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(54) **Title:**
POWDER FEEDING NOZZLE, ASSEMBLY AND METHOD FOR LASER AIDED ADDITIVE MANUFACTURING

(57) **Abstract:**
15 POWDER FEEDING NOZZLE, ASSEMBLY AND METHOD FOR LASER AIDED ADDITIVE MANUFACTURING 5 ABSTRACT An inner nozzle portion for a powder feeding nozzle is provided capable of being coaxially arranged within an outer nozzle portion of the powder feeding nozzle, the inner 10 nozzle portion including: an upper section having a plurality of defined shapes on a surface thereof configured to manipulate a stream of powder flowing across said surface of the upper section; and a lower section having a substantially flat conical surface for forming a channel between said substantially flat conical surface and an inner surface of the outer nozzle portion when the inner nozzle portion is coupled to the outer nozzle 15 portion, the inner nozzle portion being in communication with a powder inlet for receiving the stream of powder to flow across the surface of the upper section through the channel and towards a powder discharge outlet of the channel. There is also provided a powder feeding nozzle including the inner nozzle portion being coaxially arranged within the outer nozzle portion, an assembly and a method for laser aided additive manufacturing 20 including the powder feeding nozzle FIG. 2

POWDER FEEDING NOZZLE, ASSEMBLY AND METHOD FOR LASER AIDED ADDITIVE MANUFACTURING

ABSTRACT

An inner nozzle portion for a powder feeding nozzle is provided capable of being coaxially arranged within an outer nozzle portion of the powder feeding nozzle, the inner nozzle portion including: an upper section having a plurality of defined shapes on a surface thereof configured to manipulate a stream of powder flowing across said surface of the upper section; and a lower section having a substantially flat conical surface for forming a channel between said substantially flat conical surface and an inner surface of the outer nozzle portion when the inner nozzle portion is coupled to the outer nozzle portion, the inner nozzle portion being in communication with a powder inlet for receiving the stream of powder to flow across the surface of the upper section through the channel and towards a powder discharge outlet of the channel. There is also provided a powder feeding nozzle including the inner nozzle portion being coaxially arranged within the outer nozzle portion, an assembly and a method for laser aided additive manufacturing including the powder feeding nozzle

FIG. 2

POWDER FEEDING NOZZLE, ASSEMBLY AND METHOD FOR LASER AIDED ADDITIVE MANUFACTURING

FIELD OF INVENTION

The present invention generally relates to laser aided additive manufacturing, and more particularly to a powder feeding nozzle, as well as related components thereof, including the inner nozzle portion, and the associated assembly and method including the powder feeding nozzle for laser aided additive manufacturing.

BACKGROUND

Laser aided additive manufacturing (LAAM) (also known as laser cladding) is a process in which a laser beam is used as a heat source to melt a material, e.g., in the form of powder, onto a substrate or a workpiece. This process can be used in diverse industries for repairing damaged components, improving or modifying the surface of a component, or the direct manufacturing of three-dimensional components. For example, typical track dimensions of macro-laser claddings are in the range of about 0.2 to 3 mm thick and about 0.5 to 5 mm wide. In cases where macro-laser cladding processes and equipment may be unsuitable for the repair or fabrication of small parts (which tend to be prone to heat damage), micro-LAAM (µ-LAAM) can be used to more precisely repair damaged parts or for the direct manufacture of tiny three-dimensional components. For example, typical track width and height in µ-LAAM can be less than 300 microns (µm) and 100 µm, respectively, and a much finer powder focus (for example, smaller than 500 µm) is required to obtain a desired resolution of the clad track.

With both macro-LAAM and micro-LAAM where the additive material is in the form of powder, it is desirable to provide a powder feeding nozzle that discharges powder with a stable powder jet having a powder focus at a predetermined standoff. However, conventional powder feeding nozzles may not satisfactorily achieve a stable powder jet, especially in the case of micro-LAAM due to the much finer powder focus required. Accordingly, the present invention seeks to provide a powder feeding nozzle, and the associated apparatus and method including the powder feeding nozzle, which overcome, or at least ameliorate, the above-mentioned problems of the conventional art.

SUMMARY

According to a first aspect of the present invention, there is provided an inner nozzle portion for a powder feeding nozzle capable of being coaxially arranged within an outer nozzle portion of the powder feeding nozzle, the inner nozzle portion comprising:

an upper section having a plurality of defined shapes on a surface thereof configured to manipulate a stream of powder flowing across said surface of the upper section; and

a lower section having a substantially flat conical surface for forming a channel between said substantially flat conical surface and an inner surface of the outer nozzle portion when the inner nozzle portion is coupled to the outer nozzle portion, the inner nozzle portion being in communication with a powder inlet for receiving the stream of powder to flow across the surface of the upper section through the channel and towards a powder discharge outlet of the channel.

Preferably, the plurality of defined shapes comprises a plurality of protrusions.

Alternatively, the plurality of defined shapes comprises a plurality of holes, each hole configured for supporting a protrusion such that the protrusion protrudes from the surface of the upper section.

Preferably, the upper section comprises a recessed portion, and the plurality of defined shapes is arranged on the recessed portion.

Preferably, the recessed portion has a generally concave profile and extends circumferentially around the upper section.

Preferably, the lower portion has a generally conical profile having a narrower tip portion at the powder discharge outlet.

Preferably, the inner nozzle portion comprises an opening extending along its longitudinal axis in communication with a laser outlet at the narrower tip portion, the opening forming a passage for a laser beam.

Preferably, the channel is configured to discharge the stream of powder from the powder discharge outlet with a powder focus intersecting the laser beam at a predetermined distance from the narrower tip portion.

Preferably, the plurality of defined shapes is arranged in staggered rows on the surface of the upper section for promoting uniform mixing of the powder.

Preferably, the plurality of protrusions is formed integrally with the upper section.

Alternatively, the plurality of protrusions is releasably coupled to the surface of the upper section.

Preferably, the plurality of protrusions is generally hemispherical in shape.

According to a second aspect of the present invention, there is provided a powder feeding nozzle, comprising:

an inner nozzle portion according to the above-mentioned first aspect of the present invention; and

an outer nozzle portion, wherein the inner nozzle portion is coaxially arranged within the outer nozzle portion for defining said channel therebetween in communication with the powder discharge outlet.

Preferably, the outer nozzle portion comprises the powder inlet arranged to supply powder directly to the surface of the upper section of the inner nozzle portion.

Preferably, a gap of the channel at the powder discharge outlet is arranged is in the range of about 0.1 mm to 1 mm.

According to a third aspect of the present invention, there is provided an assembly for laser aided additive manufacturing, the assembly comprises:

a body configured to be coupled to a controller and for receiving a laser beam;

a powder feeding nozzle including the inner nozzle portion according to the above-mentioned first aspect of the present invention and an outer nozzle portion, wherein the inner nozzle portion is coaxially arranged within the outer nozzle portion for defining said channel therebetween in communication with the powder discharge outlet, and the powder feeding nozzle is coupled to an end of the body, and

adjustment mechanisms on the body for aligning the powder feeding nozzle with respect to the laser beam.

According to a fourth aspect of the present invention, there is provided a method for laser aided additive manufacturing, the method comprises:

arranging a powder feeding nozzle for receiving a laser beam, the powder feeding nozzle including the inner nozzle portion according to the above-mentioned first aspect of the present invention and an outer nozzle portion, wherein the inner nozzle portion is coaxially arranged within the outer nozzle portion for defining said channel therebetween in communication with the powder discharge outlet;

directing the laser beam output from the powder feeding nozzle towards a substrate for generating a melt pool on the substrate; and

feeding powder through the powder discharge outlet of the powder feeding nozzle to the melt pool for forming a desired clad on the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 depicts a perspective view of an assembly for laser aided additive manufacturing ("LAAM") including a powder feeding nozzle according to a first embodiment of the present invention;

Figure 2 depicts a cross-sectional side view of the powder feeding nozzle according to the first embodiment;

Figure 3 depicts a front perspective view of the inner nozzle portion of the powder feeding nozzle according to the first embodiment;

Figure 4 depicts front and perspective cross-sectional views of a powder feeding nozzle according to a second embodiment of the present invention;

Figures 5 and 6 depict a front view of the inner nozzle portion of the powder feeding nozzle according to the second embodiment;

Figure 7 depicts an exemplary flow diagram of a method of LAAM according to an embodiment of the present invention.

DETAILED DESCRIPTION

Figure 1 depicts a perspective view of a powder feeding nozzle assembly (hereinafter "nozzle assembly") 100 for laser aided additive manufacturing ("LAAM") according to a first embodiment of the present invention. The nozzle assembly 100 is illustrated generally, and additional features and components can be implemented into or removed from the nozzle assembly 100 as necessary or desired. The nozzle assembly 100 comprises a body 102, a powder feeding nozzle (hereinafter nozzle) 104 coupled to an end of the body 102, and an adapter 106 for mounting the body 102 to an axis 108 of a controller (not shown) at an opposite end of the body 102. The controller is operable to guide the nozzle 104 across a substrate, a surface or other workpiece 109 for various purposes such as repairing damaged components, improving or modifying the surface of a component, or the direct manufacturing of three-dimensional components. For example, the controller may be a computer numerical control (CNC) machine or robot. CNC machines and robots are well known in the art and thus need not be described in detail herein.

The body 102 is preferably a hollow tubular member for providing a passage through which a laser beam 110 generated by a laser source 111 can travel to the nozzle 104. The nozzle 104 has a central axial opening coaxially aligned with the axis of the laser beam 110 passing through the body 102. In this regard, preferably, the nozzle assembly 100 further comprises adjustment mechanism 112 installed on the body 102 capable of adjusting the nozzle 104 in the X, Y and/or Z directions for aligning the central axial opening of the nozzle 104 with respect to the laser beam 110. For example as shown in Figure 1, the adjustment mechanism 112 may comprises a first set of screws 112a for adjusting the nozzle 104 in the X direction, a second set of screws 112b for adjusting the nozzle 104 in the Y direction, and a third set of screws 112c for adjusting the nozzle 104 in the Z direction. In the example, each set of screws comprises two screws located on opposing portions of the body 102 configured to adjust the nozzle 104 in the respective direction when turned. It will be appreciated by a person skilled in the art that the adjustment mechanism 112 is not limited to that shown in Figure 1 and various other types of adjustment mechanisms 112 or implementations may be applied without deviating from the scope of the present invention.

The nozzle 104 is configured to discharge powder with a substantially stable powder jet having a powder focus which intersects with the laser beam 110 such that the laser beam 110 can melt the discharged powder to form a melt pool 114 on the substrate 109. As non-limiting examples, the powder may be in the form of metal powder, ceramic powder, carbide power, or a mixture thereof. The stable powder jet provides a constant feed of powder into the melt pool 114. The powder focus refers to the point or portion where the powder discharged from the nozzle 104 converges. The standoff refers to the displacement of the powder focus to the tip end (i.e., the powder discharging end) 118 of the nozzle 104. Configuring the nozzle 104 advantageously encourages uniform flow or distribution of the powder within the nozzle 104 improving the stability and quality of the powder being discharged from the nozzle 104, thereby forming a substantially stable powder jet. In this regard, details of the nozzle 104 will now be described below.

Figure 2 depicts a cross-sectional side view of the nozzle 104 according to the first embodiment of the present invention coupled to the body 102 of the assembly 100. The nozzle 104 comprises an inner nozzle portion 202 and an outer nozzle portion 204. The inner nozzle portion 202 is, or capable of being, coaxially arranged within the outer nozzle portion 204 for defining a channel 206 therebetween in communication with a powder discharge outlet 208. The inner nozzle portion 202 comprises a lower section 210 having a substantially flat conical surface 212 for forming the channel 206 between the substantially flat conical surface 212 and an inner surface 213 of the outer nozzle portion 204 when the inner nozzle portion 202 is coupled to the outer nozzle portion 204. The upper section 214 has a plurality of defined shapes 216 on a surface 218 thereof configured to manipulate a stream of powder flowing across the surface 218 of the upper section 214 towards the channel 206. Such manipulation of the stream of powder at the upper section 214 facilitates homogeneous mixing and distribution of the powder resulting in a more uniform flow of powder around the circumference of the channel 206, which leads to a more stable powder jet being formed at the powder discharge outlet 208.

In the first embodiment, the plurality of defined shapes 216 is in the form of a plurality of protrusions 216 protruding from the surface 218 of the upper section 214 as illustrated in Figure 3. Powder is introduced from one or more powder inlets 222 as illustrated in Figure 2. The powder inlet 222 is arranged to supply powder directly to the surface 218 of the upper section 214 of the inner nozzle portion 202 where the plurality of protrusions 216 are located. With the plurality of protrusions 216, the stream of powder is prevented from flowing downstream towards the channel 206 in a direct or straight path manner. Instead, the stream of powder encounters or collides with a number of protrusions 216 as it flows downstream towards the channel 206, thereby causing the mixing and dispersion of the powder. This results in a more uniform flow or distribution of powder within the nozzle 104, and particularly in the channel 206 prior to the powder being discharged.

In the first embodiment, the plurality of protrusions 216 is integrally formed with the upper section 214 of the inner nozzle portion 202 as shown in Figure 3. In a second embodiment, the plurality of protrusions 216 is releasably coupled to the surface 218 of the upper section 214 of the inner nozzle portion 202. In particular, the plurality of defined shapes 216 comprises a plurality of holes 402 as shown in Figures 4 to 6. Each hole 402 is configured for supporting a protrusion 602 (see Figure 6) such that the protrusion 602 protrudes from the surface 218 of the upper section 214. With the second embodiment, the protrusions 602 can be selectively replaced for various reasons (e.g., worn or damaged) without having to replace the entire inner nozzle portion 202, thus minimising costs. The protrusions 602 may be secured to the holes 402 by a number of methods, such as, but not limited to, adhesive, screwing or brazing.

Preferably, the protrusions 216, 602 above the surface 218 are rounded such as being generally hemispherical or circular in shape. As illustrated in Figures 2 to 6, the upper section 214 of the inner nozzle portion 202 comprises a recessed portion 224 extending circumferentially around the upper section 214. For example, the recessed portion 224 may have a generally concave profile, therefore resulting in the upper section 214 having an hourglass profile. The plurality of defined shapes (i.e., the protrusions 216 or the holes 402) is arranged on the recessed portion 224. With the recessed portion 224, the stream of powder injected from the powder inlet has the tendency to flow on the surface 218 of the upper section 214 around the protrusions 216, 602 thereon, rather than flowing over the protrusions and dropping straight down towards the channel 206. Preferably, the plurality of defined shapes 216 is arranged in staggered rows on the surface 218 of the upper section 214 of the inner nozzle portion 202 as shown in Figures 3 and 5 so as to maximise the number of protrusions 216, 602 which the stream of powder will encounter or collide with as it flows downstream towards the channel 206. This will enhance mixing and dispersion of the powder, thus resulting in a more uniform flow or distribution of powder within the nozzle 104.

As shown in Figures 2 to 6, the lower portion 210 has a generally conical profile having a narrower tip portion 226. Similarly, the inner surface 213 of the outer nozzle portion 204 has a generally conical profile. Therefore, the channel 206 formed between the surface 212 of the lower section 210 of the inner nozzle portion 202 and the inner surface 213 of the outer nozzle portion 204 is generally annular or conical in shape. The width or gap of the channel 206 at its entrance 228 (i.e., at the interface between the upper section and the lower section) is configured to be wider than the width of the channel 206 at the powder discharge outlet 208, that is, the channel 206 tapers from its entrance to its outlet 208.

The inner nozzle portion 202 comprises an opening (or central axial opening) 230 extending along its longitudinal axis 231 in communication with the laser outlet 232 at the narrower tip portion 226. In particular, an end of the opening 230 at the narrower tip portion 226 constitutes the laser outlet 232. As described hereinbefore, the longitudinal axis 231 of the opening 230 is aligned so as to be substantially coaxial with the axis of the laser beam 110. With this configuration, the channel 206 is operable to discharge powder from the powder discharge outlet 208 with a powder focus intersecting the laser beam 110 at predetermined distance (i.e., standoff) from the narrower tip portion 226. It is known to a person skilled in the art that the standoff of the powder focus can be adjusted by a number of ways, for example, by configuring the profile of the channel (e.g., the gap or width of the channel, and the slope of the surfaces of the inner and outer nozzle portions forming the channel), or by adjusting the feed rate of the powder. For example, it is apparent to a person skilled in the art that the gap or profile of the channel can be adjusted accordingly (e.g., based on the powder size, applied beam size, and the powder feed rate) to achieve a powder jet at a desired standoff.

By way of examples only, and without any limitations, the nozzle 104 may be configured to provide a powder jet with a powder focus of less than 1 mm in the case of micro-LAAM. For micro-LAAM, the powder size may be in the range of 20 to 45 μm, and thus the gap of the channel at the powder discharge outlet may be configured to be in the range of 0.1 to 0.2 mm. In an example, the nozzle 104 can be configured to provide powder to a melt pool suitable for forming a clad with a width of about 300 μm wide and a height (or thickness) of about 100 μm. This advantageously promotes good gas shielding for preventing oxidation. For macro-LAAM, for powder size of 45 to 150 μm, the gap may be configured to range from 0.3 to 1 mm.

The nozzle 104 can be configured to deliver a powder jet at processing conditions suitable for repairing or fabricating a component made of most of the metals including, but not limited to stainless steels, super-alloys such as Ni-, Ti-, Co-base alloys, etc., and precious metals such as gold, silver, platinum, etc., by providing improved powder focus quality and oxidation protection. The nozzle 104 can be made of any material with good heat conductivity and machinability, such as, but not limited to, copper and copper alloys, aluminium alloys and steels.

A method 700 for laser aided additive manufacturing using the nozzle 104 as described hereinbefore according to embodiments of the present invention will now be generally described as shown in Figure 7. The method comprises a step 702 of arranging a nozzle 104 according to any one of the above embodiments for receiving a laser beam 110. For example, the nozzle 104 may be arranged so as to be coupled to a controller (e.g., a CNC machine) for receiving the laser beam 110. The method further comprises a step

704 of directing the laser beam 110 output from nozzle 104 towards a substrate 109 (or a substrate or other workpiece) for generating a melt pool 114 on the substrate 109 (e.g., a small melt pool such as one less than 500 µm), and a step 706 of feeding powder through the nozzle 104 to the melt pool 114 for forming a desired clad on the substrate 109. The powder is melted by the laser beam 110 and upon re-solidification forms a desired clad on the substrate 109 suitable for repairing or fabrication. With this method, a single layer of cladding or a three-dimensional micro-deposition may be formed accordingly.

Accordingly, a nozzle 104 according to exemplary embodiments of the present invention has been described herein which is configured to advantageously facilitate homogeneous mixing and distribution of the powder as the powder is delivered into the channel, such that upon emerging from the tip of the nozzle 104, the powder forms a substantially stable powder jet with a desired powder focus at a predetermined standoff.

It will be appreciated by those skilled in the art that modifications and variations to the present invention described herein will be apparent without departing from the scope of the present invention. For example, although Figure 1 illustrates that the nozzle 104 is part of an assembly 100 coupled to a controller, it will be apparent to a person skilled in the art that the nozzle 104 can instead be coupled to a hand-held device (not shown) without deviating from the scope of the present invention. The variations and modifications as would be apparent to persons skilled in the art are deemed to fall within the broad scope and ambit of the present invention as herein set forth.

CLAIMS

What is claimed is:

1. An inner nozzle portion for a powder feeding nozzle capable of being coaxially arranged within an outer nozzle portion of the powder feeding nozzle, the inner nozzle portion comprising:

an upper section having a plurality of defined shapes on a surface thereof configured to manipulate a stream of powder flowing across said surface of the upper section; and

a lower section having a substantially flat conical surface for forming a channel between said substantially flat conical surface and an inner surface of the outer nozzle portion when the inner nozzle portion is coupled to the outer nozzle portion, the inner nozzle portion being in communication with a powder inlet for receiving the stream of powder to flow across the surface of the upper section through the channel and towards a powder discharge outlet of the channel.

2. The inner nozzle portion according to claim 1, wherein the plurality of defined shapes comprises a plurality of protrusions.

3. The inner nozzle portion according to claim 1, wherein the plurality of defined shapes comprises a plurality of holes, each hole configured for supporting a protrusion such that the protrusion protrudes from the surface of the upper section.

4 The inner nozzle portion according to claim 1, wherein the upper section comprises a recessed portion, and the plurality of defined shapes is arranged on the recessed portion.

5. The inner nozzle portion according to claim 4, wherein the recessed portion has a generally concave profile and extends circumferentially around the upper section.

6. The inner nozzle portion according to claim 1, wherein the lower portion has a generally conical profile having a narrower tip portion at the powder discharge outlet.

7. The inner nozzle portion according to claim 6, wherein the inner nozzle portion comprises an opening extending along its longitudinal axis in communication with a laser outlet at the narrower tip portion, the opening forming a passage for a laser beam.

8. The inner nozzle portion according to claim 7, wherein the channel is configured to discharge the stream of powder from the powder discharge outlet with a powder focus intersecting the laser beam at a predetermined distance from the narrower tip portion.

9. The inner nozzle portion according to claim 1, where the plurality of defined shapes is arranged in staggered rows on the surface of the upper section for promoting uniform mixing of the powder.

10. The inner nozzle portion according to claim 2, wherein the plurality of protrusions is formed integrally with the upper section.

11. The inner nozzle portion according to claim 2, wherein the plurality of protrusions is releasably coupled to the surface of the upper section.

12. The inner nozzle portion according to claim 2, wherein the plurality of protrusions is generally hemispherical in shape.

13. A powder feeding nozzle, comprising:

an inner nozzle portion according to any one of claims 1 to 12; and

an outer nozzle portion, wherein the inner nozzle portion is coaxially arranged within the outer nozzle portion for defining said channel therebetween in communication with the powder discharge outlet.

14. The powder feeding nozzle according to claim 13, wherein the outer nozzle portion comprises the powder inlet arranged to supply powder directly to the surface of the upper section of the inner nozzle portion.

15. The powder feeding nozzle according to claim 13, wherein a gap of the channel at the powder discharge outlet is arranged is in the range of about 0.1 mm to 1 mm.

16. An assembly for laser aided additive manufacturing, the assembly comprises:

a body configured to be coupled to a controller and for receiving a laser beam;

a powder feeding nozzle including the inner nozzle portion according to any one of claims 1 to 12 and an outer nozzle portion, wherein the inner nozzle portion is coaxially arranged within the outer nozzle portion for defining said channel therebetween in communication with the powder discharge outlet, and the powder feeding nozzle is coupled to an end of the body, and

adjustment mechanisms on the body for aligning the powder feeding nozzle with respect to the laser beam.

17. A method for laser aided additive manufacturing, the method comprises:

arranging a powder feeding nozzle for receiving a laser beam, the powder feeding nozzle including the inner nozzle portion according to any one of claims 1 to 12 and an outer nozzle portion, wherein the inner nozzle portion is coaxially arranged within the outer nozzle portion for defining said channel therebetween in communication with the powder discharge outlet;

directing the laser beam output from the powder feeding nozzle towards a substrate for generating a melt pool on the substrate; and

feeding powder through the powder discharge outlet of the powder feeding nozzle to the melt pool for forming a desired clad on the substrate.

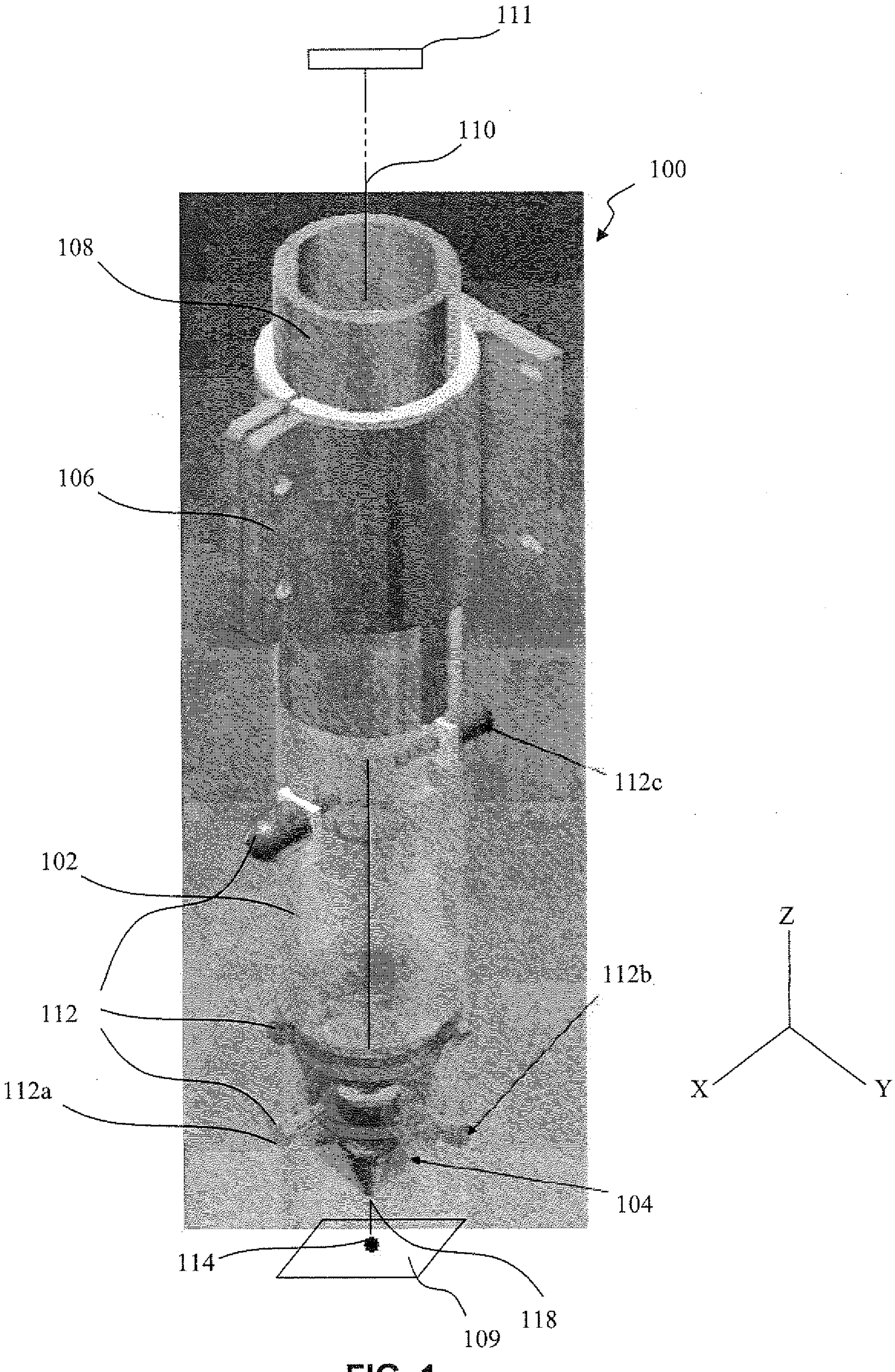

FIG. 1

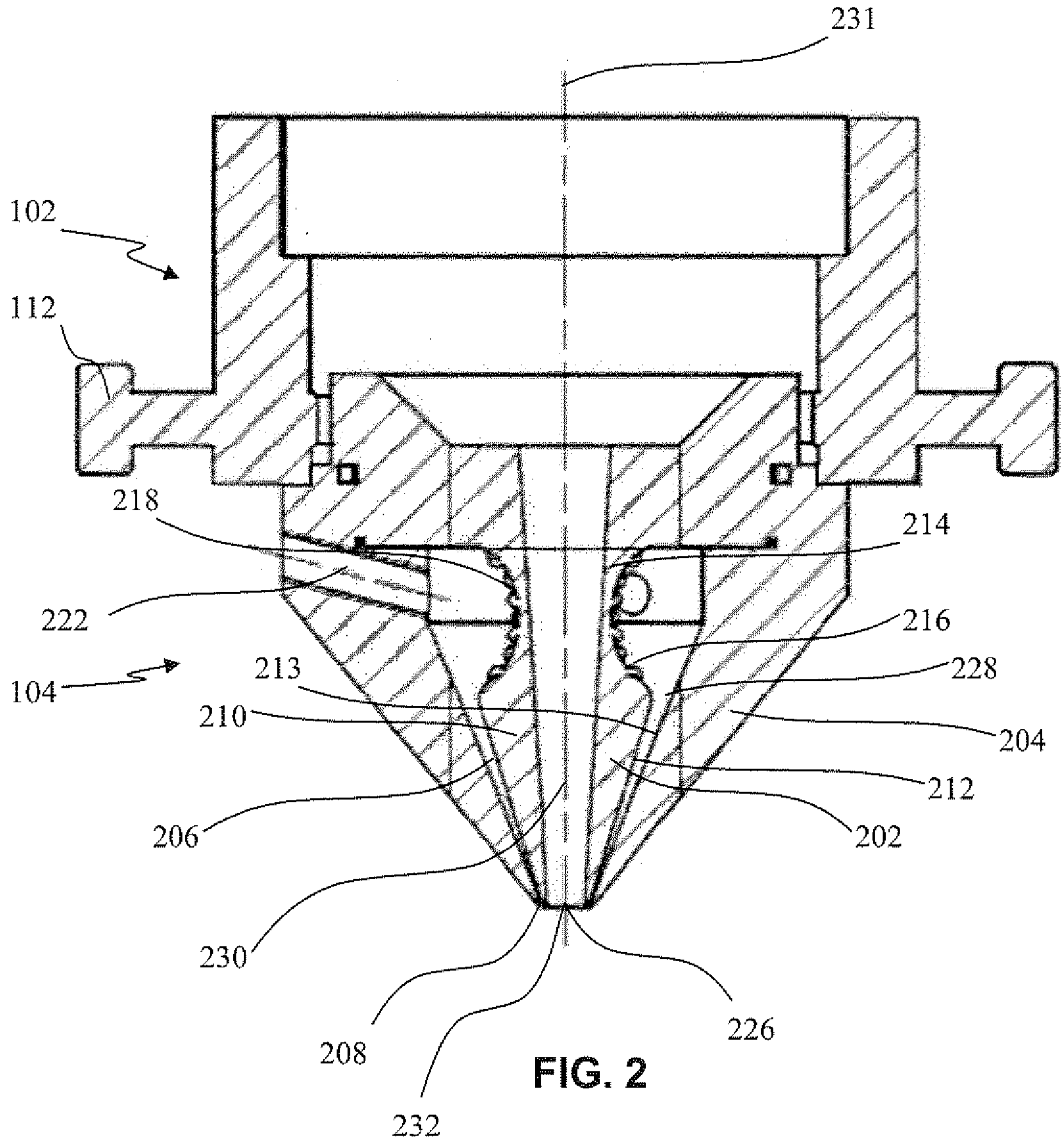
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FIG. 2

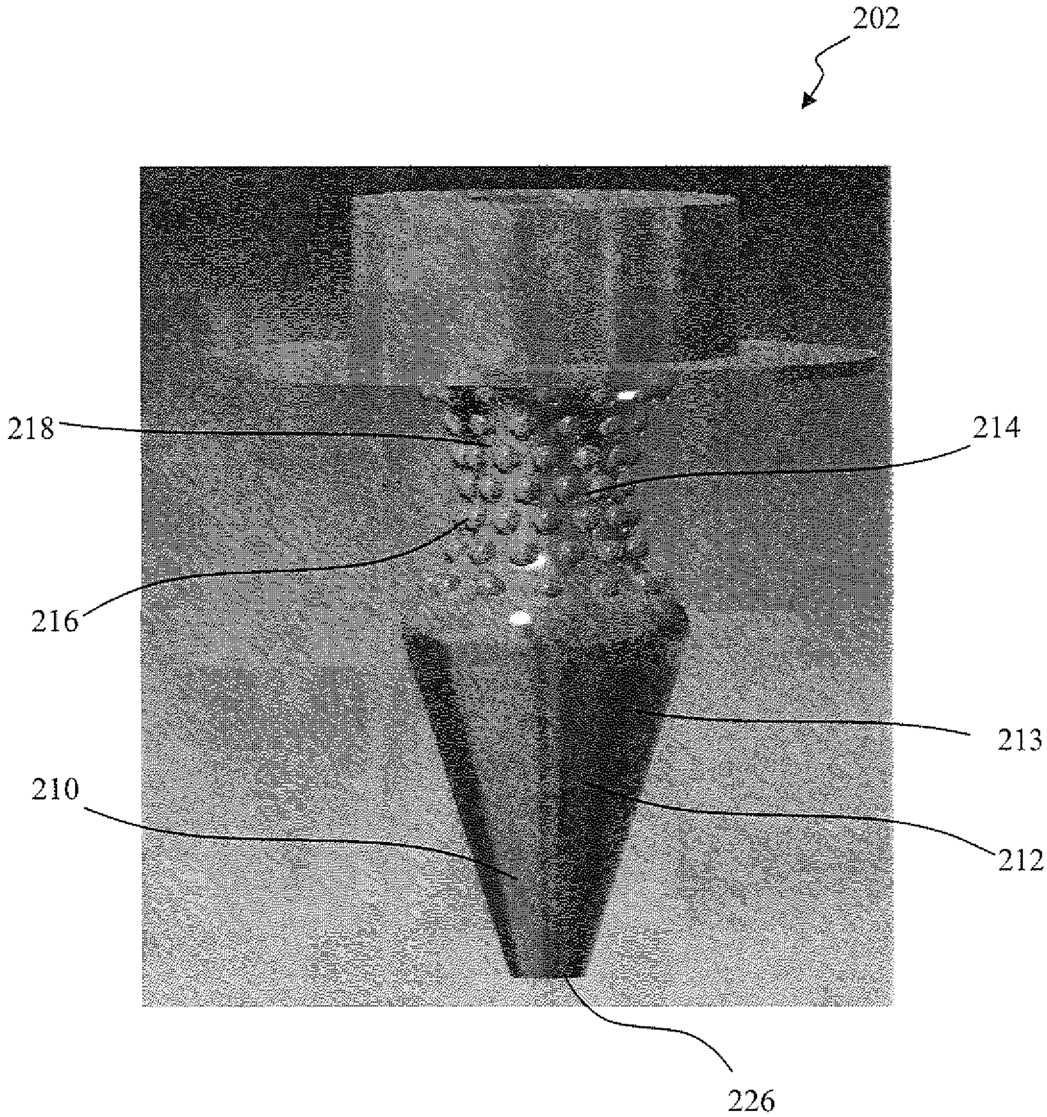
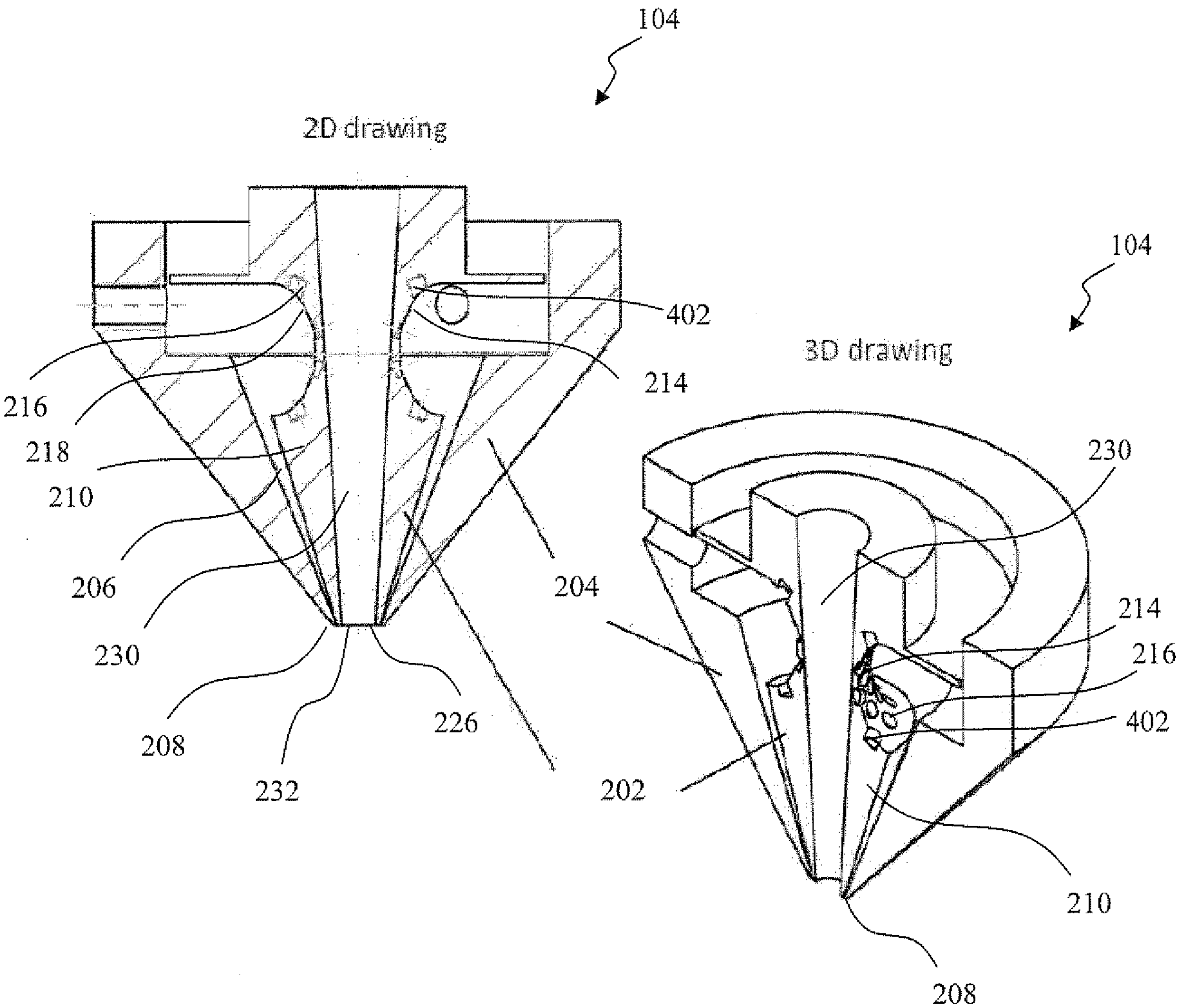


FIG. 3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226
232
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3D drawing
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202
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208

FIG. 4

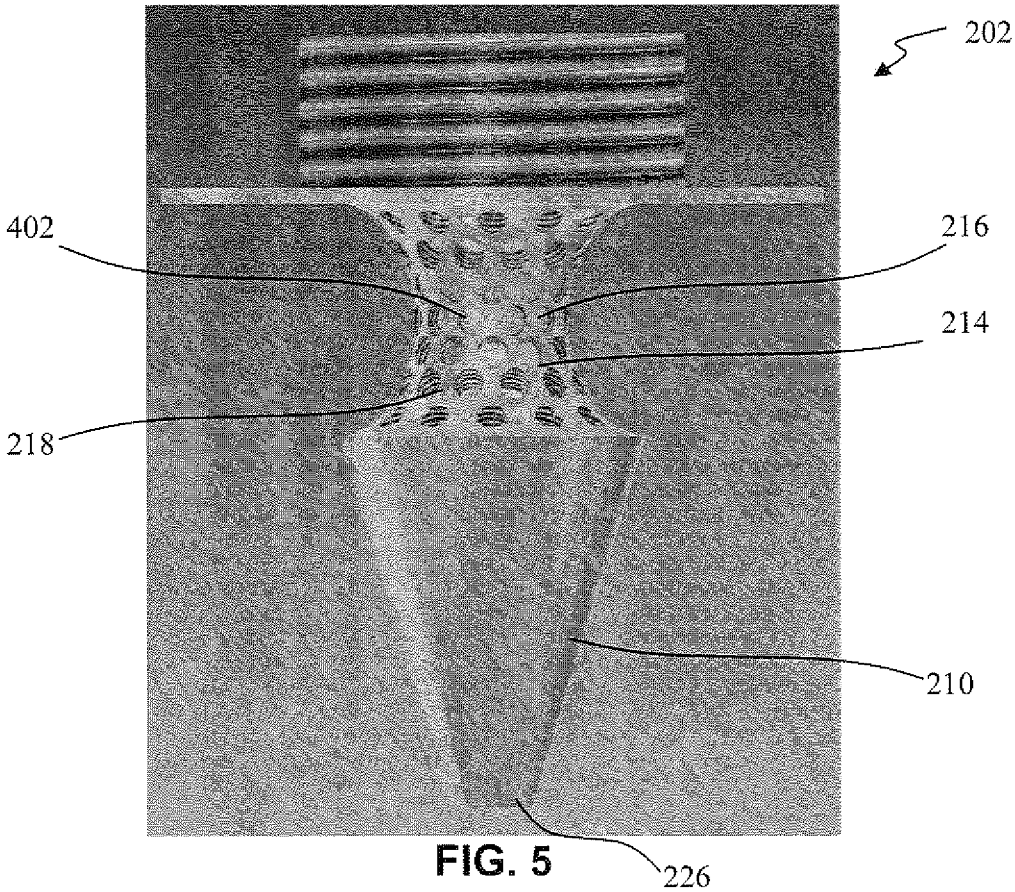

FIG. 5

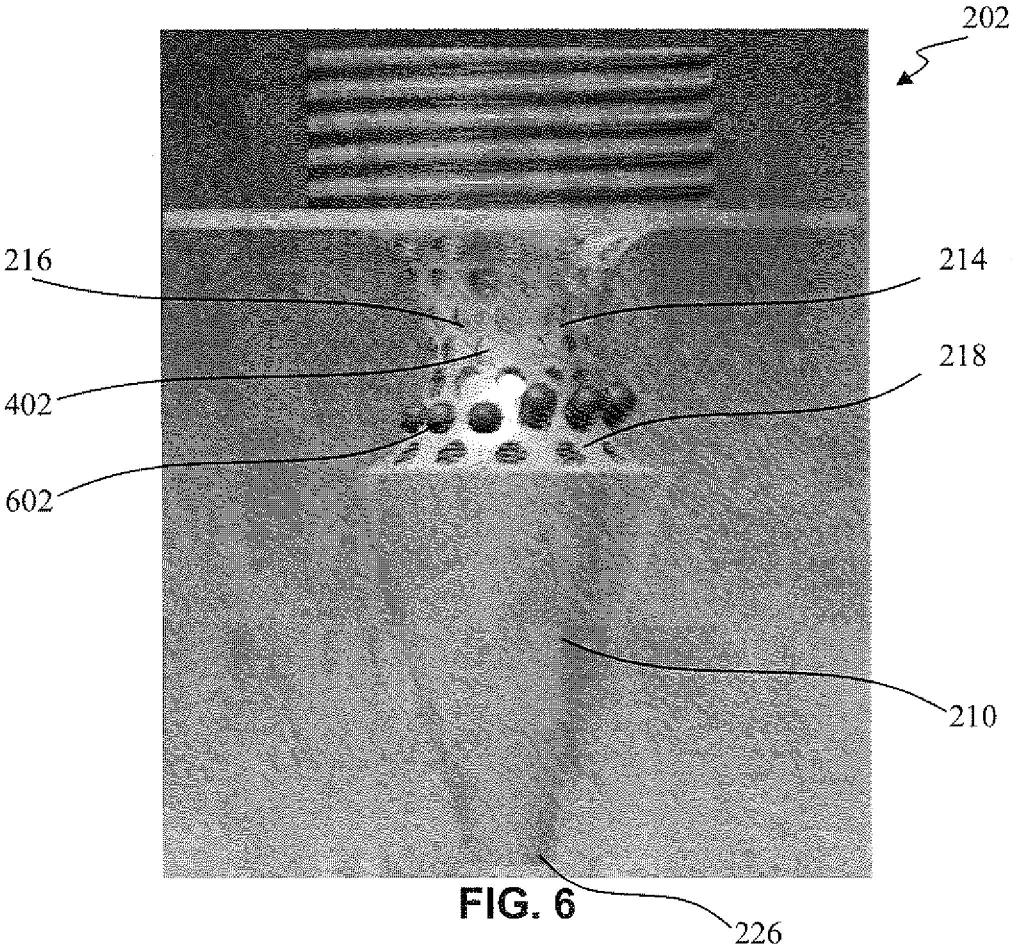

FIG. 6

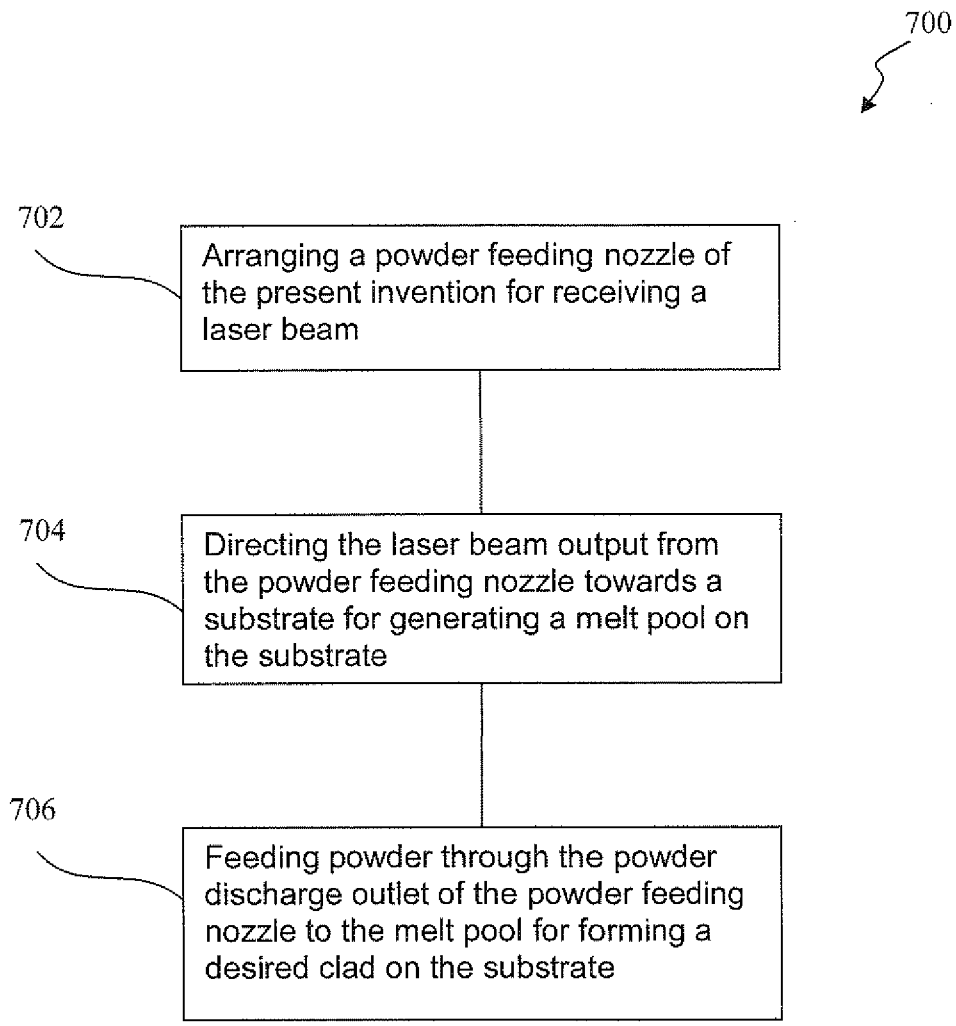
700
702
Arranging a powder feeding nozzle of the present invention for receiving a laser beam
704
Directing the laser beam output from the powder feeding nozzle towards a substrate for generating a melt pool on the substrate
706
Feeding powder through the powder discharge outlet of the powder feeding nozzle to the melt pool for forming a desired clad on the substrate

FIG. 7