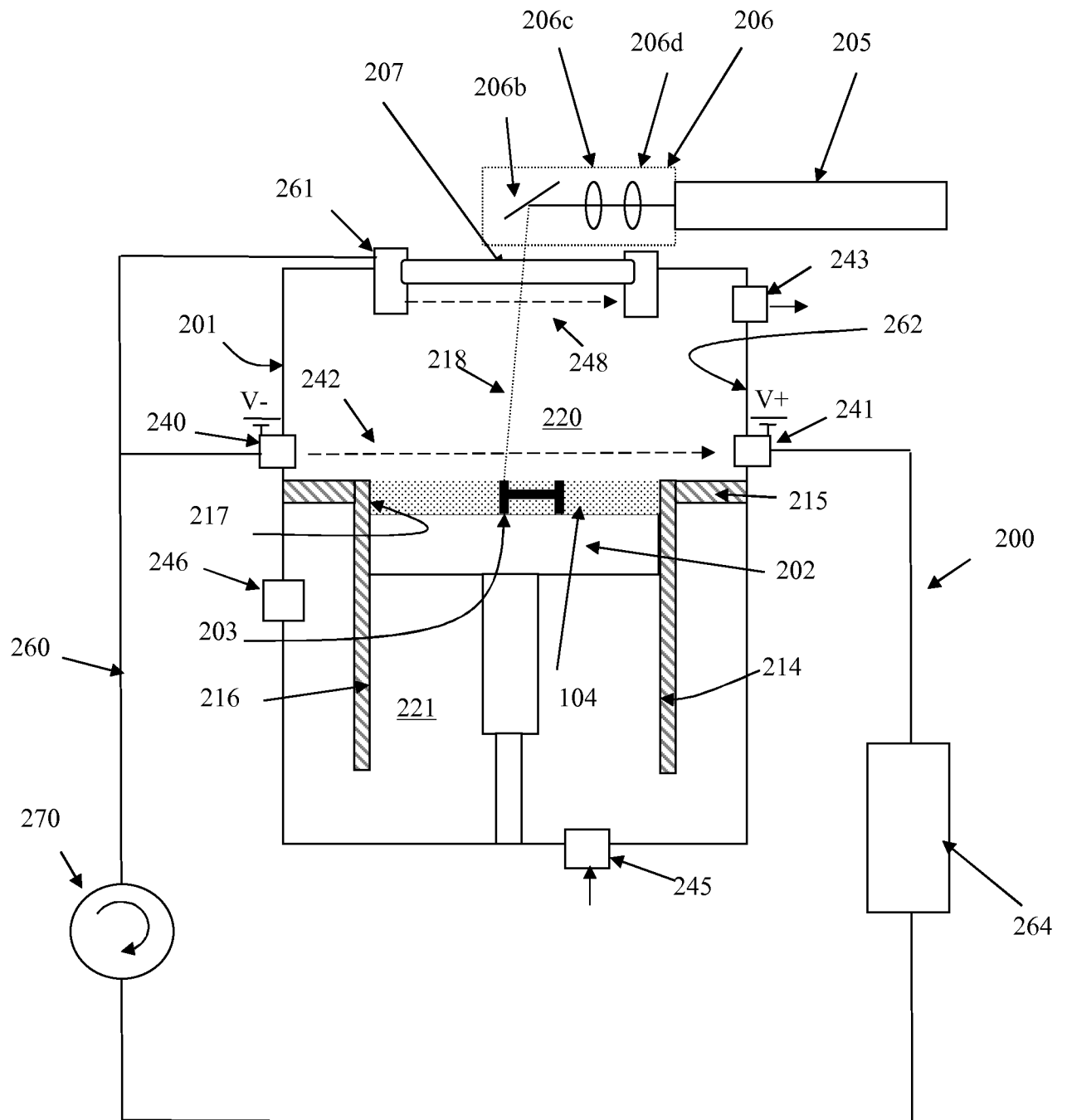


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/072821

A. CLASSIFICATION OF SUBJECT MATTER

INV. B22F3/00 B22F3/105 B29C67/00 B03C3/00
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)

B22F B29C B03C

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 practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A,P	claims 1, 3-12 paragraphs [0011] - [0024], [0026], [0032] - [0040] figure 1	2,9,12, 15,18
X,P	& US 2016/016336 A1 (HESS THOMAS [DE] ET AL) 21 January 2016 (2016-01-21)	1,3-8, 10,11, 13,14, 16,17
A,P	claims 1, 3-12 paragraphs [0003] - [0005], [0012] - [0027], [0035] - [0043] figure 1 ----- -/--	2,9,12, 15,18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

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Date of mailing of the international search report

31/01/2017

Name and mailing address of the ISA/

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Traon, Nicolas

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/072821

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	claims 1, 2, 5, 7, 9, 11, 13-15, 18, 20 paragraphs [0049], [0052], [0058], [0061], [0064], [0066], [0067], [0069], [0070], [0075], [0077], [0081], [0086] figures 1, 2	5,12
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A	paragraphs [0061] - [0065], [0077] - [0081] figures 9-12	5,7-15
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A	claims 1, 11 page 1, lines 1-27 page 2, lines 1-6, 20-28 page 3, lines 1-3 page 4, lines 1-27 page 5, lines 1-27 page 6, lines 1-27 page 7, lines 1-27 page 8, lines 1-19 figures 1-2	1-4, 6-11, 13-18
A	----- US 2006/192322 A1 (ABE SATOSHI [JP] ET AL) 31 August 2006 (2006-08-31) paragraphs [0056], [0057] figure 9	1-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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