SUMMARY

[0006] Examples of the disclosure include systems and methods for producing fiber structures, and for producing three-dimensional (3D) structures from digital files. In some examples, the printed fibers comprise living cells.

[0006a] In one aspect, the present disclosure refers to a system for producing a fiber structure, the system comprising:

a print head comprising:

a dispensing channel comprising a distal end and a proximal end;

a dispensing orifice located at the distal end of the dispensing channel;

one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel;

a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; and

a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel;

one or more fluid reservoirs that are in fluid communication with the print head;

wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and

wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel, wherein a fluid reservoir comprises the buffer solution;

a receiving surface for receiving a first layer of material dispensed from the print head; and

a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head.

[0007] Examples of the disclosure include a print head for producing a fiber structure, the print head comprising: a dispensing channel comprising a distal end and a proximal end; a dispensing orifice located at the distal end of the dispensing channel; one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel; a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; and a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel; wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in

fluid communication with the dispensing channel; and wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel.

[0008] In some examples, a print head comprises a first and a second material channel. In some examples, the sheath solution channel diverges into two or more sheath solution sub-channels at a divergence position. In some examples, the two or more sheath solution sub-channels converge with the dispensing channel at the sheath fluid convergence position. In some examples, each of the one or more material channels comprises a material input orifice and a control valve. In some examples, the buffer solution channel comprises a buffer solution input orifice and a control valve. In some examples, the sheath solution channel comprises a sheath solution input orifice and a control valve.

[0009] Examples of the disclosure include a system for producing a fiber structure, the system comprising: a print head comprising: a dispensing channel comprising a distal end and a proximal end; a dispensing orifice located at the distal end of the dispensing channel; one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel; a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; and a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel; wherein the one or

more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel; a receiving surface for receiving a first layer of material dispensed from the print head; and a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head.

[0010] In some examples, a system further comprises a programmable control processor for controlling the positioning component and for controlling a flow rate of one or more fluids through the print head. In some examples, a system further comprises a fluid removal component that is configured to remove an excess fluid that is dispensed from the print head. In some examples, the fluid removal component comprises a porous membrane that is configured to allow passage of the excess fluid. In some examples, the fluid removal component comprises an absorbent material. In some examples, the fluid removal component comprises a vacuum that is configured to aspirate the excess fluid. In some examples, the vacuum is applied below the receiving surface. In some examples, the vacuum is applied above the receiving surface. In some examples, the vacuum is applied through one or more vacuum channels on the print head. In some examples, the one or more vacuum channels are positioned near the dispensing orifice on the print head.

[0011] In some examples, a system further comprises a pressure control component that is configured to regulate the flow rate of the one or more fluids through the print head. In some examples, a system further comprises one or more fluid reservoirs that are in fluid communication with the print head. In some examples, a fluid reservoir comprises a sheath solution. In some examples, the sheath solution comprises a crosslinking solution that is configured to solidify an input material. In some examples, the crosslinking solution comprises a divalent cation. In some examples, the divalent cation is Ca++. In some examples, a fluid reservoir comprises a buffer solution. In some examples, the buffer solution is miscible with an input material. In some examples, a fluid reservoir comprises an input material. In some examples, the input material comprises a hydrogel. In some examples, the hydrogel comprises an alginate. In some examples, the alginate is a depolymerized alginate. In some examples, the input material comprises one or more living cells. In some examples, the input material comprises an extra cellular matrix material. In some examples, the input material comprises an active agent.

[0012] In some examples, the print head is configured to produce a constant mass flow rate through the dispensing channel. In some examples, a system further comprises a crosslinking component. In some examples, the crosslinking component comprises a UV lamp. In some examples, the crosslinking component is positioned adjacent to the dispensing orifice.

[0013] Aspects of the disclosure include a method for generating a solidified fiber structure, the method comprising: providing a system for producing a fiber structure, the system comprising: a print head comprising: a dispensing channel comprising a distal end and a proximal end; a dispensing orifice located at the distal end of the dispensing channel; one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel; a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; and a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel; wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel; a receiving surface for a receiving a first layer of material dispensed from the print head; a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head; a programmable control processor for controlling the positioning component and for controlling a flow rate of one or more fluids through the print head; a first fluid reservoir comprising a first input material; a second fluid reservoir comprising the buffer solution; and a third fluid reservoir comprising a sheath solution, wherein the sheath solution comprises a crosslinking solution; wherein the fluid reservoirs are in fluid communication with the print head; contacting the first input material with the sheath solution in the dispensing channel to generate the solidified fiber structure; and dispensing the solidified fiber structure from the dispensing orifice of the print head.

[0014] Aspects of the disclosure include a method for generating a solidified fiber structure, the method comprising: providing a system for producing a fiber structure, the system comprising: a print head comprising: a dispensing channel comprising a distal end and a proximal end; a dispensing orifice located at the distal end of the dispensing channel; one or more material channels converging with the dispensing channel at the proximal end of

the dispensing channel; a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel; and a crosslinking component; wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel; a receiving surface for a receiving a first layer of material dispensed from the print head; a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head; a programmable control processor for controlling the positioning component and for controlling a flow rate of one or more fluids through the print head; a first fluid reservoir comprising a first input material; a second fluid reservoir comprising the buffer solution; and a third fluid reservoir comprising a sheath solution, wherein the sheath solution comprises a crosslinking solution; wherein the fluid reservoirs are in fluid communication with the print head; passing the first input material through the dispensing channel; crosslinking the first input material with the crosslinking component to generate the solidified fiber structure; and dispensing the solidified fiber structure from the dispensing orifice of the print head.

[0015] In some examples, the first input material is crosslinked in the dispensing channel. In some examples, the crosslinking component is located adjacent to the dispensing orifice, and the first input material is crosslinked as it is dispensed from the dispensing orifice.

[0016] In some examples, a method further comprises: encoding the programmable control processor with a planar structure to be printed; and depositing a first layer of the solidified fiber structure on the receiving surface to print the planar structure.

[0017] In some examples, a method further comprises: encoding the programmable control processor with a 3D structure to be printed; and depositing a subsequent layer of the solidified fiber structure on top of the planar structure to print a 3D structure.

[0018] In some examples, a method further comprises displacing an input material with the buffer solution in the dispensing channel to cease deposition of a solidified fiber structure comprising the input material. In some examples, displacing the input material

with the buffer solution in the dispensing channel comprises maintaining a constant mass flow rate in the dispensing channel.

[0019] In some examples, a method further comprises displacing a buffer solution with an input material in the dispensing channel to commence deposition of a solidified fiber structure comprising the input material. In some examples, displacing the buffer solution with the input material in the dispensing channel comprises maintaining a constant mass flow rate in the dispensing channel.

[0020] In some examples, a system further comprises a fourth fluid reservoir comprising a second input material, and a method comprises generating a solidified fiber structure that comprises the second input material.

[0021] In some examples, a method further comprises displacing the first input material with the second input material in the dispensing channel to generate a solidified fiber structure that comprises a transition from the first input material to the second input material. In some examples, displacing the first input material with the second input material in the dispensing channel comprises maintaining a constant mass flow rate in the dispensing channel.

[0022] In some examples, a method further comprises simultaneously dispensing the first and the second input materials to generate a solidified fiber structure that comprises a mixture of the first and second input materials.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] **FIG. 1** is an illustration of a conventional print head design wherein stopping the deposition sequence of the printed fiber exposes the input material at the junction and slightly upstream of the junction to a crosslinking agent until the channels are flushed with buffer solution. As a result, the depicted system is prone to clogging.

[0024] **FIG. 2** is an illustration of a conventional print head design wherein starting the deposition sequence of the printed fiber requires first that the full volume of buffer solution be flushed out and replaced with sheath fluid (crosslinking solution) and then the flow of input material can be restarted. If the input material is restarted too early, an insufficient concentration of crosslinker may be present in the dispensing channel to fully crosslink the input material, resulting in poor fiber strength. In the illustration, the buffer solution displaces

Claims:

1. A system for producing a fiber structure, the system comprising:

a print head comprising:

a dispensing channel comprising a distal end and a proximal end;

a dispensing orifice located at the distal end of the dispensing channel;

one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel;

a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; and

a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel;

one or more fluid reservoirs that are in fluid communication with the print head;

wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and

wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel, wherein a fluid reservoir comprises the buffer solution;

a receiving surface for receiving a first layer of material dispensed from the print head; and

a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head.

2. The system according to claim 1, further comprising a programmable control processor for controlling the positioning component and for controlling a flow rate of one or more fluids through the print head.

3. The system according to claim 1, further comprising a fluid removal component that is configured to remove an excess fluid that is dispensed from the print head.

4. The system according to claim 3, wherein the fluid removal component comprises a porous membrane that is configured to allow passage of the excess fluid.

5. The system according to claim 3, wherein the fluid removal component comprises an absorbent material.

6. The system according to claim 3, wherein the fluid removal component comprises a vacuum that is configured to aspirate the excess fluid.

7. The system according to claim 6, wherein the vacuum is applied below the receiving surface.

8. The system according to claim 6, wherein the vacuum is applied above the receiving surface.

9. The system according to claim 6, wherein the vacuum is applied through one or more vacuum channels on the print head.

10. The system according to claim 9, wherein the one or more vacuum channels are positioned near the dispensing orifice on the print head.

11. The system according to claim 2, further comprising a pressure control component that is configured to regulate the flow rate of the one or more fluids through the print head.

12. The system according to claim 1, wherein a fluid reservoir comprises a sheath solution.

13. The system according to claim 12, wherein the sheath solution comprises a crosslinking solution that is configured to solidify an input material.

14. The system according to claim 13, wherein the crosslinking solution comprises a divalent cation.

15. The system according to claim 14, wherein the divalent cation is Ca^{++}.

16. The system according to claim 1, wherein the buffer solution is miscible with an input material.

17. The system according to claim 1, wherein a fluid reservoir comprises an input material.

18. The system according to claim 17, wherein the input material comprises a hydrogel.

19. The system according to claim 18, wherein the hydrogel comprises an alginate.

20. The system according to claim 19, wherein the alginate is a depolymerized alginate.

21. The system according to claim 17, wherein the input material comprises one or more living cells.

22. The system according to claim 17, wherein the input material comprises an extra cellular matrix material.

23. The system according to claim 17, wherein the input material comprises an active agent.

24. The system according to claim 1, wherein the print head is configured to produce a constant mass flow rate through the dispensing channel.

25. The system according to claim 1, further comprising a crosslinking component.

26. The system according to claim 25, wherein the crosslinking component comprises a UV lamp.

27. The system according to claim 25, wherein the crosslinking component is positioned adjacent to the dispensing orifice.

28. A method for generating a solidified fiber structure, the method comprising:
providing a system for producing a fiber structure, the system comprising:
a print head comprising:

a dispensing channel comprising a distal end and a proximal end;

a dispensing orifice located at the distal end of the dispensing channel;

one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel;

a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel; and

a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel;

wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and

wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel;

a receiving surface for a receiving a first layer of material dispensed from the print head;

a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head;

a programmable control processor for controlling the positioning component and for controlling a flow rate of one or more fluids through the print head;

a first fluid reservoir comprising a first input material;

a second fluid reservoir comprising the buffer solution; and

a third fluid reservoir comprising a sheath solution, wherein the sheath solution comprises a crosslinking solution;

wherein the fluid reservoirs are in fluid communication with the print head;

contacting the first input material with the sheath solution in the dispensing channel to generate the solidified fiber structure; and

dispensing the solidified fiber structure from the dispensing orifice of the print head.

29. A method for generating a solidified fiber structure, the method comprising:

providing a system for producing a fiber structure, the system comprising:

a print head comprising:

a dispensing channel comprising a distal end and a proximal end;

a dispensing orifice located at the distal end of the dispensing channel;

one or more material channels converging with the dispensing channel at the proximal end of the dispensing channel;

a buffer solution channel converging with the one or more material channels at the proximal end of the dispensing channel;

a sheath solution channel converging with the dispensing channel at a sheath fluid convergence position that is located between the proximal end and the distal end of the dispensing channel; and

a crosslinking component;

wherein the one or more material channels, the buffer solution channel and the sheath solution channel are in fluid communication with the dispensing channel; and

wherein the print head is configured to displace one or more input materials with a buffer solution at the proximal end of the dispensing channel;

a receiving surface for a receiving a first layer of material dispensed from the print head;

a positioning component for positioning the dispensing orifice of the print head in 3D space, wherein the positioning component is operably coupled to the print head;

a programmable control processor for controlling the positioning component and for controlling a flow rate of one or more fluids through the print head;

a first fluid reservoir comprising a first input material;

a second fluid reservoir comprising the buffer solution; and

a third fluid reservoir comprising a sheath solution, wherein the sheath solution comprises a crosslinking solution;

wherein the fluid reservoirs are in fluid communication with the print head;

passing the first input material through the dispensing channel;

crosslinking the first input material with the crosslinking component to generate the solidified fiber structure; and

dispensing the solidified fiber structure from the dispensing orifice of the print head.

30. The method according to claim 29, wherein the first input material is crosslinked in the dispensing channel.

31. The method according to claim 29, wherein the crosslinking component is located adjacent to the dispensing orifice, and wherein the first input material is crosslinked as it is dispensed from the dispensing orifice.

32. The method according to any one of claims 28-31, further comprising:

encoding the programmable control processor with a planar structure to be printed; and

depositing a first layer of the solidified fiber structure on the receiving surface to print the planar structure.

33. The method according to claim 32, further comprising:

encoding the programmable control processor with a 3D structure to be printed; and

depositing a subsequent layer of the solidified fiber structure on top of the planar structure to print a 3D structure.

34. The method according to any one of claims 28-33, further comprising displacing an input material with the buffer solution in the dispensing channel to cease deposition of a solidified fiber structure comprising the input material.

35. The method according to claim 34, wherein displacing the input material with the buffer solution in the dispensing channel comprises maintaining a constant mass flow rate in the dispensing channel.

36. The method according to any one of claims 28-33, further comprising displacing the buffer solution with an input material in the dispensing channel to commence deposition of a solidified fiber structure comprising the input material.

37. The method according to claim 36, wherein displacing the buffer solution with the input material in the dispensing channel comprises maintaining a constant mass flow rate in the dispensing channel.

38. The method according to any one of claims 28-33, wherein the system further comprises a fourth fluid reservoir comprising a second input material, and wherein the method comprises generating a solidified fiber structure that comprises the second input material.

39. The method according to claim 38, further comprising displacing the first input material with the second input material in the dispensing channel to generate a solidified fiber structure that comprises a transition from the first input material to the second input material.

40. The method according to claim 39, wherein displacing the first input material with the second input material in the dispensing channel comprises maintaining a constant mass flow rate in the dispensing channel.

41. The method according to claim 38, further comprising simultaneously dispensing the first and the second input materials to generate a solidified fiber structure that comprises a mixture of the first and second input materials.