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*B29C 64/118* (2017.01)    *B29C 64/295* (2017.01)  
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(71) Applicant: **ESSENTIUM MATERIALS, LLC** [US/US];  
5880 Imperial Loop Dr., Ste 10, College Station, TX 77845  
(US).

(72) Inventors: **SWEENEY, Charles, Brandon**; 5880 Imperial Loop Dr., Ste 10, College Station, TX 77845 (US). **TEIPEL, Blake**; 5880 Imperial Loop Dr., Ste 10, College Station, TX 77845 (US). **EUBANKS, Travis**; 5880 Imperial Loop Dr., Ste 10, College Station, TX 77845 (US). **STOCKTON, John**; 5880 Imperial Loop Dr., Ste 10, College Station, TX 77845 (US). **STOCKTON, Alex**; 5880 Imperial Loop Dr., Ste 10, College Station, TX 77845 (US).

(74) Agent: **CHAN, James, M.**; Vivacqua Law, PLLC, 3101 E. Eisenhower Pkwy, Suite 1, Ann Arbor, MI 48108 (US).

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(54) Title: ATMOSPHERIC PLASMA CONDUCTION PATHWAY FOR THE APPLICATION OF ELECTROMAGNETIC ENERGY TO 3D PRINTED PARTS

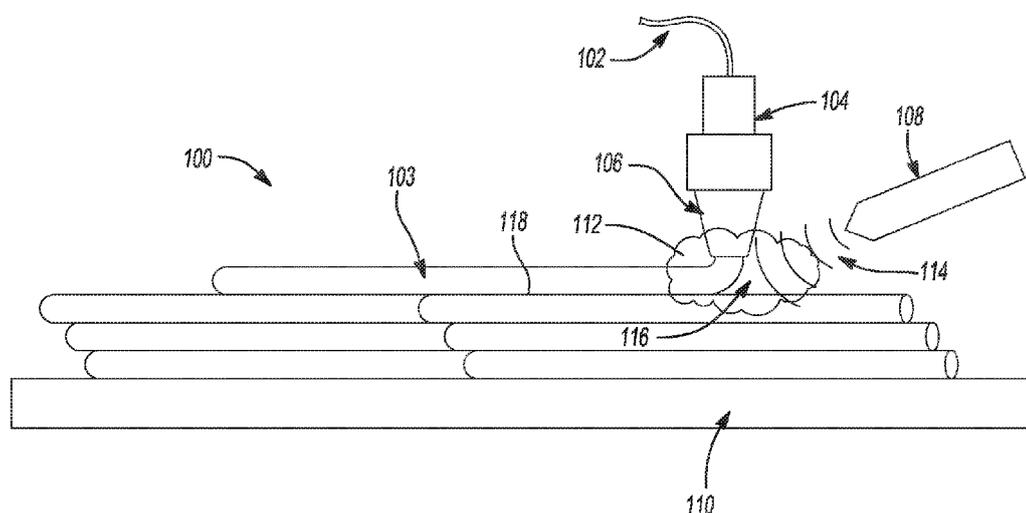


FIG. 1

(57) Abstract: A three-dimensional (3D) printing process utilizing an atmospheric plasma to conduct an electromagnetic energy to fuse extruded successive layers of thermoplastic material having a conductive material is disclosed. A 3D printing system for the 3D printing process is also provided. The 3D printing system includes a 3D printer, an extrusion nozzle, a plasma emitter, and an electromagnetic energy source. The 3D printing process includes the steps of extruding a thermoplastic composite with the extrusion nozzle in successive layers to form a 3D part; directing a substantially evenly distributed plasma onto a predetermined location on the 3D part; and emitting an electromagnetic energy through the plasma. The plasma conducts the electromagnetic energy to the predetermined location on the 3D part. The thermoplastic composite includes a conductive material that generates heat by reacting to the electromagnetic energy.



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ATMOSPHERIC PLASMA CONDUCTION PATHWAY FOR THE  
APPLICATION OF ELECTROMAGNETIC ENERGY TO 3D PRINTED PARTS

CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** This international application is based on and claims the benefit of priority from United States Provisional Application No. 62/463,368, filed on February 24, 2017, the contents of which are incorporated by reference.

TECHNICAL FIELD

**[0002]** The present disclosure relates generally to an apparatus and system for heating polymer composites for enhanced bonding of 3D printed parts.

BACKGROUND

**[0003]** The statements in this section merely provide background information related to the present disclosure and may or may not constitute prior art.

**[0004]** Three-dimensional (3D) printing is an additive manufacturing process for producing 3D models, which may include prototype or production parts, directly from a digital model. Additive manufacturing is a process that takes virtual blueprints from computer aided design (CAD) or animation modeling software and slices them into digital cross-sections for the 3D printing apparatus for use as a guideline for printing the 3D model. Layers of composite material are successively deposited in droplets or continuous

beads until the final 3D model has been printed. These layers are jointly welded, also known as fused, to create and maintain the shape of the printed 3D model.

**[0005]** For 3D printing apparatus that use an extrusion deposition process, such as Fused Filament Fabrication (FFF) and Fused Deposition Modeling (FDM), a thermoplastic composite filament is applied through a heated extrusion nozzle. The thermoplastic composite filament may include various polymers such as acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polylactic acid (PLA), and high density polyethylene (HDPE). The extrusion nozzle heats the filament to render the composite material flowable and regulates the flow of the composite material by controlling the filament feed rate. The extrusion nozzle can be moved in both horizontal and vertical directions by a computer-controlled mechanism. Alternatively, the printer platform bed may be moved relative to the extrusion nozzle, or coordinated movements of both the nozzle and platform may be used to achieve the desired extrusion path in the x, y, and z directions.

**[0006]** The 3D model is printed by extruding small beads or lines of the thermoplastic composite filament to form consecutive layers in the vertical direction (z direction). The material hardens immediately after extrusion from the extrusion nozzle. 3D printing capabilities are hindered by the weaker welds between printed filaments in the z direction, which often leads to delamination between filaments. Thus, there is a need for an apparatus, system, and/or process to make a 3D model using 3D printing that has improved welds between printed filaments in the z direction resulting in improved structural integrity of the printed 3D model.

## SUMMARY

**[0007]** According to several aspects, a three-dimensional (3D) printing process is disclosed. The process includes the steps of: extruding a thermoplastic composite in successive layers to form a 3D part; directing an evenly distributed plasma onto a predetermined location on the 3D part; and emitting an electromagnetic energy through the plasma. The plasma conducts the electromagnetic energy to the predetermined location on the 3D part. The thermoplastic composite includes a conductive material that generates heat by reacting to the electromagnetic energy, which includes an electric current.

**[0008]** In an additional aspect of the present disclosure, the predetermined location on the 3D part is a location adjacent where a newly extruded layer of the thermoplastic composite is deposited onto a previously extruded layer of the thermoplastic composite.

**[0009]** In another aspect of the present disclosure, the electric current includes sufficient power to fuse the newly extruded layer of the thermoplastic composite with the previously extruded layer of the thermoplastic composite.

**[0010]** In another aspect of the present disclosure, the conductive material reacts includes at least one nanomaterial selected from a group consisting of carbon nanotube, carbon black, buckyballs, graphene, magnetic nanoparticles, and ferroelectric materials such as barium titanate.

**[0011]** In another aspect of the present disclosure, the conductive material includes a carbon nanotube selected from a group consisting of a

single-wall carbon nanotubes (SWNT) and a multi-walled carbon nanotubes (MWNT).

**[0012]** In another aspect of the present disclosure, the thermoplastic composite includes at least one thermoplastic selected from a group consisting of acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polylactic acid (PLA), polyamide (PA), polyetheretherketone (PEEK), and high density polyethylene (HDPE).

**[0013]** According to several aspects, an extrusion nozzle for a three-dimensional (3D) printer is disclosed. The extrusion nozzle includes a nozzle body defining a filament extrusion channel extending along an extrusion axis-A, the filament extrusion channel includes an extrusion end; and a plasma generating portion adjacent the extrusion end. The plasma generating portion is configured to generate and discharge an atmospheric plasma capable of conducting an electric current in a predetermined direction.

**[0014]** In an additional aspect of the present disclosure, the extrusion nozzle further includes a nozzle housing coaxially disposed about the extrusion nozzle body. The nozzle housing cooperates with the nozzle body to define a plasma generation channel configured for a gas flow there-through.

**[0015]** In another aspect of the present disclosure, the extrusion nozzle further includes a pair of electrodes disposed within the plasma generation channel. The pair of electrodes are configured to excite the gas flowing there-through to generate the atmospheric plasma.

**[0016]** In another aspect of the present disclosure, the plasma generation channel includes a plasma outlet adjacent the extrusion end of the

filament extrusion channel. The plasma outlet is configured to direct the atmospheric plasma in a predetermined direction.

**[0017]** In another aspect of the present disclosure, the extrusion nozzle further includes means to induce a pressurized stream of gas through the plasma generation channel and exiting the plasma outlet.

**[0018]** In another aspect of the present disclosure, the extrusion nozzle further includes a first electrode disposed about an annulus on the nozzle body adjacent the extrusion end of the filament extrusion channel.

**[0019]** In another aspect of the present disclosure, the first electrode is configured to cooperate with a second electrode spaced from the first electrode to excite a gas therebetween to form the atmospheric plasma.

**[0020]** In another aspect of the present disclosure, the second electrode is spaced from the extrusion nozzle.

**[0021]** According to several aspects, three-dimensional (3D) printing system is disclosed. The 3D printing system includes a 3D printer configured to print a 3D part by extruding successive layers of a thermoplastic composite having a conductive material that generates heat by reacting to an electric current; a plasma emitter configured to generate and directed a plasma toward the 3D part being printed; and an electromagnetic energy source configured to generate and direct an electric current into the plasma such that the plasma conducts the electric current to the 3D part being printed.

**[0022]** In an additional aspect of the present disclosure, the 3D printing system further includes an extrusion nozzle configured to extrude the successive layers of the thermoplastic composite, wherein the plasma emitter and electromagnetic energy source are adjacent the extrusion nozzle.

**[0023]** In another aspect of the present disclosure, the plasma emitter includes a first electrode located on the extrusion nozzle and a second electrode spaced from the extrusion nozzle.

**[0024]** In another aspect of the present disclosure, the plasma emitter includes a first electrode located on the extrusion nozzle and a second electrode located on the extrusion nozzle.

**[0025]** In another aspect of the present disclosure, the 3D printing system further includes a first voltage source configured to power the plasma emitter; and a second voltage source configured to power the electromagnetic energy source. The first voltage source is independent of the second voltage source.

**[0026]** Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0027]** Features and advantages of examples of the present disclosure will become apparent by reference to the following detailed description and drawings, in which like reference numerals correspond to similar components. The drawings are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

**[0028]** FIG. 1 is an illustration of an exemplary embodiment of a 3D printing process using atmospheric plasma as an electrical conduction

pathway for the application of electromagnetic energy at the point of extrusion to control the welding of interlayers of extruded materials;

**[0029]** FIG. 2 is an illustration of a semi-schematic cross-section of an embodiment of a 3D printer nozzle for generating a plasma;

**[0030]** FIG. 3 is an illustration of a semi-schematic cross-section of another embodiment of a 3D printer nozzle for generating a plasma;

**[0031]** FIG. 4 is a schematic of an embodiment of a 3D printing system using plasma as an electrical conduction pathway for the application of electromagnetic energy to fuse 3D printed parts; and

**[0032]** FIG. 5 is a schematic of another embodiment of a 3D printing system using plasma as an electrical conduction pathway for the application of electromagnetic energy to fuse 3D printed parts.

#### DETAILED DESCRIPTION

**[0033]** The present disclosure relates to using atmospheric plasma as an electrical conduction pathway for the application of electromagnetic energy, such as an alternating electric current or a direct electric current, for improving the interlayer adhesive strength of 3D printed parts produced with material extrusion 3D printing. The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

**[0034]** Shown in FIG. 1 is a 3D printing process 100 for printing 3D parts by extrusion deposition of a thermoplastic material 102 in droplets or continuous beads 103 in multiple layers. The 3D printing process 100 includes an extrusion nozzle 104 having a plasma generating portion 106, an

electric current applicator source 108, and a platform bed 110. While the electric current applicator source 108 is shown separate from the extrusion nozzle 104, the electric current applicator 108 may be an integral part of the extrusion nozzle 104.

**[0035]** The 3D printing process 100 uses an atmospheric plasma 112 as an electrical conduction pathway for the application of electric current 114 at the point of extrusion 116 to control the welding of interlayers 118 of the extruded thermoplastic materials 102. It is desirable that the atmospheric plasma 112 is substantially evenly disturbed between the nozzle 104 and the 3D part being printed for the conduction of the electric current 114 between the nozzle 104 and the 3D part. A substantially evenly distributed atmospheric plasma 112 means a volume of plasma having uniform intensity and power to provide a conductive pathway to enable even heating of the 3D part or at least a portion of the 3D part proximal to the extrusion nozzle 104.

**[0036]** The extrusion nozzle 104 may be moved through a predetermined extrusion path in both horizontal and vertical directions by a computer-controlled mechanism (not shown) to print a 3D part having a predetermined shape and size. Alternatively, the platform bed 110 may be moved relative to the extrusion nozzle 104 or coordinated movements of both the nozzle 104 and platform 110 may be used to achieve the desired extrusion path in the x, y, and z directions.

**[0037]** The thermoplastic material 102 is fed through the extrusion nozzle 104 in a form of a thermoplastic composite filaments 102. The thermoplastic filament 102 may include various polymers such as, but not limited to, acrylonitrile butadiene styrene (ABS), polycarbonate (PC),

polylactic acid (PLA), and high density polyethylene (HDPE). The thermoplastic filament 102 is surface coated and/or embedded throughout its volume with materials having conductive properties that reacts to the electric current or absorbs the electric current to generate heat. It is desirable that sufficient heat is generated to weld the interlayers 118 of extruded thermoplastic materials 102, thus increasing the interlayer 118 bond strength throughout the body of the 3D printed part. In the exemplary embodiment shown, the thermoplastic composite filaments 102 are surface coated with carbon nanotubes (CNTs). The CNTs may include single-wall carbon nanotubes (SWNT), multi-walled carbon nanotubes (MWNT), and/or functionalized carbon nanotubes. Other forms of electric current absorbing nanomaterials, such as carbon black, buckyballs, graphene, and/or magnetic nanoparticles, can also be used.

**[0038]** Referring to both FIG. 1 and FIG. 2, the extrusion nozzle 104a is configured to heat the thermoplastic filament 102 to a molten state and extrude the molten thermoplastic material 102 in successive layers onto the platform bed 110 until the 3D part has been printed. The extrusion nozzle 104a includes a plasma generating portion 106 configured to generate an atmospheric plasma 112 for conducting electric current to weld the interlayers 118 of extruded composite material 102. Shown in FIG. 2, the extrusion nozzle 104a includes a nozzle body 120 defining a filament extrusion channel 122 extending along an extrusion axis-A. The filament extrusion channel 122 includes a filament feed end 124 and an opposite filament extrusion end 126. The extrusion nozzle 104a further includes a heater element 128 in thermal contact with the extrusion channel 122. The heater element 128 melts the

thermoplastic filament 102 to a molten state as the thermoplastic filament 102 is fed through the filament extrusion channel 122 from the feed end 124 to the extrusion end 126. Heat breaks 130 are provided adjacent the filament feed end 124 to insulate the extrusion nozzle 104a from the remainder of the 3D printer (not shown).

**[0039]** Coaxially disposed about the extrusion nozzle body 120 is a nozzle housing 132. The nozzle housing 132 cooperates with the nozzle body 120 to define a plasma generation channel 134 therebetween. The plasma generation channel 134 includes a gas inlet 136 and a plasma outlet 138 opposite the gas inlet 136 adjacent the extrusion end 126 of the filament extrusion channel 122. A pair of electrodes 140, 142 is disposed within the plasma generation channel 134. A pressurized stream of gas including, but not limited to, argon, helium, carbon dioxide, and air is induced through the plasma generation channel 134 from the inlet 136 to the outlet 138. The pressurized stream of gas may be generated via fans, blowers, pumps, or pressurized gas tanks. As the gas flows through the plasma generation channel, the pair of electrodes 140, 142 are configured to excite the gas to generate a plasma stream 112. The plasma stream 112 exits the plasma outlet 138 and is directed at the 3D part being printed

**[0040]** Shown in FIG. 3 is another embodiment of an extrusion nozzle 104b having a plasma generating portion 106. Similar to the extrusion nozzle 104a, the extrusion nozzle 104b includes a nozzle body 120 defining a filament extrusion channel 122, a filament feed end 124, a filament extrusion end 126, a heater element 128, and heat breaks 130. The extrusion nozzle 104a further includes a first electrode 140 disposed about an annulus 141 on

the nozzle body 120 adjacent the extrusion end 126 of the filament extrusion channel 122. The first electrode 140 is configured to cooperate with a second electrode 142 spaced apart from the first electrode 140 to excite a gas therebetween to form a plasma 112. The second electrode 142 may be provided on the platform bed 110, conductive materials on the newly printed 3D part, or the coating on the surface of the thermoplastic filaments 102 or embedded within the volume of the recently printed layer of thermoplastic material 102 itself.

**[0041]** Referring back to FIG. 1, the electric current applicator source 108 is configured to emit an electric current 114 toward the plasma 112 produced by the extrusion nozzle 104. The electric current 114 includes a predetermined frequency and power sufficient to react with the CNTs in the extruded thermoplastic materials 102 to generate sufficient heat to weld or fuse the interlayers of extruded thermoplastic material 102 into a solid integral structure. The electric current 114 can be focused upon the newly, or immediately, printed location 116 using the electric current applicator source 108 located immediate adjacent the nozzle 104. The application of electric current 114 adjacent the nozzle 104 generates localized heating 116 as the part is being printed. The electric current applicator source 108 can be attached to the printer head directly in order to move with the extrusion nozzle 104. This localized electric current heating allows for the electric current 114 to be applied during printing, with only the immediately-printed area being exposed rather than the entire volume of the 3D part. The nozzles 104a, 104b and electric current applicator source 108 may be used in conjunction

with a thermoplastic material extrusion 3D printer either as a built-in feature or as an add-on kit to be connected to an existing 3D printer.

**[0042]** FIG. 4 is a schematic of an embodiment of a 3D printing system 200a using plasma as an electrical conduction pathway for the application of electromagnetic energy, such as an electric current, to fuse interlayers of 3D printed parts. The 3D printing system 200a includes an electromagnetic energy source 202 for generating an electric current, a plasma emitter 204, a 3D printer 206, a high voltage isolator 208, 3D printer controls 210, and a high voltage supply 212, which could may include a direct current (DC) source, pulsed DC source, or alternating current (AC) source. The electromagnetic energy source 202 is powered by the high voltage supply 212.

**[0043]** The 3D printer 206 includes a 3D printer nozzle head, such as the extrusion nozzles 104a, 104b shown in FIGS. 2 and 3, configured to allow a high voltage potential to be applied directly to the nozzle body, to an electrode near the print head, or to a collar surrounding the nozzles. This high voltage potential will excite either a distributed plasma cloud or a focused plasma stream directed at the 3D printed parts. The plasma emitter 204 requires a high voltage source 212, a control unit to manage the voltage and current during the print, and certain circuit isolation 208 shielding requirements necessary to isolate the high voltage potential from damaging or interfering with the electronic 3D printer controls 210.

**[0044]** It is desirable to combine optimal plasma distribution and electromagnetic heating to produce optimal 3D print strength improvement. The electromagnetic energy applied through the plasma could come from the

plasma generating high voltage electronics. The electromagnetic energy is applied directly to the 3D printer nozzles 104a, 104b or concentrically around the nozzle body 120. A benefit is the ability to provide a local conduction pathway for the coupling of the electric current applicator 108 to the 3D part being printed. The plasma is produced near the 3D printer nozzle 104a, 104b and directed at a local region where the electric current energy is required to be dissipated. The plasma interacts with the conductive thermoplastic in such a way as to provide an ionized electron pathway either to or from the electric current applicator source 108 located at or near the nozzle 104.

**[0045]** Alternatively, the electromagnetic energy source 202 could be powered from an external source 216 as shown in FIG. 5. The 3D printing system 200b includes an electromagnetic energy source 202, a plasma emitter 204, 3D printer controls 210, circuit isolation 214, a high voltage supply 212 (first voltage source), and an external voltage supply 216 (second voltage source). The plasma emitter 204 and electromagnetic energy source 202 are operated independently and separately from the 3D printer nozzle 104a, 104b. The important factor being that the plasma emitter 204 and electromagnetic energy source 202 are co-located or adjacently located to enable a conduction pathway for the electric current energy. In the 3D printing system 200b where the plasma emitter 204 operates independently from the electromagnetic energy source 202, the electrical energy flowing through the plasma is also flowing through the conductive 3D printed part to improve the interlayer adhesive strength. Since an external source 216 is used, it may require a signal generator, signal filter, power amplifier, power supply, isolation circuits 214 for printer protection, and

additional print nozzle attachments for quick release connections of the electromagnetic energy source 202. For this exemplary embodiment, the electromagnetic energy is supplied by the external voltage supply 216.

**[0046]** An early prototype of the plasma conduction pathway for 3D printing was developed using a 15-kHz high voltage generator and a flyback transformer to produce voltages near 80,000 volts with an associated current less than 0.5 milliAmps. The high voltage ground connection was attached to the hot end of a 3D printer, and the high voltage hot connection was attached to an electron emitter. An annular ring type electron emitter was cut from aluminum sheet to produce an evenly distributed plasma around the 3D printer nozzle 104. The high voltage plasma generator successfully produced both plasma and an electromagnetic signal, which heated conductive plastics through the plasma during multiple 3D prints. Additional experiments have shown that evenly distributed plasma jets can be produced with the same hardware to potentially reduce the localized heating effects from an arc discharge type plasma. It is desirable that the distributed plasma includes uniform intensity and power in order to provide a conductive pathway between the 3D printer nozzle 104 and the 3D printed part to enable even heating of the 3D part.

**[0047]** By using an atmospheric plasma as a conduction pathway for electromagnetic energy that heats the conductive 3D printed parts, the electromagnetic energy source can use a constant power level to heat 3D printed parts evenly even as the parts grow larger. With the current 3D printed parts, the geometry dependent resistance is eliminated because the resistive pathway being heated is a constant volume and shape as

determined by the shape of the plasma produced and the penetration depth of the electromagnetic energy into the 3D printed part. As the part is being printed, a local ground path is generated near the nozzle 104 through the conductive atmospheric plasma 112, which allows a constant power dissipation and heating rate to be maintained.

**[0048]** The following references are incorporated herein by reference in their entireties:

**[1]** C. B. Sweeney, B. Teipel, T. Eubanks, J. Stockton, and A. Stockton. "Non-radiating near-field and direct contact application of electrical energy for in-situ and targeted heating of thermoplastic 3D printed parts." Essentium Materials, patent in process since Oct 11, 2016.

**[2]** T.-C. Tsai, et al. "3d printers having plasma applicators and methods of using same." US 20160271874 A1, Sept. 22, 2016.

**[3]** T.-C. Tsai, et al. "3d printers having plasma applicators and method of using same." WO 2016154103 A1, Sept. 29, 2016.

**[4]** K. Ramaswamy, T. Detrick, S. Nemani, and A. Joshi. "Three-dimensional (3d) processing and printing with plasma sources." US 20150042017 A1, Feb. 12, 2015.

**[0049]** The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

## CLAIMS

What is claimed is:

1. A three-dimensional (3D) printing process comprising the steps of:
  - extruding a thermoplastic composite in successive layers to form a 3D part, wherein the thermoplastic composite comprises a conductive material reactive to an electromagnetic energy for heat generation;
  - directing a plasma onto a predetermined location on the 3D part; and
  - emitting the electromagnetic energy into the plasma, wherein the plasma conducts the electromagnetic energy to the predetermined location on the 3D part.
  
2. The process of claim 1, further comprises an electromagnetic energy source configured to emit the electromagnetic energy;
  - wherein the plasma is substantially evenly distributed between the electromagnetic energy source and the 3D part.
  
3. The process of claim 2, wherein the predetermined location on the 3D part is a location adjacent where a newly extruded layer of the thermoplastic composite is deposited onto a previously extruded layer of the thermoplastic composite.

4. The process of claim 3, wherein the electromagnetic energy includes an electric current having sufficient power such that the conductive material generates sufficient heat to fuse the newly extruded layer of the thermoplastic composite with the previously extruded layer of the thermoplastic composite.

5. The process of claim 1, wherein the conductive material comprises at least one nanomaterial selected from a group consisting of carbon nanotube, carbon black, buckyballs, graphene, and magnetic nanoparticles, and ferroelectric materials such as barium titanate.

6. The process of claim 1, where the conductive material comprises a carbon nanotube selected from a group consisting of a single-wall carbon nanotubes (SWNT) and a multi-walled carbon nanotubes (MWNT).

7. The process of claim 1, wherein the thermoplastic composite comprises at least one thermoplastic selected from a group consisting of acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polylactic acid (PLA), polyamide (PA), polyetheretherketone (PEEK), and high density polyethylene (HDPE).

8. An extrusion nozzle for a three-dimensional (3D) printer comprising:
- a nozzle body defining a filament extrusion channel having an extrusion end; and
  - a plasma generating portion adjacent the extrusion end, wherein the plasma generating portion is configured to generate and discharge an atmospheric plasma capable of conducting an electric current in a predetermined direction.
9. The extrusion nozzle of claim 8, further comprising a nozzle housing disposed about the extrusion nozzle body, wherein the nozzle housing cooperates with the nozzle body to define a plasma generation channel configured for a gas flow there-through.
10. The extrusion nozzle of claim 9, further comprising a pair of electrodes disposed within the plasma generation channel, wherein the pair of electrodes are configured to excite the gas flow there-through to generate the atmospheric plasma.
11. The extrusion nozzle of claim 9, wherein the plasma generation channel comprises a plasma outlet adjacent the extrusion end of the filament extrusion channel, wherein the plasma outlet is configured to direct the atmospheric plasma in the predetermined direction.

12. The extrusion nozzle of claim 11, further comprising means to induce the gas flow there-through the plasma generation channel.

13. The extrusion nozzle of claim 8, further comprising a first electrode disposed about an annulus of the nozzle body adjacent the extrusion end of the filament extrusion channel.

14. The extrusion nozzle of claim 13, wherein the first electrode is configured to cooperate with a second electrode spaced from the first electrode to excite a gas there-between to form the atmospheric plasma.

15. The extrusion nozzle of claim 14, wherein the second electrode is spaced from the extrusion nozzle.

16. A three-dimensional (3D) printing system comprising:  
a 3D printer configured to print a 3D part by extruding successive layers of a thermoplastic composite comprising a conductive material that generates heat by reacting to an electric current;  
a plasma emitter configured to generate and directed a plasma toward the 3D part being printed; and  
an electromagnetic energy source configured to generate and direct an electric current into the plasma such that the plasma conducts the electric current to the 3D part being printed.

17. The 3D printing system of claim 16, wherein the 3D printer comprises an extrusion nozzle configured to extrude the successive layers of the thermoplastic composite, wherein the plasma emitter and the electromagnetic energy source are adjacent the extrusion nozzle.

18. The 3D printing system of claim 17, wherein the plasma emitter includes a first electrode located on the extrusion nozzle and a second electrode spaced from the extrusion nozzle.

19. The 3D printing system of claim 16, wherein the plasma emitter includes a first electrode and a second electrode, wherein both first and second electrodes are located on the extrusion nozzle.

20. The 3D print system of claim 19, further comprising:  
a first voltage source configured to power the plasma emitter;  
and  
a second voltage source configured to power the electromagnetic energy source;  
wherein the first voltage source is independent of the second voltage source.

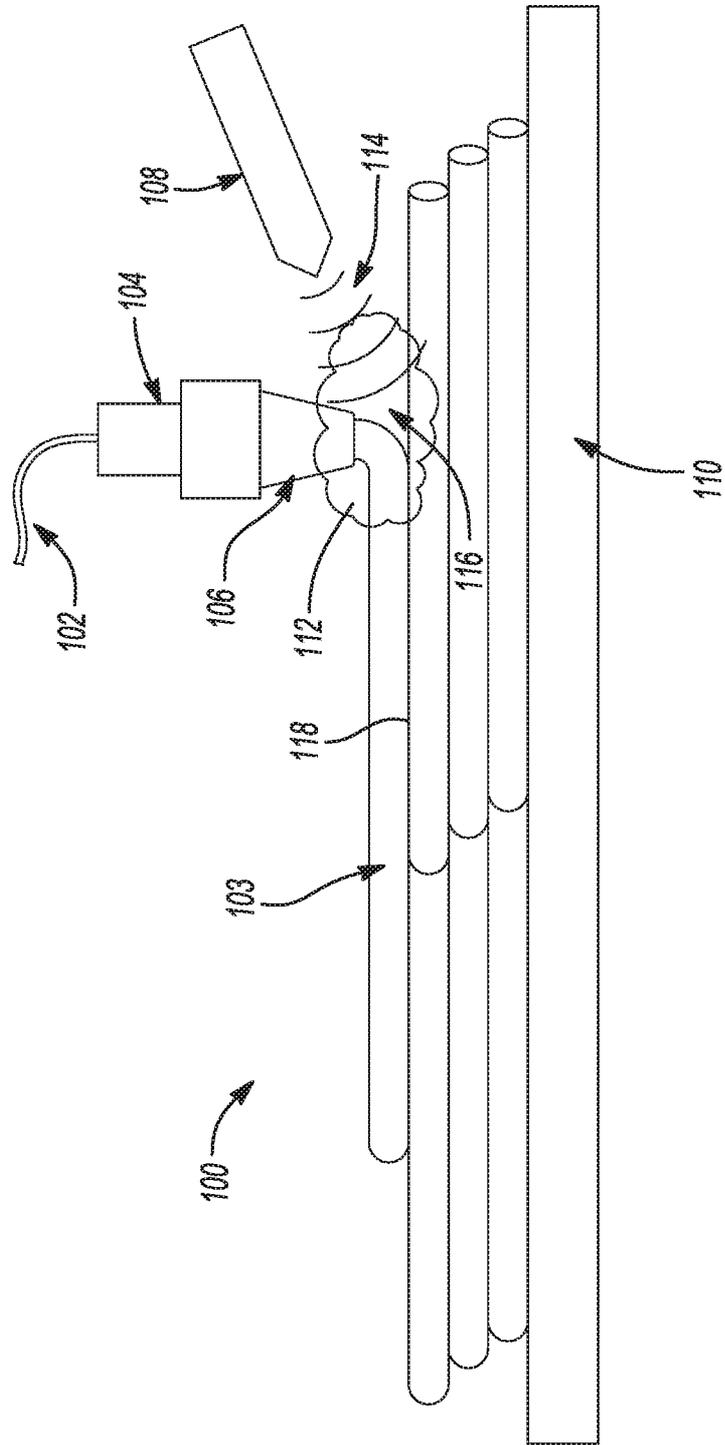


FIG. 1

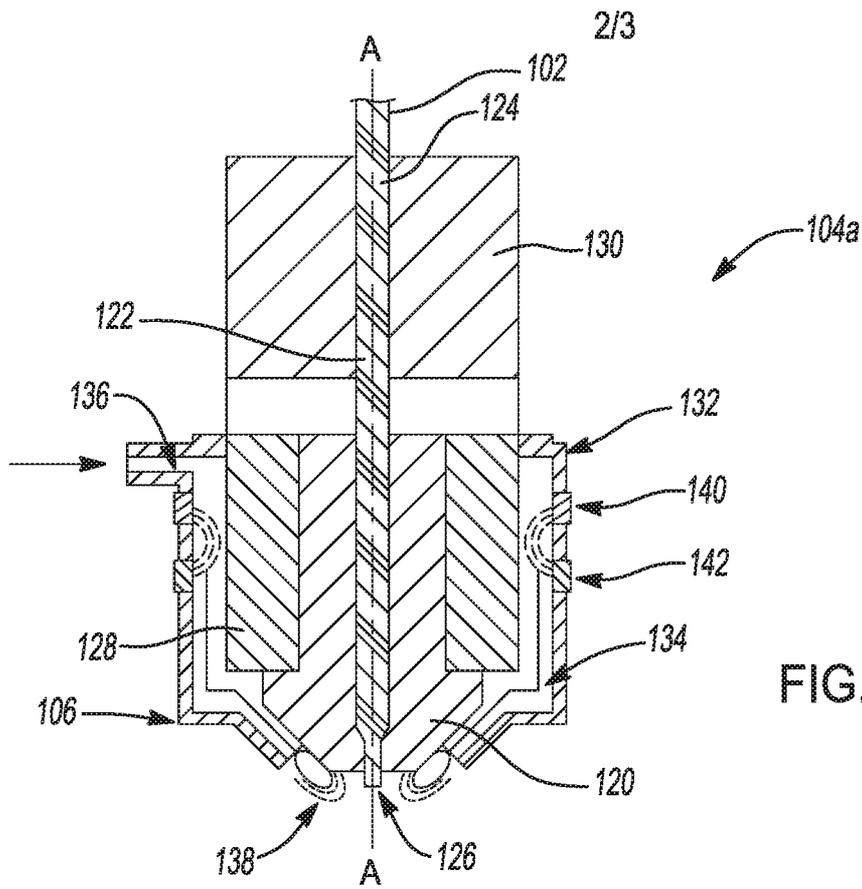


FIG. 2

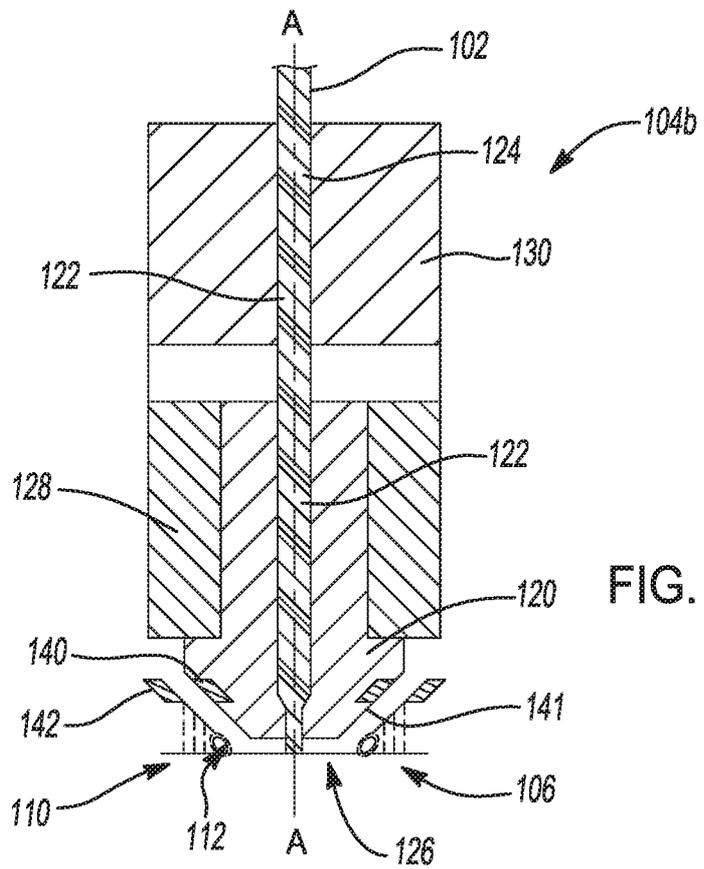


FIG. 3

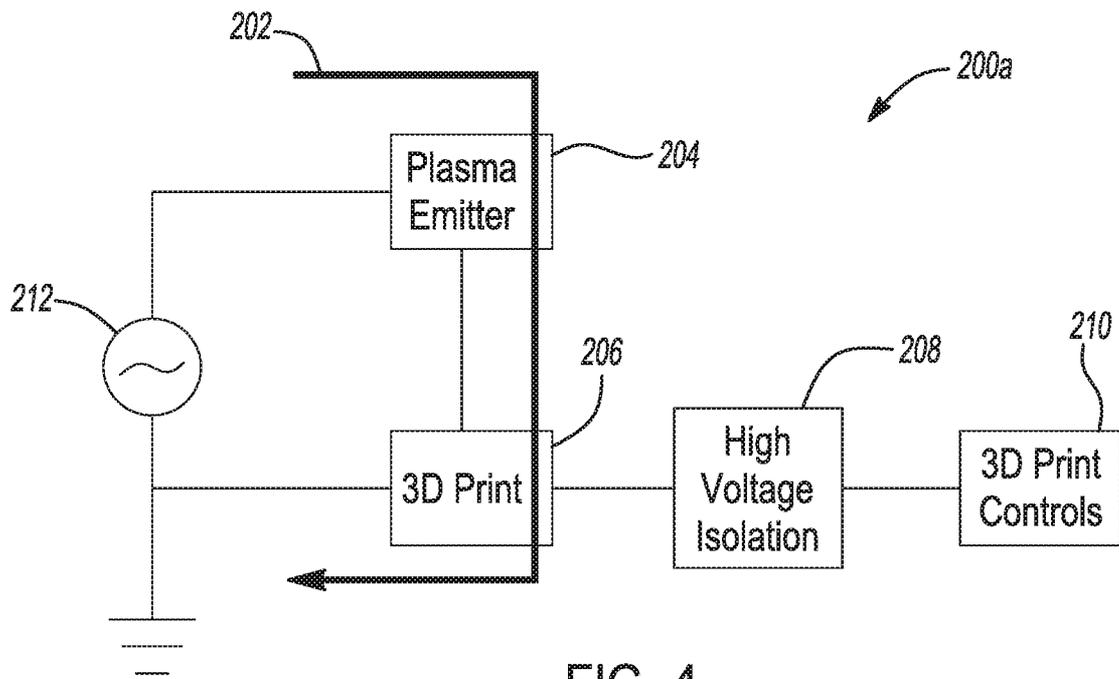


FIG. 4

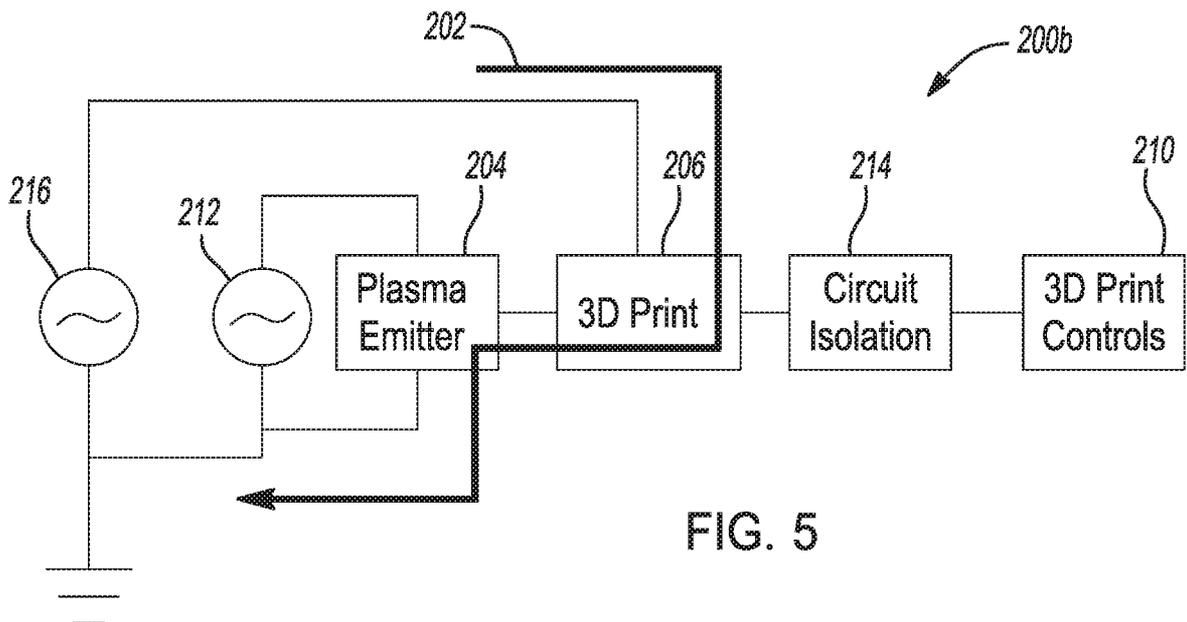


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US18/18629

| <p>A. CLASSIFICATION OF SUBJECT MATTER</p> <p>IPC - B29C 64/10, 64/106, 64/112, 64/118, 64/129, 64/20, 64/205, 64/209, 64/295 (2018.01)</p> <p>CPC - B29C 64/10, 64/106, 64/112, 64/118, 64/129, 64/20, 64/205, 64/209, 64/295</p> <p>According to International Patent Classification (IPC) or to both national classification and IPC</p>  |  |   |  |   |   |  |   |  |  |  |  |   |  |     |   |  |              |   |   |       |
|--|--|---|--|---|---|--|---|--|--|--|--|---|--|-----|---|--|--------------|---|---|-------|
| <p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols)<br/>See Search History document</p> <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br/>See Search History document</p> <p>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br/>See Search History document</p>  |  |   |  |   |   |  |   |  |  |  |  |   |  |     |   |  |              |   |   |       |
| <p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1"> <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<br/>--<br/>Y</td> <td>US 2016/0325487 A1 (EMPIRE TECHNOLOGY DEVELOPMENT LLC) 10 November 2016; abstract; figure 1B; paragraphs [0007], [0025]-[0027], [0032]-[0033]</td> <td>8-12<br/>--<br/>13-15</td> </tr> <tr> <td>Y</td> <td>US 2016/0325491 A1 (TEXAS TECH UNIVERSITY SYSTEM) 10 November 2016; abstract; paragraphs [0014], [0016]-[0018], [0024], [0086], [0093]-[0094], [0111]-[0112], [0120], [0135], [0137]</td> <td>1-7, 16-20</td> </tr> <tr> <td>Y</td> <td>US 2015/0053656 A1 (TRUMPF WERKZEUGMASCHINEN GMBH AND CO. KG) 26 February 2015; abstract; figure 1b; paragraphs [0011], [0045], [0051], [0065]</td> <td>1-7</td> </tr> <tr> <td>Y</td> <td>WO 2013/152805 A1 (EUROPEAN SPACE AGENCY) 17 October 2013; page 10, lines 14-23; page 11, lines 1-3; page 12, lines 1-4; page 16, lines 3-9; page 21, lines 7-9; figures 1-2</td> <td>13-15, 17-20</td> </tr> <tr> <td>Y</td> <td>US 2016/0271874 A1 (EP TECHNOLOGIES LLC) 22 September 2016; abstract; paragraphs [0022], [0024], [0040], [0043]</td> <td>15-20</td> </tr> </tbody> </table>   |  |   | Category*  | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No.   | X<br>--<br>Y   | US 2016/0325487 A1 (EMPIRE TECHNOLOGY DEVELOPMENT LLC) 10 November 2016; abstract; figure 1B; paragraphs [0007], [0025]-[0027], [0032]-[0033]                           | 8-12<br>--<br>13-15  | Y  | US 2016/0325491 A1 (TEXAS TECH UNIVERSITY SYSTEM) 10 November 2016; abstract; paragraphs [0014], [0016]-[0018], [0024], [0086], [0093]-[0094], [0111]-[0112], [0120], [0135], [0137] | 1-7, 16-20   | Y | US 2015/0053656 A1 (TRUMPF WERKZEUGMASCHINEN GMBH AND CO. KG) 26 February 2015; abstract; figure 1b; paragraphs [0011], [0045], [0051], [0065] | 1-7 | Y | WO 2013/152805 A1 (EUROPEAN SPACE AGENCY) 17 October 2013; page 10, lines 14-23; page 11, lines 1-3; page 12, lines 1-4; page 16, lines 3-9; page 21, lines 7-9; figures 1-2 | 13-15, 17-20 | Y | US 2016/0271874 A1 (EP TECHNOLOGIES LLC) 22 September 2016; abstract; paragraphs [0022], [0024], [0040], [0043] | 15-20 |
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| <p><input type="checkbox"/> Further documents are listed in the continuation of Box C.      <input type="checkbox"/> See patent family annex.</p>  |  |   |  |   |   |  |   |  |  |  |  |   |  |     |   |  |              |   |   |       |
| <p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"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</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"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</td> </tr> <tr> <td>"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)</td> <td>"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</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&amp;" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table> |  |   | "A" document defining the general state of the art which is not considered to be of particular relevance | "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 | "E" earlier application or patent but published on or after the international filing date | "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 | "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) | "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 | "O" document referring to an oral disclosure, use, exhibition or other means | "&" document member of the same patent family  | "P" document published prior to the international filing date but later than the priority date claimed |   |  |     |   |  |              |   |   |       |
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| <p>Date of the actual completion of the international search</p> <p>30 March 2018 (30.03.2018)</p>   |  | <p>Date of mailing of the international search report</p> <p><b>09 APR 2018</b></p>                       |  |   |   |  |   |  |  |  |  |   |  |     |   |  |              |   |   |       |
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