[Continued on next page]
Declarations under Rule 4.17:
— of inventorship (Rule 4.17(iv))

Published:
— with international search report (Art. 21(3))
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))
LOCAL CONTAMINATION DETECTION IN ADDITIVE MANUFACTURING

BACKGROUND

The described subject matter relates generally to the field of additive manufacturing. More particularly, the subject matter relates to detecting contamination in an additive manufacturing environment.

Additive manufacturing refers to a category of manufacturing methods characterized by the fact that the finished part is created by layer-wise construction of a plurality of thin sheets of material. Additive manufacturing may involve applying liquid or powder material to a workstage, then doing some combination of sintering, curing, melting, and/or cutting to create a layer. The process is repeated up to several thousand times to construct the desired finished component or article.

Various types of additive manufacturing are known. Examples include stereo lithography (additively manufacturing objects from layers of a cured photosensitive liquid), electron beam melting (using a powder as feedstock and selectively melting the powder using an electron beam), laser additive manufacturing (using a powder as a feedstock and selectively melting the powder using a laser), and laser object manufacturing (applying thin solid sheets of material over a workstage and using a laser to cut away unwanted portions).

Additive manufacturing processes typically require managed environments to protect the product from deterioration or contamination. Inert or otherwise unreactive gas flow atmospheres are typical. Despite this, raw materials can become contaminated, causing defects in the built components. However, due to limitations of current machines and processes, the type and degree of raw material contamination is not known until the build process is complete.

SUMMARY

An additive manufacturing system comprises a build chamber, a powder bed additive manufacturing device disposed in the build chamber, and a powder contamination detection system. The powder contamination detection system is in communication with an atmosphere in the build chamber.

An additive manufacturing system comprises a plurality of powder bed additive manufacturing devices disposed in at least one build chamber. A plurality of sample ports are connected to the at least one build chamber. Each sample port is separately in communication with a protective atmosphere proximate each of the plurality of powder
bed additive manufacturing devices. A powder contamination detection system is in communication with the plurality of sample ports.

A method of manufacturing a solid freeform object, the method comprises operating a first powder bed additive manufacturing device disposed in a build chamber. A first set of byproducts is generated from operation of the first powder bed additive manufacturing device. At least one of the first set of byproducts is communicated to a powder bed contamination detection system. A powder bed contamination detection system is operated to detect contamination of powder used in the first powder bed additive manufacturing device during operation of the first powder bed additive manufacturing device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically depicts an additive manufacturing apparatus.

FIG. 2 shows an example working chamber and gas analyzer for the additive manufacturing apparatus of FIG. 1.

FIG. 3 shows an example additive manufacturing system with a plurality of devices and contamination detection systems.

DETALLDE DESCRIPTION

An additive manufacturing system includes a build chamber, a powder bed deposition apparatus, and a broad spectrum gas analyzer or sensor which can be tailored to the type of deposition apparatus.

FIG. 1 is a schematic of an example additive manufacturing system 10 with build chamber 12. Build chamber 12 contains one or more devices that are capable of producing solid freeform objects by additive manufacturing. Non-limiting embodiments of such devices include those which fabricate objects by direct laser sintering (DLS) manufacturing, direct laser melting (DLM) manufacturing, selective laser sintering (SLS) manufacturing, selective laser melting (SLM) manufacturing, laser engineering net shaping (LENS) manufacturing, electron beam melting (EBM) manufacturing, direct metal deposition (DMD) manufacturing, and others known in the art. One non-limiting example of a suitable device is shown in more detail in FIG. 2.

In the example shown, main controller 14 can cooperate with and/or manage one or more individual controllers. Manufacturing controller 16 may allow fully automatic, semi-automatic, or manual control of additive manufacturing devices in manufacturing chamber 12.
Additive manufacturing system 10 can also include contamination detection system 18 in communication with build chamber 12. Contamination detection system 18 includes contamination detector 19 and analyzer/controller 20. Contamination analyzer/controller 20 can be a separate controller, or one or more functions of analyzer/controller 20 can be incorporated into main controller 14 and/or manufacturing controller 16. Alternatively, one or more functions of analyzer/controller 20 can be incorporated into an environmental controller (not shown) used to manage the environment in build chamber 12. In certain embodiments, a protective inert partial pressure atmosphere, or vacuum atmosphere may be required in build chamber 12 to produce flaw free solid freeform objects having structural integrity, dimensional accuracy, and surface finish.

Contamination detection system 18 can operate and provide relevant contamination information effectively in real time. For example, contamination detector 19 can periodically receive samples of gases 22 during a build process. These gases can include byproducts generated during operation of one or more powder bed build devices disposed in build chamber 12. Generally, positive pressure exhaust gases 22 or other build process byproducts are discharged from build chamber 12. Detector 19 samples gases 22 and communicates corresponding signals to analyzer/controller 20. In certain embodiments, detector 19 comprises at least one mass spectral gas detector capable of detecting at least one of a plurality of gases indicative of powder contamination in build chamber 12. Analyzer/controller 20 receives one or more resulting powder contamination signals generated by detector(s) 19. Analyzer/controller 20 then evaluates the resulting powder contamination signals to identify constituent components of gases 22, including those indicative of powder contamination.

Analyzer/controller 20 can also analyze and compile data reflecting one or more aspects of identified powder contamination. These can include, for example, gas composition, contaminant composition, peak magnitude of contamination, and cumulative magnitude of contamination. Relevant contaminant data from analyzer/controller 20 can be shared with main controller 14 and/or manufacturing controller 16. In combination with deposition location data from controllers 14 and/or 16, contaminant data can be used to evaluate the expected quality of the finished object during the build process effectively in real time. Thus in some cases, the data is evaluated and a determination of quality can be made before a build process is fully completed. This reduces wasted processing time and excess scrap caused by the building of solid
freeform objects with unreparable defects that are not detected until the component can be removed from build chamber 12.

FIG. 2 shows a detailed example of a powder-bed build device 24 disposed in build chamber 12 and in communication with contamination detection system 18. A non-limiting example embodiment includes SLS device 24 housed in build chamber 12, comprises powder storage chamber 25, build platform 26, energy beam apparatus 28, and exhaust 30. During operation of SLS device 24, raw material powder 32 is fed upward by piston 34 and is spread over build surface 36 by roller or recoater blade 38. After powder 32 is spread onto build surface 36, energy beam generator 26 is activated to direct a laser or electron beam 40. Beam 40 can be steered using a number of different apparatus, such as but not limited to mirror 41, so as to sinter selective areas of powder 32. The sintered powder forms a single build layer 42 of solid object 44 adhered to the underlying platform (or a preceding build layer) according to a computer model of object 44 stored in an STL memory file. Roller or recoater 38 is returned to a starting position, piston 34 advances to expose another layer of powder, and build platform 26 indexes down by one layer thickness and the process repeats for each successive build surface 36 until solid freeform object 44 is completed. SLS device 24 is only one example of solid freeform manufacturing apparatus and is not meant to limit the invention to any single machine known in the art.

To test for powder contamination in real time, additive manufacturing system 10 also includes sample port 50 connected to a build chamber (e.g., build chamber 12). Sample port 50 can be connected to an exhaust port or exhaust line, or to a part of the environmental control system (not shown). Build chamber 12 can then be selectively placed into communication with contamination detection system 18, such as by a solenoid operated valve 52. Contamination detector(s) 19 then provide signals to contamination analyzer/ controller 20 as noted above. Contamination analyzer/controller 20, which can be a broad spectrum, software-based residual gas analyzer, can be customized to identify and analyze particular signals indicative of powder contamination in build chamber 12. Example compounds indicative of powder contamination include, but are not limited to, carbonaceous gases, nitrogen, hydrogen, and combinations thereof. Alternatively, several suitable commercially available gas analyzer packages are available from vendors, such as Inficon, Inc. of East Syracuse, New York, U.S.A., and Hiden Analytical, Inc. of Livonia, Michigan, U.S.A. These and other commercially available software modules can also be adapted to measure, record, and report the relevant data.
With sample port 50 providing communication between chamber 12 and contamination detection system 18, localized powder contamination can be detected in situ. Current powder bed manufacturing systems are not able to test for powder contamination during the build process. While some systems include a general oxygen sensor to detect infiltration of atmospheric oxygen into the chamber, an oxygen sensor cannot detect other gases indicative of powder contamination that could cause defects in the freeform object. Testing bulk powder before it is placed in the feed chamber or platform does not account for bad sampling techniques, nor is there any way to identify powder contamination occurring between the time of bulk sampling and powder deposition. In some instances, sacrificial test bars can be built up on the same build plate as the freeform object, and then examined for signs of contamination. However, test bars require that the build process be completed before contamination can be detected. Neither oxygen sensors nor test bars are able to determine quantity, type, and location of localized powder contamination during a build.

Manufacturing controller 16, adapted to operate powder bed additive manufacturing device 24, and contaminant controller/analyzer 20, adapted to operate contamination detection system 18 cooperate to identify the location and extent of powder contamination in the object as it is being built. This allows repairability of the object to be evaluated throughout the build process. This can be done in addition to existing bulk powder quality controls performed prior to feeding powder 32 into the additive manufacturing device (e.g., powder storage chamber 25 of powder bed build device 24).

When one or more gases indicative of contamination are detected, an approximate or exact location of the defect on object 44 can be determined by correlating the timing of detection to the most recent position(s) of the energy beam and the stage of the build platform. Severity of powder contamination can also be determined by the duration and/or peak levels of the relevant signals sent to contaminant controller/analyzer 20.

In one example, when contamination is detected, XY location data of the energy beam can be determined from manufacturing controller 14 and/or main controller 16. Z position data can be determined from the relative height of build platform 26. Data from contaminant analyzer/controller 20 is combined with positional coordinate data to record and/or communicate details of a potential defect in object 44 for later resolution.

Any of controllers 14, 16, 20 can also be configured to record and analyze cumulative and peak contamination data, and compare that data to various thresholds. Since different gases may be indicative of different combinations of contaminants and
raw materials, and since each potential contaminant can have varying effects on the finished object, controllers 14, 16, 20 can also be configured to treat the detected gases differently.

Information about potential contamination locations and one or more aspects of the powder contamination can be combined to evaluate repairability, either alone or in aggregate. The evaluation can be made in different ways. In one example, an overall determination is made on whether the type and extent of contamination make the part (a) usable; (b) repairable; or (c) unrepairable. Additionally or alternatively, the evaluation can be made using a numeric scale (e.g., 1-10 or 1-100), with specified ranges of the scale corresponding to various real-time evaluations of part quality and/or repairability. In response to an evaluation of unrepairability, the build process can be terminated prior to completion. When an unrepairability determination can be made before the build process is complete, this saves processing time, effort, and reduces scrap.

For each potential contaminant, there may be multiple instantaneous, peak, and/or cumulative thresholds which will trigger a corresponding response by additive manufacturing system. For example, a first contaminant such as hydrogen may be detected in minimal quantities. Breaching a first instantaneous contaminant threshold during the build process may be indicative of small localized areas of contamination. Isolated events of this contamination may be deemed insignificant by the system and a response may be deferred until more contamination is detected. The first contaminant may periodically exceed a second higher instantaneous threshold for less than a maximum time duration. In certain instances, the object may be deemed damaged but repairable, barring the finding of further moderate defects by contamination detection system 18. In certain embodiments, the build process can be interrupted to perform a suitable repair process, if applicable. The repair process can include operating energy beam 26 or a separate subtractive device (not shown) in such a way so as to burn off or otherwise remove the potentially contaminated region. The build process can then be repeated in the repaired area before resuming the standard build. Alternatively, one or more contamination locations can be mapped (e.g., by saving contamination coordinates and other details in a data file) for later inspection, evaluation, and localized repairs.

In certain embodiments, real-time results of contamination detected by system 18 will exceed a cumulative level, or will exceed a peak threshold level, duration, or combination thereof during the build process. In such instances, the object can be deemed unrepairable, and any of controllers 14, 16, 20 can then terminate the build
process. Unlike the use of test bars, this arrangement allows a build process subject to powder contamination to be abandoned before running to completion, thereby saving efforts in processing effort, time, materials, and scrap. Such an arrangement is useful in a high level testing or production environment.

FIG. 3 shows an example additive manufacturing system 110 suitable for scaling into pilot or production environments. Build chamber 112 contains multiple powder bed build devices 124A, 124B, 124C, 124D, each capable of producing solid freeform objects by additive manufacturing as described with respect to FIGS. 1 and 2. In the example of FIG. 3, main controller 114 can communicate with and/or manage one or more manufacturing controllers 116, each of which can allow fully automatic, semi-automatic, or manual control of additive manufacturing devices 124A–124D in build chamber 112.

Additive manufacturing system 110 can also include one or more contamination detection systems 118A, 118B. Similar to FIGS. 1 and 2, each contamination detection system 118A, 118B can include contamination detector 119 and analyzer/controller 120 which cooperate with main controller 114 and/or manufacturing controllers 116A, 116B to detect contamination during operation of one or more powder bed build devices 124A–124D.

As shown in FIG. 3, there are four powder bed build devices 124A–124D. Each contamination analyzer/controller 120 can be a separate controller, or can be incorporated into main controller 114. Alternatively, analyzer/controller 120 can be incorporated into an environmental controller (not shown) used to manage the environment in build chambers 112.

Contamination detectors 119A, 119B can receive atmospheric gases and byproducts from operation of each powder bed build device 124A–124D. Detectors 119A, 119B, arranged in series or parallel, selectively receive sampled exhaust gases 122A–122D and each then communicate corresponding data signals to respective analyzer/controllers 120A, 120B. For simplicity of illustration, individual sample ports 150A–150D are shown leading directly to contamination detectors 119A, 119B, while corresponding exhaust lines, sample port valves, and other ancillary elements have been omitted.

Similar to FIGS. 1 and 2, signals from contamination detectors 119A, 119B can be evaluated by one or both analyzers/controllers 120A, 120B. Data collected or created by analyzers/controllers 120A, 120B can include the types and concentrations of contaminant gases found. Contaminant data can then be communicated to main controller
114 and/or manufacturing controller 116 along with positional data corresponding to the build position at the time contamination was detected by system(s) 118A, 118B. The contaminant data can be combined with positional coordinates for the respective powder bed build device 124A–124D experiencing contamination. In combination with deposition location data from controllers 114 and/or 116, contaminant data can be used to make a determination of the expected quality of the finished part. In some cases, a determination is made before each build process is fully completed.

In FIG. 3, powder bed build devices 124A–124D are shown in a single build chamber 112, while each contamination detection system 118A, 118B is shown in a separate location. In alternative embodiments, powder bed build devices can be disposed in individual build chambers, or there may be a number of powder bed build devices different from four in each build chambers 112, as required by design. While only two contamination detection systems 118A, 118B are shown, others may be added or subtracted as necessary.

**Discussion of Possible Embodiments**

The following are non-exclusive descriptions of possible embodiments of the present invention:

An additive manufacturing system comprises a build chamber, a powder bed additive manufacturing device disposed in the build chamber, and a powder contamination detection system. The powder contamination detection system is in communication with an atmosphere in the build chamber.

The system of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing additive manufacturing system, wherein the build chamber is maintained under vacuum.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the build chamber is maintained with an inert partial pressure atmosphere.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the powder contamination detection system comprises at least one mass spectral gas detector capable of detecting at least one of a plurality of gases indicative of powder contamination in the build chamber.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the at least one mass spectral gas detector produces at least one resulting powder...
contamination signal in response to detecting the at least one gas indicative of powder contamination in the build chamber.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the powder contamination detection system further comprises an analyzer/controller module including broad spectrum gas analyzer software adapted to process the at least one powder contamination signal to identify one or more aspects of the powder contamination in the build chamber.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the one or more identified aspects are selected from a group consisting of: gas composition, contaminant composition, peak magnitude of contamination, and cumulative magnitude of contamination.

A further embodiment of any of the foregoing additive manufacturing systems, further comprising a manufacturing controller adapted to operate the powder bed additive manufacturing device during a build process, wherein, upon detection of powder contamination by the powder contamination detection system, the manufacturing controller is adapted to provide spatial coordinates of a build location targeted by the powder bed additive manufacturing device, the spatial coordinates corresponding to a potential contamination location.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the potential contamination location and the one or more aspects of the powder contamination are combined in real time to evaluate repairability of an object being formed in the build chamber during the build process.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the at least one gas indicative of powder contamination in the build chamber is selected from a group consisting of: hydrogen, nitrogen, carbonaceous gases, and combinations thereof.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the powder bed additive manufacturing apparatus is selected from a group consisting of: a direct laser sintering apparatus; a direct laser melting apparatus; a selective laser sintering apparatus; a selective laser melting apparatus; a laser engineered net shaping apparatus; an electron beam melting apparatus; and a direct metal deposition apparatus.

An additive manufacturing system comprises a plurality of powder bed additive manufacturing devices disposed in at least one build chamber. A plurality of sample
ports are connected to the at least one build chamber. Each sample port is separately in communication with a protective atmosphere proximate each of the plurality of powder bed additive manufacturing devices. A powder contamination detection system is in communication with the plurality of sample ports.

The system of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing additive manufacturing system, further comprising a manufacturing controller adapted to operate at least one of the plurality of powder bed additive manufacturing devices during a build process, the manufacturing controller adapted to provide spatial coordinates of a build location targeted by the at least one powder bed additive manufacturing device.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the powder contamination detection system comprises a first mass spectral gas detector in selective communication with at least one of the sample ports, the first mass spectral gas detector capable of detecting at least one of a plurality of gases indicative of powder contamination in at least one of the plurality of powder bed additive manufacturing devices; and an analyzer/controller module including broad spectrum gas analyzer software.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the analyzer/controller module is adapted to receive at least one powder contamination signal from the first mass spectral gas detector in response to detecting the at least one gas indicative of powder contamination in the at least one powder bed additive manufacturing device.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the analyzer/controller module is adapted to process the at least one powder contamination signal to identify one or more aspects of powder contamination, the one or more aspects selected from a group consisting of: gas composition, contaminant composition, peak magnitude of contamination, and cumulative magnitude of contamination.

A further embodiment of any of the foregoing additive manufacturing systems, wherein a potential contamination location and the one or more aspects of the powder contamination are combined to evaluate repairability of an object during the build process.
A further embodiment of any of the foregoing additive manufacturing systems, wherein the at least one gas indicative of powder contamination in the build chamber is selected from a group consisting of: hydrogen, nitrogen, carbonaceous gases, and combinations thereof.

A further embodiment of any of the foregoing additive manufacturing systems, wherein the powder contamination detection system comprises a second mass spectral gas detector in selective communication with at least one of the sample ports, the second mass spectral gas detector capable of detecting at least one of a plurality of gases indicative of powder contamination in at least one of the plurality of powder bed additive manufacturing devices.

A method of manufacturing a solid freeform object, the method comprises operating a first powder bed additive manufacturing device disposed in a build chamber. A first set of byproducts is generated from operation of the first powder bed additive manufacturing device. At least one of the first set of byproducts is communicated to a powder bed contamination detection system. A powder bed contamination detection system is operated to detect contamination of powder used in the first powder bed additive manufacturing device during operation of the first powder bed additive manufacturing device.

The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, steps, configurations and/or additional components:

A further embodiment of the foregoing method, wherein the step of operating the powder bed contamination detection system comprises: detecting at least one gas indicative of powder contamination in the build chamber; producing at least one resulting powder contamination signal in response to detecting the at least one gas; and processing the at least one powder contamination signal to identify one or more aspects of the powder contamination in the build chamber.

A further embodiment of any of the foregoing methods, wherein the one or more identified aspects are selected from a group consisting of: gas composition, contaminant composition, peak magnitude of contamination, and cumulative magnitude of contamination.

A further embodiment of any of the foregoing methods, wherein the at least one gas indicative of powder contamination in the build chamber is selected from a group consisting of: hydrogen, nitrogen, carbonaceous gases, and combinations thereof.
A further embodiment of any of the foregoing methods, further comprising: upon
detection of powder contamination in the build chamber, recording spatial coordinates of
a build location targeted by the at least one powder bed additive manufacturing device,
the recorded spatial coordinates corresponding to a potential contamination location.

A further embodiment of any of the foregoing methods, further comprising:
evaluating repairability of an object during the build process based on a potential
contamination location and one or more aspects of powder contamination.

A further embodiment of any of the foregoing methods, further comprising: in
response to a real-time evaluation of unrepairability, terminating the build process prior to
completion.

Although the present invention has been described with reference to preferred
embodiments, workers skilled in the art will recognize that changes may be made in form
and detail without departing from the spirit and scope of the invention.
CLAIMS:
1. An additive manufacturing system comprising:
   a build chamber;
   a powder bed additive manufacturing device disposed in the build
   chamber; and
   a powder contamination detection system in communication with an
   atmosphere in the build chamber.
2. The additive manufacturing system of claim 1, wherein the build chamber is
   maintained under vacuum.
3. The additive manufacturing system of claim 1, wherein the build chamber is
   maintained with an inert partial pressure atmosphere.
4. The additive manufacturing system of claim 1, wherein the powder contamination
   detection system comprises:
   at least one mass spectral gas detector capable of detecting at least one of a
   plurality of gases indicative of powder contamination in the build
   chamber.
5. The additive manufacturing system of claim 4, wherein the at least one mass
   spectral gas detector produces at least one resulting powder contamination signal in
   response to detecting the at least one gas indicative of powder contamination in the build
   chamber.
6. The additive manufacturing system of claim 5, wherein the powder contamination
   detection system further comprises:
   an analyzer/controller module including broad spectrum gas analyzer
   software adapted to process the at least one powder contamination
   signal to identify one or more aspects of the powder contamination
   in the build chamber.
7. The additive manufacturing system of claim 6, wherein the one or more identified
   aspects are selected from a group consisting of: gas composition, contaminant
   composition, peak magnitude of contamination, and cumulative magnitude of
   contamination.
8. The additive manufacturing system of claim 6, further comprising:
   a manufacturing controller adapted to operate the powder bed additive
   manufacturing device during a build process;
wherein, upon detection of powder contamination by the powder contamination detection system, the manufacturing controller is adapted to provide spatial coordinates of a build location targeted by the powder bed additive manufacturing device, the spatial coordinates corresponding to a potential contamination location.

9. The additive manufacturing system of claim 8, wherein the potential contamination location and the one or more aspects of the powder contamination are combined in real time to evaluate repairability of an object being formed in the build chamber during the build process.

10. The additive manufacturing system of claim 5, wherein the at least one gas indicative of powder contamination in the build chamber is selected from a group consisting of: hydrogen, nitrogen, carbonaceous gases, and combinations thereof.

11. The additive manufacturing system of claim 1, wherein the powder bed additive manufacturing apparatus is selected from a group consisting of:

- a direct laser sintering apparatus;
- a direct laser melting apparatus;
- a selective laser sintering apparatus;
- a selective laser melting apparatus;
- a laser engineered net shaping apparatus;
- an electron beam melting apparatus; and
- a direct metal deposition apparatus.

12. An additive manufacturing system comprising:

- a plurality of powder bed additive manufacturing devices disposed in at least one build chamber;
- a plurality of sample ports connected to the at least one build chamber, each sample port separately in communication with a protective atmosphere proximate each of the plurality of powder bed additive manufacturing devices; and
- a real-time powder contamination detection system in communication with the plurality of sample ports.

13. The additive manufacturing system of claim 12, further comprising:

- a manufacturing controller adapted to operate at least one of the plurality of powder bed additive manufacturing devices during a build process, the manufacturing controller adapted to provide spatial
coordinates of a build location targeted by the at least one powder bed additive manufacturing device.

14. The additive manufacturing system of claim 12, wherein the powder contamination detection system comprises:

   a first mass spectral gas detector in selective communication with at least one of the sample ports, the first mass spectral gas detector capable of detecting at least one of a plurality of gases indicative of powder contamination in at least one of the plurality of powder bed additive manufacturing devices; and

   an analyzer/controller module including broad spectrum gas analyzer software.

15. The additive manufacturing system of claim 14, wherein the analyzer/controller module is adapted to receive at least one powder contamination signal from the first mass spectral gas detector in response to detecting the at least one gas indicative of powder contamination in the at least one powder bed additive manufacturing device.

16. The additive manufacturing system of claim 15, wherein the analyzer/controller module is adapted to process the at least one powder contamination signal to identify one or more aspects of powder contamination, the one or more aspects selected from a group consisting of: gas composition, contaminant composition, peak magnitude of contamination, and cumulative magnitude of contamination.

17. The additive manufacturing system of claim 15, wherein a potential contamination location and the one or more aspects of the powder contamination are combined to evaluate repairability of an object during the build process.

18. The additive manufacturing system of claim 14, wherein the at least one gas indicative of powder contamination in the build chamber is selected from a group consisting of: hydrogen, nitrogen, carbonaceous gases, and combinations thereof.

19. The additive manufacturing system of claim 13, wherein the powder contamination detection system comprises:

   a second mass spectral gas detector in selective communication with at least one of the sample ports, the second mass spectral gas detector capable of detecting at least one of a plurality of gases indicative of powder contamination in at least one of the plurality of powder bed additive manufacturing devices.

20. A method of manufacturing a solid freeform object, the method comprising:
operating a first powder bed additive manufacturing device disposed in a
build chamber;
generating a first set of byproducts from operation of the first powder bed
additive manufacturing device;
communicating at least one of the first set of byproducts to a powder bed
contamination detection system;
operating the powder bed contamination detection system to detect
contamination of powder used in the first powder bed additive
manufacturing device during the step of operating the first powder
bed additive manufacturing device.

21. The method of claim 20, wherein the step of operating the powder bed
contamination detection system comprises:
detecting at least one gas indicative of powder contamination in the build
chamber;
producing at least one resulting powder contamination signal in response
to detecting the at least one gas; and
processing the at least one powder contamination signal to identify one or
more aspects of the powder contamination in the build chamber.

22. The method of claim 21, wherein the one or more identified aspects are selected
from a group consisting of: gas composition, contaminant composition, peak magnitude
of contamination, and cumulative magnitude of contamination.

23. The method of claim 21, wherein the at least one gas indicative of powder
contamination in the build chamber is selected from a group consisting of: hydrogen,
nitrogen, carbonaceous gases, and combinations thereof.

24. The method of claim 20, further comprising:
upon detection of powder contamination in the build chamber, recording
spatial coordinates of a build location targeted by the at least one
powder bed additive manufacturing device, the recorded spatial
coordinates corresponding to a potential contamination location.

25. The method of claim 24, further comprising:
evaluating repairability of an object during the build process based on a
potential contamination location and one or more aspects of
powder contamination.

26. The method of claim 25, further comprising:
in response to a real-time evaluation of unrepairability, terminating the build process prior to completion.
FIG. 1
A. CLASSIFICATION OF SUBJECT MATTER
B22D 2/00(2006.01)i, G01N 27/62(2006.01)i, B22D 23/06(2006.01)i, B22F 1/00(2006.01)i, B22F 3/105(2006.01)i

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)
B22D 2/00; B29C 67/00; H01L 21/02; B01D 59/44; H01J 49/00; G01J 3/30; B29C 35/08; B22F 3/105; G01N 27/62; B22D 23/06; B22F 1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: contamination, sensor, detector, additive manufacturing, three-dimensional, sample, chamber, and gas

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 2012-0139166 A1 (ABE et al.) 07 June 2012 See paragraphs [0040]-[0045],[0056]-[0059],[0063], claims 1,5,6, and figure 15.</td>
<td>1-3,11,20-21,23-26</td>
</tr>
<tr>
<td>Y</td>
<td>KR 10-2006-0042741 A (SAMSUNG ELECTRONICS CO., LTD.) 15 May 2006 See abstract, page 2, lines 20-48, and figure 1.</td>
<td>4-10,12-19,22</td>
</tr>
<tr>
<td>Y</td>
<td>US 8378293 B1 (QUIMBY et al.) 19 February 2013 See abstract, column 10, lines 1-29, column 4, lines 4-51, and figure 1.</td>
<td>4-10,12-19,22</td>
</tr>
<tr>
<td>A</td>
<td>US 6757061 B2 (POWELL, GARY) 29 June 2004 See abstract, column 2, lines 1-40, and claims 1,20.</td>
<td>1-26</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C. See patent family annex.

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search
14 August 2014 (14.08.2014)

Date of mailing of the international search report
18 August 2014 (18.08.2014)

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongro-ro, Seo-gu, Daepyeong Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
LEE, Chang Ho
Telephone No. +82-42-481-8398

Form PCT/ISA/210 (second sheet) (July 2009)
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 2012-0139166 A1</td>
<td>07/06/2012</td>
<td>DE 112004000301 B4</td>
<td>20/05/2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 112004000301 T5</td>
<td>26/01/2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2004-277878 A</td>
<td>07/10/2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 8562897 B2</td>
<td>22/10/2013</td>
</tr>
<tr>
<td>KR 10-2006-0042741 A</td>
<td>15/05/2006</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>US 8378293 B1</td>
<td>19/02/2013</td>
<td>CN 102998362 A</td>
<td>27/03/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE102012214217 A1</td>
<td>14/03/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2013-061324 A</td>
<td>04/04/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2013-0062515 A1</td>
<td>14/03/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 8513593 B2</td>
<td>20/08/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 101541511 B</td>
<td>21/12/2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 11200800027 T5</td>
<td>10/06/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 202008017990 U1</td>
<td>10/02/2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 04238938 B2</td>
<td>18/03/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 05027780 B2</td>
<td>19/09/2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2009-078558 A</td>
<td>16/04/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2010-0006228 A1</td>
<td>14/01/2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 8070474 B2</td>
<td>06/12/2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 2008-146920 A1</td>
<td>04/12/2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 1489685 A</td>
<td>14/04/2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 1489685 C0</td>
<td>24/01/2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2004-515066 A</td>
<td>20/05/2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TW 530156 A</td>
<td>01/05/2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 6538734 B2</td>
<td>25/03/2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 7019829 B2</td>
<td>28/03/2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 02-044687 A3</td>
<td>27/02/2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 02-44687 A2</td>
<td>06/06/2002</td>
</tr>
</tbody>
</table>