CLAIMS

1. A printed three-dimensional (3D) functional part comprising:

a 3D structure comprising a structural material;

at least one functional electronic device at least partially embedded in the 3D structure and having a base secured against an interior surface thereof; and

one or more conductive filaments at least partially embedded in the 3D structure and electrically connected to the at least one functional electronic device.

2. The printed 3D functional part of claim 1, wherein the 3D structure comprises a plurality of layers.

3. The printed 3D functional part of claim 1 or 2, wherein the structural material comprises a polymer, a composite, and/or a ceramic.

4. The printed 3D functional part of claim 3, wherein the polymer is selected from the group consisting of consisting of acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), poly(methyl methacrylate) (PMMA), epoxy, polydimethylsiloxane (PDMS), polyamide (Nylon), polyimide (PI), polyethylene (PE), polypropylene (PP), polystyrene (PS), polytetrafluorethylene (PTFE), polyvinylchloride (PVC), polyurethane PU), polycarbonate (PC), photocurable resins, epoxies, and hydrogels.

5. The printed 3D functional part of any one of claims 1-4, wherein the at least one functional electronic device is selected from the group consisting of electromechanical components, electrochemical components, active electronic components, passive electronic components, and integrated circuits.

6. The printed 3D functional part of any one of claims 1-5, comprising a plurality of the functional electronic devices, each of the functional electronic devices having a base secured against one of the interior surfaces of the 3D structure.

7. The printed 3D functional part of claim 6, wherein the base of at least one of the functional electronic devices is oriented at a non-zero angle with respect to the bases of other of the functional electronic devices.

8. The printed 3D functional part of any of one of claims 1-7, wherein at least one of the one or more conductive filaments is unsupported along at least a portion of a length thereof.

9. The printed 3D functional part of any one of claims 1-8, wherein at least one of the one or more conductive filaments follows a nonplanar pathway between connection points.

10. The printed 3D functional part of any one of claims 1-9, wherein the one or more conductive filaments comprise a conductive material selected from the group consisting of: silver, copper, lead, tin, lithium, cobalt, gold, platinum, palladium, titanium, molybdenum, tungsten, tantalum, rhenium, zirconium, vanadium, chromium, niobium, iron, nickel, zinc, aluminum, magnesium, and carbon.

11. The printed 3D functional part any one of claims 1-10, wherein each of the one or more conductive filaments exhibits a conductivity of at least about 2.5% a bulk conductivity of the conductive material.

12. The printed 3D functional part of any one of claims 1-11, wherein each of the one or more conductive filaments comprises a diameter or width of about 500 microns or less.

13. The printed 3D functional part of any one of claims 1-12, wherein each of the one or more conductive filaments comprises a percolating network of conductive particles.

14. The printed 3D functional part of claim 13, wherein the conductive particles comprise silver flakes.

15. The printed 3D functional part of any one of claims 1-14, wherein the conductive filaments comprise one or more secured portions attached to the 3D structure with an adhesion strength sufficient to pass an adhesion test conducted according to ASTM Test Method D3359.

16. A method of printing a three-dimensional (3D) functional part, the method comprising:

extruding and depositing a structural filament in a predetermined pattern on a substrate to form one or more portions of a 3D structure;

placing or forming at least one functional electronic device on an exposed surface of the one or more portions; and

extruding and depositing one or more conductive filaments to form interconnections with the at least one functional electronic device.

17. The method of claim 16, wherein the structural filament is extruded out of a first nozzle and the one or more conductive filaments are extruded out of a second nozzle.

18. The method of claim 16 or 17, wherein at least one of the one or more conductive filaments are extruded and deposited while the structural filament is being extruded and deposited.

19. The method of claim 16 or 17, wherein the one or more conductive filaments are extruded and deposited after the structural filament is extruded and deposited.

20. The method of any one of claims 16-19, further comprising:

extruding and depositing an additional length of the structural filament in a predetermined pattern on the substrate to form one or more additional portions of the 3D structure, the one or more additional portions at least partially covering the at least one functional electronic device.

21. The method of claim 20, wherein the one or more additional portions completely cover the at least one functional electronic device.

22. The method of claim 20 or 21, wherein the one or more additional portions at least partially cover the one or more conductive filaments.

23. The method of any one of claims 16-22, wherein the one or more conductive filaments comprise conductive particles in a solvent, and

wherein the structural filament comprises a polymer.

24. The method of claim 23, wherein the solvent comprises Hansen solubility parameters (∂_d, ∂_p, ∂_h) lying within a solubility sphere of the polymer.

25. The method of claim 23 or 24, wherein the solvent comprises one or more of: ethyl acetate, butyl acetate, propyl acetate, pentyl acetate, hexyl acetate, heptyl acetate, butoxyethyl acetate, ethylene glycol butyl ether, ethyl 3-ethoxypropionate, propylene glycol butyl ether acetate, ethylene glycol butyl ether acetate, propylene carbonate, methanol, ethanol, propanol, butanol, pentanol, hexanol, heptanol, octanol, formic acid, acetic acid, propionic acid, water, ethylene glycol, glycerol, n-methyl-pyrrolidone, dimethyl sulfoxide, dimethylformamide, tetrahydrofuran and 2-methyl tetrahydrofuran.

26. The method of any one of claims 23-25, wherein the polymer is selected from the group consisting of: acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), poly(methyl methacrylate) (PMMA), polydimethylsiloxane (PDMS), polyamide (Nylon), polyimide (PI), polyethylene (PE), polypropylene (PP), polystyrene (PS), polytetrafluorethylene (PTFE), polyvinylchloride (PVC), polyurethane PU), polycarbonate (PC), photocurable resins, epoxies, and hydrogels.

27. The method of any one of claims 16-26, wherein placing the at least one functional device on the exposed surface comprises a pick and place maneuver.

28. The method of any one of claims 16-27, wherein the at least one functional electronic device is placed in a cavity comprising the exposed surface, the functional electronic device being surrounded on all sides except

for an exposed face by structural material, so as to be partially embedded in the 3D structure, and wherein the exposed face comprises accessible contact pads for electrical connection to the functional electronic device.

29. The method of any one of claims 16-28, wherein the at least one functional device includes a battery, and the battery is placed on the exposed surface.

30. The method of any one of claims 16-29, wherein forming the at least one functional device on the exposed surface comprises extruding at least one device filament and depositing the device filament in a predetermined pattern on the substrate.

31. The method of claim 30, wherein the at least one functional device includes a battery, wherein the at least one device filament comprises an anode filament and a cathode filament, and wherein forming the battery comprises:

extruding the cathode filament comprising a first electrochemically active material and depositing the cathode filament in a predetermined pattern on the second exposed surface to form a cathode structure; and

extruding the anode filament comprising a second electrochemically active material and depositing the anode filament in a predetermined pattern on the second exposed surface to form an anode structure.

32. A method of printing a three-dimensional (3D) functional part, the method comprising:

extruding and depositing a structural filament in a predetermined pattern on a substrate to form one or more portions of a 3D structure, the 3D structure having a predetermined volume;

placing or forming at least one functional electronic device on an exposed surface of the one or more portions;

forming a battery on another exposed surface of the one or more portions, the battery having dimensions customized to the predetermined

volume; and

extruding and depositing one or more conductive filaments to form interconnections with the at least one functional electronic device and the battery.

33. The method of claim 32, wherein the exposed surface is part of a cavity or a channel in the 3D structure.

34. The method of claim 32 or 33, further comprising extruding and depositing an additional length of the structural filament in a predetermined pattern on the substrate to form one or more additional portions of the 3D structure, the one or more additional portions at least partially covering the at least one functional electronic device and the microbattery.

35. The method of claim 34, wherein the one or more additional portions completely cover the at least one functional electronic device and the battery.

36. The method of any one of claims 32-35, wherein forming the battery comprises:

extruding and depositing a cathode filament comprising a first electrochemically active material in a predetermined pattern on the second exposed surface to form a cathode structure; and

extruding and depositing an anode filament comprising a second electrochemically active material in a predetermined pattern on the second exposed surface to form an anode structure.

37. The method of any one of claims 32-36, wherein the 3D functional part comprises a hearing aid and the 3D structure comprises a polymeric body.

38. A method of printing a three-dimensional (3D) functional part, the method comprising:

forming one or more portions of a 3D structure using a 3D printing method;

positioning at least one functional electronic device on an exposed surface of the one or more portions; and

forming conductive interconnects to and from the at least one functional electronic device using a 3D printing method.

39. The method of claim 38, further comprising

forming one or more additional portions of the 3D structure using a 3D printing method, the one or more additional portions at least partially covering the at least one functional electronic device.

40. The method of claim 39, wherein the one or more additional portions completely cover the at least one functional electronic device.

41. The method of claim any one of claims 38-40, wherein the positioning of the at least one functional electronic device comprises a pick and place maneuver.

42. The method of any one of claims 38-41, wherein the positioning of the at least one electronic device comprises a 3D printing method.

43. The method of any one of claims 38-42, comprising a plurality of functional electronic devices, and wherein the positioning of at least one of the functional electronic devices comprises a pick and place maneuver, and wherein the positioning of another of the functional electronic devices comprises a 3D printing method.

44. The method of any one of claims 38-43, wherein the 3D printing method is selected from the group consisting of: direct-write fabrication, inkjet printing on a powder bed, selective laser sintering of a powder bed, stereolithography, fused deposition modeling, direct inkjet printing of UV curable resins.

45. The method of any one of claims 38-44, wherein the conductive interconnects include one or more secured portions attached to the 3D structure, the one or more secured portions being attached with an adhesion

strength sufficient to pass an adhesion test conducted according to ASTM Test Method D3359.

46. The method of any one of claims 38-45, wherein the conductive interconnects comprise a percolating network of conductive particles.

47. A 3D printer comprising:

two or more computer-controlled modular printheads removeably mounted adjacent to each other, each printhead comprising at least one nozzle for extruding a structural and/or functional filament.

48. The 3D printer of claim 47, comprising up to eight of the computer-controlled modular printheads.

49. The 3D printer of claim 47 or 48, wherein at least one of the computer-controlled modular printheads is an elevated-temperature printhead comprising a heater for extrusion at elevated temperatures.

50. The 3D printer of claim 49, wherein the elevated temperature printhead is configured to receive a continuous feed of a monofilament of material to be extruded.

51. The 3D printer of any one of claims 47-50, wherein at least one of the computer-controlled modular printheads is a room-temperature printhead configured for connection to at least one ink reservoir.

52. The 3D printer of claim 51, wherein the room-temperature printhead is pneumatically-driven at a constant pressure.

53. The 3D printer of claim 51, wherein the room-temperature printhead is mechanically driven at a constant displacement rate.

54. The 3D printer of any one of claims 47-53, wherein at least one of the computer-controlled, modular printheads comprises a plurality of nozzles.

55. The 3D printer of any one of claims 47-54, further comprising a substrate underlying the computer-controlled, modular printheads for deposition of extruded filaments.

CLAIMS

1. A printed three-dimensional (3D) functional part comprising:

a 3D structure comprising a structural material;

at least one functional electronic device at least partially embedded in the 3D structure and having a base secured against an interior surface thereof; and

one or more conductive filaments at least partially embedded in the 3D structure and electrically connected to the at least one functional electronic device.

2. The printed 3D functional part of claim 1, wherein the structural material comprises a polymer, a composite, and/or a ceramic.

3. The printed 3D functional part of any one of claims 1-2, wherein the at least one functional electronic device is selected from the group consisting of electromechanical components, electrochemical components, active electronic components, passive electronic components, and integrated circuits.

4. The printed 3D functional part of any one of claims 1-3, comprising a plurality of the functional electronic devices, each of the functional electronic devices having a base secured against one of the interior surfaces of the 3D structure.

5. The printed 3D functional part of any of one of claims 1-4, wherein at least one of the one or more conductive filaments is unsupported along at least a portion of a length thereof.

6. The printed 3D functional part of any one of claims 1-5, wherein at least one of the one or more conductive filaments follows a nonplanar pathway between connection points.

7. The printed 3D functional part of any one of claims 1-6, wherein each of the one or more conductive filaments comprises a diameter or width of about 500 microns or less.

8. The printed 3D functional part of any one of claims 1-7, wherein each of the one or more conductive filaments comprises a percolating network of conductive particles.

9. A method of printing a three-dimensional (3D) functional part, the method comprising:

extruding and depositing a structural filament in a predetermined pattern on a substrate to form one or more portions of a 3D structure;

placing or forming at least one functional electronic device on an exposed surface of the one or more portions; and

extruding and depositing one or more conductive filaments to form interconnections with the at least one functional electronic device.

10. The method of claim 9, wherein the structural filament is extruded out of a first nozzle and the one or more conductive filaments are extruded out of a second nozzle.

11. The method of any one of claims 9-10, further comprising:

extruding and depositing an additional length of the structural filament in a predetermined pattern on the substrate to form one or more additional portions of the 3D structure, the one or more additional portions at least partially covering the at least one functional electronic device.

12. The method of claim 11, wherein the one or more additional portions at least partially cover the one or more conductive filaments.

13. The method of any one of claims 9-12, wherein the one or more conductive filaments comprise conductive particles in a solvent, and

wherein the structural filament comprises a polymer.

14. The method of claim 13, wherein the solvent comprises one or more of: ethyl acetate, butyl acetate, propyl acetate, pentyl acetate, hexyl acetate, heptyl acetate, butoxyethyl acetate, ethylene glycol butyl ether, ethyl 3-ethoxypropionate, propylene glycol butyl ether acetate, ethylene glycol butyl ether acetate, propylene carbonate, methanol, ethanol, propanol, butanol, pentanol, hexanol, heptanol, octanol, formic acid, acetic acid, propionic acid, water, ethylene glycol, glycerol, n-methyl-pyrrolidone, dimethyl sulfoxide, dimethylformamide, tetrahydrofuran and 2-methyl tetrahydrofuran.

15. The method of any one of claims 13-14, wherein the polymer is selected from the group consisting of: acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), poly(methyl methacrylate) (PMMA), polydimethylsiloxane (PDMS), polyamide (Nylon), polyimide (PI), polyethylene (PE), polypropylene (PP), polystyrene (PS), polytetrafluorethylene (PTFE), polyvinylchloride (PVC), polyurethane PU), polycarbonate (PC), photocurable resins, epoxies, and hydrogels.

16. The method of any one of claims 9-15, wherein placing the at least one functional device on the exposed surface comprises a pick and place maneuver.

17. The method of any one of claims 9-16, wherein the at least one functional electronic device is placed in a cavity comprising the exposed surface, the functional electronic device being surrounded on all sides except for an exposed face by structural material, so as to be partially embedded in the 3D structure, and wherein the exposed face comprises accessible contact pads for electrical connection to the functional electronic device.

18. The method of any one of claims 9-17, wherein the at least one functional device includes a battery, and the battery is placed on the exposed surface.

19. The method of any one of claims 9-18, wherein forming the at least one functional device on the exposed surface comprises extruding at least

one device filament and depositing the device filament in a predetermined pattern on the substrate.

20. The method of claim 19, wherein the at least one functional device includes a battery, wherein the at least one device filament comprises an anode filament and a cathode filament, and wherein forming the battery comprises:

extruding the cathode filament comprising a first electrochemically active material and depositing the cathode filament in a predetermined pattern on the second exposed surface to form a cathode structure; and

extruding the anode filament comprising a second electrochemically active material and depositing the anode filament in a predetermined pattern on the second exposed surface to form an anode structure.

21. A method of printing a three-dimensional (3D) functional part, the method comprising:

extruding and depositing a structural filament in a predetermined pattern on a substrate to form one or more portions of a 3D structure, the 3D structure having a predetermined volume;

placing or forming at least one functional electronic device on an exposed surface of the one or more portions;

forming a battery on another exposed surface of the one or more portions, the battery having dimensions customized to the predetermined volume; and

extruding and depositing one or more conductive filaments to form interconnections with the at least one functional electronic device and the battery.

22. The method of claim 21, wherein the exposed surface is part of a cavity or a channel in the 3D structure.

23. The method of claim 21 or 22, further comprising extruding and depositing an additional length of the structural filament in a predetermined

pattern on the substrate to form one or more additional portions of the 3D structure, the one or more additional portions at least partially covering the at least one functional electronic device and the microbattery.

24. The method of any one of claims 21-23, wherein forming the battery comprises:

extruding and depositing a cathode filament comprising a first electrochemically active material in a predetermined pattern on the second exposed surface to form a cathode structure; and

extruding and depositing an anode filament comprising a second electrochemically active material in a predetermined pattern on the second exposed surface to form an anode structure.

25. The method of any one of claims 21-24, wherein the 3D functional part comprises a hearing aid and the 3D structure comprises a polymeric body.