[0010] SUMMARY OF THE INVENTION

[0011] In a first aspect, a system for additive manufacturing of three-dimensional structures is provided. The system comprises at least one a print head for receiving and dispensing materials, the materials comprising a sheath fluid and a hydrogel. In one embodiment, the print head comprises an orifice for dispensing the materials; microfluidic channels comprising one or more first channels for receiving and directing the sheath fluid and one or more respective second channels for receiving and directing the hydrogel, the second channels intersecting at a first intersection point with the first channels, the second and first channels joining together at the first intersection point to form a dispensing channel which extends to the orifice; and fluidic switches, each fluidic switch corresponding to one of the microfluidic channels in the print head and configured to allow or disallow fluid flow in the microfluidic channels of the print head when actuated. In one embodiment, the system further comprises a receiving surface for receiving a first layer of the materials dispensed from the orifice; a positioning unit for positioning the orifice of the print head in three dimensional space, the positioning unit operably coupled to the print head; and a dispensing means for dispensing the materials from the orifice of the print head.

[0012] In one embodiment of the first aspect, the system comprises a programmable control processor for controlling the positioning unit and for controlling dispensing of the materials from the print head onto the receiving surface.

[0013] In one embodiment of the first aspect, the one or more first channels comprise at least two channels, the one or more first channels being configured to flank respective second channels at the first intersection point.

[0014] In one embodiment of the first aspect, the sheath fluid comprises a cross-linking agent for solidifying the hydrogel upon contact therewith at the intersection point and/or in the dispensing channel.

[0015] In one embodiment of the first aspect, each second channel has a diameter less than that of the first channels and the dispensing channel, whereby flow from the first channels forms a coaxial sheath around the hydrogel in the dispensing channel.

[0016] In one embodiment of the first aspect, the hydrogel comprises living cells.

[0017] In one embodiment of the first aspect, the system further comprises a fluid removal feature for removing excess sheath fluid from dispensed from the print head.

channel [506] intersect at a hydrogel focussing intersection point [510], for example in a "y-shaped" configuration (similar to intersection [528] shown in Figure 3) joining together to form a focussing channel [226] downstream of channels [506] and [508]. At the hydrogel focussing intersection [510], the shell material focusses the core material coaxially such that the shell material forms a sheath around the core material. In preferred embodiments, channels [508] and [226] have a larger diameter than channel [506] to facilitate coaxial focussing of the core and shell materials. In a preferred embodiment, the purpose of the shell material is to provide the core material with physical structural support so that it may be formed into a 3D geometry. The core may be solidified after the material is deposited, the precise method of solidification being specific to different core materials. For example, the core may comprise a material that solidifies very slowly. In another embodiment, the core and shell materials comprise the same materials. In yet another embodiment, the shell material comprises a hydrogel that rapidly solidifies and the core material comprises a material that will not gel, thereby facilitating generation of a hollow fiber.

[0090] In one embodiment, the print head [100] depicted in Figure 6 could further comprise additional core material channels, each with a corresponding fluidic switch, for example a valve, for regulating flow of the material therein. The fluidic switch facilitates rapid and frequent adjustments to the composition of the core material in the fiber being dispensed, for example, by commands provided by the programmable control processor.

[0091] In one embodiment, several print heads could be arranged, for example in parallel, to allow simultaneous printing of multiple structures. This would increase throughput production.

[0092] In some embodiments the print head is disposable. Use of disposable print heads can reduce the likelihood of contamination of materials used in different print jobs.

[0093] The print head can be fabricated, for example, using known microfluidics molding techniques (e.g., casting, imprinting or injection molding) and one or more moldable polymers, for example, polydimethylsiloxane (PDMS). Alternatively, commercially available 3D printing technology could be used to fabricate the print head.

[0094] FLUIDIC REMOVAL FEATURE

[0095] In an aspect, the invention provides a system for additive manufacturing of three-dimensional structures that comprises a feature for removing excess sheath fluid from the receiving surface where a first layer of material dispensed from the orifice of the print head is deposited and optionally from a surface of dispensed hydrogel. During printing, it is possible

WE CLAIM:

1. A system for additive manufacturing of three-dimensional structures, the system comprising:

- at least one print head for receiving and dispensing materials, the materials comprising at least one first material and at least one second material, the print head comprising:

- an orifice for dispensing the materials;

-microfluidic channels comprising one or more first channels for receiving and directing the first material and one or more respective second channels for receiving and directing the second material, the second channels intersecting at a first intersection point with the first channels, the second and first channels joining together at the first intersection point to form a dispensing channel which extends to the orifice; and

- fluidic switches, each fluidic switch corresponding to one of the microfluidic channels in the print head and configured to allow or disallow fluid flow in the microfluidic channels of the print head when actuated;

- a receiving surface for receiving a first layer of the materials dispensed from the orifice;

- a positioning unit for positioning the orifice of the print head in three dimensional space, the positioning unit operably coupled to the print head; and

- a dispensing means for dispensing the materials from the orifice of the print head.

2. The system of claim 1, wherein the at least one first material comprises a sheath fluid and the at least one second material comprises a hydrogel.

3. The system of claim 1 or 2, further comprising a programmable control processor for controlling the positioning unit and for controlling dispensing of the materials from the print head onto the receiving surface.

4. The system of any one of claims 1 to 3, wherein the one or more first channels comprise at least two channels, the one or more first channels being configured to flank respective second channels at the first intersection point.

5. The system of any one of claims 1 to 4, wherein the at least one first material comprises a cross-linking agent for solidifying the at least one second material upon contact therewith at the intersection point and/or in the dispensing channel.

6. The system any one of claims 1 to 5, wherein each second channel has a diameter less than that of the first channels and the dispensing channel, whereby flow from the first channels forms a coaxial sheath around the at least one second material in the dispensing channel.

7. The system of any one of claims 1 to 6, wherein the at least one second material comprises living cells.

8. The system of any one of claims 1 to 6, further comprising a fluid removal feature for removing excess first material dispensed from the print head.

9. The system of claim 8, wherein the receiving surface comprises a porous membrane comprising pores sized to permit passage of the excess second material there through.

10. The system of claim 9, wherein the fluid removal feature comprises absorbent material or a vacuum for drawing the excess second material away from the receiving surface.

11. The system of claim 10, wherein the absorbent material or vacuum is applied below a porous membrane.

12. The system of claim 10, wherein the vacuum is applied above the receiving surface.

13. The system of claim 12, wherein the vacuum is applied through one or more vacuum channels provided on the print head, the one or more vacuum channels having an orifice situated near the orifice of the print head.

14. The system of any one of claims 1 to 13, further comprising reservoirs for containing the materials, the reservoirs being fluidly coupled respectively to the microfluidic channels in the print head.

15. The system of claim 14, wherein the print head further comprises at least two inlets for receiving the materials from the reservoirs, each of the inlets being in fluid communication with respective microfluidic channels and the respective reservoirs.

16. The system of any one of claims 1 to 15, wherein the dispensing means comprises a pressure control unit.

17. The system of any one of claims 1 to 16, wherein the fluidic switches comprise valves.

18. The system of any one of claims 1 to 17, wherein the print head further comprises a hollow projection configured to extend from the orifice toward the receiving surface.

19. The system of any one of claims 1 to 18, wherein the print head comprises two second channels, each of the second channels being adapted to convey respective second materials, the two second channels intersecting at a second intersection and joining together at the second intersection to form a third channel which extends to the first intersection point.

20. A system for additive manufacturing of three-dimensional structures, the system comprising:

- at least one print head for receiving and dispensing materials, the materials comprising a first material and a second material, the print head comprising:
  - an orifice for dispensing the materials;
  - microfluidic channels for receiving and directing the materials to the orifice; and
  - fluidic switches, each fluidic switch corresponding to one of the microfluidic channels in the print head and configured to allow or disallow fluid flow in the microfluidic channels in the print head when actuated;
- a receiving surface for receiving the materials dispensed from the orifice;
- a fluid removal feature for removing excess first material dispensed from the orifice;
- a positioning unit for positioning the orifice of the print head in three dimensional space, the positioning unit operably coupled to the print head; and
- a dispensing means for dispensing the materials from the orifice of the print head.

21. The system of claim 20, wherein the first material comprises a sheath fluid and the second material comprises a hydrogel.

22. The system of claim 20 or 21, wherein the fluid removal feature comprises a vacuum for drawing the excess first material away from or through the receiving surface and/or from the second material dispensed on the receiving surface.

23. The system claim 22, wherein the receiving surface comprises a porous membrane comprising pores sized to permit passage of the excess first material there through.

24. The system of claim 23, wherein the vacuum is applied below the porous membrane.

25. The system of claim 22, wherein the vacuum is applied above the receiving surface.

26. The system of claim 25, wherein the vacuum is applied through one or more vacuum channels provided on the print head, the one or more vacuum channels having an orifice situated near the orifice of the print head.

27. The system of claim 20 or 21, wherein the fluid removal feature comprises an absorbent material for drawing away from the receiving surface the excess first material.

28. The system of any one of claims 23 to 27, further comprising a programmable control processor for controlling the positioning unit and for controlling dispensing of the materials from the print head onto the receiving surface.

29. The system of any one of claims 23 to 28, wherein the print head further comprises a hollow projection configured to extend from the orifice toward the receiving surface.

30. The system of any one of claims 23 to 29, wherein the print head comprises one or more first channels for receiving and directing the first material and one or more respective second channels for receiving and directing the second material, the second channels intersecting at a first intersection point with the first channels, the second and first channels joining together at the first intersection point to form a dispensing channel which extends to the orifice.

31. The system of claim 30, wherein the print head comprises two second channels, each of the second channels being adapted to convey respective second materials, the two second channels intersecting at a second intersection and joining together at the second intersection to form a third channel which extends to the first intersection point

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

- providing a 3D printer, the printer comprising:
    - at least one print head comprising an orifice for dispensing materials;
    - a receiving surface for receiving a first layer of the materials dispensed from the orifice of the print head; and
    - a positioning unit operably coupled to the print head, the positioning unit for positioning the print head in three dimensional space;
    - providing the materials to be dispensed, the materials to be dispensed comprising a sheath fluid and one or more hydrogels;
- encoding the printer with a 3D structure to be printed;
- dispensing from the print head orifice the materials to be dispensed, wherein the sheath fluid and the hydrogel are dispensed in a coaxial arrangement, and wherein the sheath fluid envelops the hydrogel;
- depositing a first layer of the dispensed materials on the receiving surface;
- repeating the depositing step by depositing subsequent dispensed material on the first and any subsequent layers of deposited material, thereby depositing layer upon layer of dispensed materials in a geometric arrangement according to the 3D structure; and
- removing excess sheath fluid dispensed by the print head orifice at one or more time point during or between depositing steps.

33. The method of claim 32, wherein the sheath fluid comprises a cross-linking agent suitable for cross-linking and solidifying the hydrogel upon contact therewith, the contact creating a hydrogel fiber.

34. The method of claim 32 or 33, wherein the depositing step and the removing step are carried out continuously, thereby continuously removing the excess sheath fluid as the layers of dispensed materials are deposited.

35. The method of claim 32 or 33, wherein the removing step is carried out intermittently between and/or at the same time as the depositing step, thereby intermittently removing the excess sheath fluid as the layers of dispensed materials are deposited.

36. The method of any one of claims 32 to 35, wherein the one or more hydrogels are adapted for supporting growth and/or proliferation of living cells dispersed therein.

[0010] SUMMARY OF THE INVENTION

[0010a] The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

[0011] In a first aspect, a system for additive manufacturing of three-dimensional structures is provided. The system comprises at least one a print head for receiving and dispensing materials, the materials comprising a sheath fluid and a hydrogel. In one embodiment, the print head comprises an orifice for dispensing the materials; microfluidic channels comprising one or more first channels for receiving and directing the sheath fluid and one or more respective second channels for receiving and directing the hydrogel, the second channels intersecting at a first intersection point with the first channels, the second and first channels joining together at the first intersection point to form a dispensing channel which extends to the orifice; and fluidic switches, each fluidic switch corresponding to one of the microfluidic channels in the print head and configured to allow or disallow fluid flow in the microfluidic channels of the print head when actuated. In one embodiment, the system further comprises a receiving surface for receiving a first layer of the materials dispensed from the orifice; a positioning unit for positioning the orifice of the print head in three dimensional space, the positioning unit operably coupled to the print head; and a dispensing means for dispensing the materials from the orifice of the print head.

[0012] In one embodiment of the first aspect, the system comprises a programmable control processor for controlling the positioning unit and for controlling dispensing of the materials from the print head onto the receiving surface.

[0013] In one embodiment of the first aspect, the one or more first channels comprise at least two channels, the one or more first channels being configured to flank respective second channels at the first intersection point.

[0014] In one embodiment of the first aspect, the sheath fluid comprises a cross-linking agent for solidifying the hydrogel upon contact therewith at the intersection point and/or in the dispensing channel.

[0015] In one embodiment of the first aspect, each second channel has a diameter less than that of the first channels and the dispensing channel, whereby flow from the first channels forms a coaxial sheath around the hydrogel in the dispensing channel.

[0016] In one embodiment of the first aspect, the hydrogel comprises living cells.

[0017] In one embodiment of the first aspect, the system further comprises a fluid removal feature for removing excess sheath fluid from dispensed from the print head.

channel [506] intersect at a hydrogel focussing intersection point [510], for example in a "y-shaped" configuration (similar to intersection [528] shown in Figure 3) joining together to form a focussing channel [226] downstream of channels [506] and [508]. At the hydrogel focussing intersection [510], the shell material focusses the core material coaxially such that the shell material forms a sheath around the core material. In preferred embodiments, channels [508] and [226] have a larger diameter than channel [506] to facilitate coaxial focussing of the core and shell materials. In a preferred embodiment, the purpose of the shell material is to provide the core material with physical structural support so that it may be formed into a 3D geometry. The core may be solidified after the material is deposited, the precise method of solidification being specific to different core materials. For example, the core may comprise a material that solidifies very slowly. In another embodiment, the core and shell materials comprise the same materials. In yet another embodiment, the shell material comprises a hydrogel that rapidly solidifies and the core material comprises a material that will not gel, thereby facilitating generation of a hollow fiber.

[0090] In one embodiment, the print head [100] depicted in Figure 6 could further comprise additional core material channels, each with a corresponding fluidic switch, for example a valve, for regulating flow of the material therein. The fluidic switch facilitates rapid and frequent adjustments to the composition of the core material in the fiber being dispensed, for example, by commands provided by the programmable control processor.

[0091] In one embodiment, several print heads could be arranged, for example in parallel, to allow simultaneous printing of multiple structures. This would increase throughput production.

[0092] In some embodiments the print head is disposable. Use of disposable print heads can reduce the likelihood of contamination of materials used in different print jobs.

[0093] The print head can be fabricated, for example, using known microfluidics molding techniques (e.g., casting, imprinting or injection molding) and one or more moldable polymers, for example, polydimethylsiloxane (PDMS). Alternatively, commercially available 3D printing technology could be used to fabricate the print head.

[0094] FLUIDIC REMOVAL FEATURE

[0095] In an aspect, it is possible to provide a system for additive manufacturing of three-dimensional structures that comprises a feature for removing excess sheath fluid from the receiving surface where a first layer of material dispensed from the orifice of the print head is deposited and optionally from a surface of dispensed hydrogel. During printing, it is possible

WE CLAIM:

1. A system for additive manufacturing of three-dimensional structures, the system comprising:

- at least one print head for receiving and dispensing materials, the materials comprising at least one first material and at least one second material, the print head comprising:

- an orifice for dispensing the materials;

-microfluidic channels comprising one or more first channels for receiving and directing the first material and one or more respective second channels for receiving and directing the second material, the second channels intersecting at a first intersection point with the first channels, the second and first channels joining together at the first intersection point to form a dispensing channel which extends to the orifice; and

- fluidic switches, each fluidic switch corresponding to one of the microfluidic channels in the print head and configured to allow or disallow fluid flow in the microfluidic channels of the print head when actuated;

- a receiving surface for receiving a first layer of the materials dispensed from the orifice;

- a positioning unit for positioning the orifice of the print head in three dimensional space, the positioning unit operably coupled to the print head; and

- a dispensing means for dispensing the materials from the orifice of the print head.

2. The system of claim 1, wherein the at least one first material comprises a sheath fluid and the at least one second material comprises a hydrogel.

3. The system of claim 1 or 2, further comprising a programmable control processor for controlling the positioning unit and for controlling dispensing of the materials from the print head onto the receiving surface.

4. The system of any one of claims 1 to 3, wherein the one or more first channels comprise at least two channels, the one or more first channels being configured to flank respective second channels at the first intersection point.

5. The system of any one of claims 1 to 4, wherein the at least one first material comprises a cross-linking agent for solidifying the at least one second material upon contact therewith at the intersection point and/or in the dispensing channel.

6. The system any one of claims 1 to 5, wherein each second channel has a diameter less than that of the first channels and the dispensing channel, the system being arranged for flow from the first channels to form a coaxial sheath around the at least one second material in the dispensing channel.

7. The system of any one of claims 1 to 6, wherein the at least one second material comprises living cells.

8. The system of any one of claims 1 to 6, further comprising a fluid removal feature for removing excess first material dispensed from the print head.

9. The system of claim 8, wherein the receiving surface comprises a porous membrane comprising pores sized to permit passage of the excess first material there through.

10. The system of claim 9, wherein the fluid removal feature comprises absorbent material or a vacuum for drawing the excess first material away from the receiving surface.

11. The system of claim 10, arranged for the absorbent material or vacuum to be applied below a porous membrane.

12. The system of claim 10, arranged for the vacuum to be applied above the receiving surface.

13. The system of claim 12, arranged for the vacuum to be applied through one or more vacuum channels provided on the print head, the one or more vacuum channels having an orifice situated near the orifice of the print head.

14. The system of any one of claims 1 to 13, further comprising reservoirs for containing the materials, the reservoirs being fluidly coupled respectively to the microfluidic channels in the print head.

15. The system of claim 14, wherein the print head further comprises at least two inlets for receiving the materials from the reservoirs, each of the inlets being in fluid communication with respective microfluidic channels and the respective reservoirs.

16. The system of any one of claims 1 to 15, wherein the dispensing means comprises a pressure control unit.

17. The system of any one of claims 1 to 16, wherein the fluidic switches comprise valves.

18. The system of any one of claims 1 to 17, wherein the print head further comprises a hollow projection configured to extend from the orifice toward the receiving surface.

19. The system of any one of claims 1 to 18, wherein the print head comprises two second channels, each of the second channels being adapted to convey respective second materials, the two second channels intersecting at a second intersection and joining together at the second intersection to form a third channel which extends to the first intersection point.

20. A system for additive manufacturing of three-dimensional structures, the system comprising:

- at least one print head for receiving and dispensing materials, the materials comprising a first material and a second material, the print head comprising:
    - an orifice for dispensing the materials;
    - microfluidic channels for receiving and directing the materials to the orifice; and
    - fluidic switches, each fluidic switch corresponding to one of the microfluidic channels in the print head and configured to allow or disallow fluid flow in the microfluidic channels in the print head when actuated;
- a receiving surface for receiving the materials dispensed from the orifice;
- a fluid removal feature for removing excess first material dispensed from the orifice;
- a positioning unit for positioning the orifice of the print head in three dimensional space, the positioning unit operably coupled to the print head; and
- a dispensing means for dispensing the materials from the orifice of the print head.

21. The system of claim 20, wherein the first material comprises a sheath fluid and the second material comprises a hydrogel.

22. The system of claim 20 or 21, wherein the fluid removal feature comprises a vacuum for drawing the excess first material away from or through the receiving surface and/or from the second material dispensed on the receiving surface.

23. The system claim 22, wherein the receiving surface comprises a porous membrane comprising pores sized to permit passage of the excess first material there through.

24. The system of claim 23, arranged for the vacuum to be applied below the porous membrane.

25. The system of claim 22, arranged for the vacuum to be applied above the receiving surface.

26. The system of claim 25, arranged for the vacuum to be applied through one or more vacuum channels provided on the print head, the one or more vacuum channels having an orifice situated near the orifice of the print head.

27. The system of claim 20 or 21, wherein the fluid removal feature comprises an absorbent material for drawing away from the receiving surface the excess first material.

28. The system of any one of claims 23 to 27, further comprising a programmable control processor for controlling the positioning unit and for controlling dispensing of the materials from the print head onto the receiving surface.

29. The system of any one of claims 23 to 28, wherein the print head further comprises a hollow projection configured to extend from the orifice toward the receiving surface.

30. The system of any one of claims 23 to 29, wherein the print head comprises one or more first channels for receiving and directing the first material and one or more respective second channels for receiving and directing the second material, the second channels intersecting at a first intersection point with the first channels, the second and first channels

joining together at the first intersection point to form a dispensing channel which extends to the orifice.

31. The system of claim 30, wherein the print head comprises two second channels, each of the second channels being adapted to convey respective second materials, the two second channels intersecting at a second intersection and joining together at the second intersection to form a third channel which extends to the first intersection point

32. A method of printing a three-dimensional (3D) structure using a 3D printer, the printer comprising:

- at least one print head comprising an orifice for dispensing materials, the materials to be dispensed comprising a sheath fluid and one or more hydrogels;
- a receiving surface for receiving a first layer of the materials dispensed from the orifice of the print head; and
- a positioning unit operably coupled to the print head, the positioning unit for positioning the print head in three dimensional space;

the method comprising:

- encoding the printer with a 3D structure to be printed;
- dispensing from the print head orifice the materials to be dispensed, wherein the sheath fluid and the hydrogel are dispensed in a coaxial arrangement, and wherein the sheath fluid envelops the hydrogel;
- depositing a first layer of the dispensed materials on the receiving surface;
- repeating the depositing step by depositing subsequent dispensed material on the first and any subsequent layers of deposited material, thereby depositing layer upon layer of dispensed materials in a geometric arrangement according to the 3D structure; and
- removing excess sheath fluid dispensed by the print head orifice at one or more time point during or between depositing steps.

33. The method of claim 32, wherein the sheath fluid comprises a cross-linking agent suitable for cross-linking and solidifying the hydrogel upon contact therewith, the contact creating a hydrogel fiber.

34. The method of claim 32 or 33, wherein the depositing step and the removing step are carried out continuously, thereby continuously removing the excess sheath fluid as the layers of dispensed materials are deposited.

35. The method of claim 32 or 33, wherein the removing step is carried out intermittently between and/or at the same time as the depositing step, thereby intermittently removing the excess sheath fluid as the layers of dispensed materials are deposited.

36. The method of any one of claims 32 to 35, wherein the one or more hydrogels are adapted for supporting growth and/or proliferation of living cells dispersed therein.