

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent of: William J. Swanson et al.
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Title: ADDITIVE MANUFACTURING METHOD FOR
PRINTING THREE-DIMENSIONAL PARTS WITH
PURGE TOWERS

DECLARATION OF MICHAEL A. HICKNER

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I, Michael A. Hickner of East Lansing, MI, declare that:

I. INTRODUCTION

1. My name is Michael A. Hickner, and I have been retained by counsel for Shenzhen Tuozhu Technology Co., Ltd. (“Shenzhen Tuozhu”/“Petitioner”) as an expert witness to provide assistance regarding U.S. Patent No. 9,421,713 (“the ’713 Patent”). Specifically, I have been asked to consider the validity of claims 1, 2, 5-7, 9, 16, and 17 of the ’713 Patent (the “Challenged Claims”).

2. I am being compensated for my time at my standard consulting rate. I am also being reimbursed for expenses that I incur during the course of this work. My compensation is not contingent upon the results of my study, the substance of my opinions, or the outcome of any proceeding involving the Challenged Claims. I have no financial interest in the outcome of this matter or on related litigation involving the ’713 Patent.

3. My analysis here is based on my years of education, research and experience, as well as my investigation and study of relevant materials, including those cited herein. I may rely upon these materials, my knowledge and experience, and/or additional materials to further explain and corroborate my analysis, and to respond to critiques of my analysis raised by the Patent Owner or the Patent Trial and Appeal Board (“Board”).

4. My analysis of the materials produced in this proceeding is ongoing and I will continue to review any new material as it is provided. This declaration represents only those opinions that I have formed to date. I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information and on my continuing analysis of the materials already provided.

II. BACKGROUND AND QUALIFICATIONS

5. I am over the age of 18 and am competent to provide this testimony. I have personal knowledge, or have developed knowledge of the technologies addressed in this declaration based upon my education, training, experience, and my review of the '713 Patent, its file history, and the related prior art. I am well qualified to serve as a technical expert in this matter based upon my qualifications, discussed in detail below.

6. In formulating my opinions, I have relied on my knowledge, training, and experience in the relevant field. My education and experience are described more fully in the attached curriculum vitae (Appendix A). For ease of reference, I have highlighted certain information below.

7. I have B.S., M.Eng., and Ph.D. degrees in Chemical Engineering. I began my chemical engineering education in 1994 and completed my Ph.D. in 2003 with an emphasis in polymer chemistry and polymer science.

8. Since 2003, I have been a researcher and professor in chemical engineering and materials science disciplines working for a number of organizations on polymers research including, specifically, polymers in the context of 3D printing technology.

9. I have taught college-level courses in chemistry, polymers, and materials science. Specifically related to this case regarding the '713 patent and additive manufacturing, I taught a graduate-level additive manufacturing course titled “Additive Manufacturing of Polymers and Composites” at Penn State University from 2018 to 2022. This course was part of the Additive Manufacturing and Design (AMD) graduate program that was started during my tenure at Penn State. The AMD graduate program covered all aspects of 3D printing—including how various build materials behave during a process to print a 3D part and support structure using multiple materials. In this course, and in my own research in 3D printing, I have used a wide range of machines with extruders of various types, including extruders with more than one nozzle for depositing build materials and extruders that use more than one build material for printing a part and/or support structure.

10. Similar teaching activities are planned at Michigan State University as I develop an additive manufacturing research program in my new role as an endowed professor.

11. I have published a number of peer-reviewed journal papers that specifically address various aspects of extruding build materials for additive manufacturing including aspects relating to printing equipment, printing strategies, and materials. For example, in papers that address extrusion 3D printing of silicones, we used different materials for the support structure and 3D part that helped with removal of 3D part from the support structure after printing. While the topic of purge towers was not a focus of our research, material degrading in idle nozzles is an issue that must be addressed in any 3D printing activity involving multiple print heads or deposition lines.

12. Since 2013, I have been the principal supervisor for students pursuing advanced degrees in additive manufacturing and been a committee member on graduate committees in additive manufacturing topics.

13. In the course of my research and teaching at the university-level, I have worked with a wide range of 3D printers since 2012. I have purchased over twenty 3D printers for my research group. My focus has included extrusion 3D printing. I have purchased more than ten 3D printers that can deposit more than one material to build 3D parts and/or support structures. I have printed a wide variety of materials in these printers, from ABS to composite polyimides.

III. LEVEL OF ORDINARY SKILL IN THE ART

14. In rendering the opinions set forth in this declaration, I was asked to consider the patent claims and the prior art through the eyes of a person of ordinary skill in the art as of the effective filing date of the '713 Patent ("POSITA"), which I have concluded is March 8, 2013 for the reasons that I address in detail below (§V.C). I understand that the factors considered in determining the ordinary level of skill in a field of art include the level of education and experience of persons working in the field; the types of problems encountered in the field; the teachings of the prior art; and the sophistication of the technology at the time of the alleged invention. I understand that a POSITA is not a specific real individual, but rather is a hypothetical individual having the qualities reflected by the factors above. I understand that a POSITA also would have knowledge from the teachings of the prior art, including the art cited below.

15. Taking these factors into consideration, on or before March 8, 2013, a POSITA relating to the technology of the '713 Patent would have had (1) at least a bachelor's degree in Mechanical Engineering, Computer Engineering, Chemical Engineering, Materials Science, or a related field, and (2) at least two years of research or industry experience in 3D printing or materials used for 3D printing. Additional experience could substitute for a formal degree or formal training (and vice versa).

16. By March 8, 2013, my education and research experience was at least that of a POSITA. I am qualified to provide opinions concerning what a POSITA would have known and understood at that time, and my analysis and conclusions herein are from the perspective of a POSITA as of that date.

IV. MATERIALS CONSIDERED AND RELIED UPON

17. In forming my opinions and reaching the conclusions described in this declaration, I have relied on the documents and materials cited herein as well as those identified in this declaration, including the '713 Patent, the prosecution history of the '713 Patent, and prior art references cited herein. These materials comprise patents, related documents, and printed publications. Each of these materials is a type of document that experts in my field would have reasonably relied upon when forming their opinions. I have also relied on my education, training, research, knowledge, and personal and professional experience in the relevant technologies and systems that were already in use prior to, and within the timeframe of the earliest effective filing date of the '713 Patent (March 8, 2013).

18. Accordingly, as part of my independent analysis of the '713 Patent, I have analyzed the following publications and materials:

<u>Exhibit</u>	<u>Description</u>
EX1001	U.S. Patent No. 9,421,713 to Swanson et al. ("the '713 Patent")

<u>Exhibit</u>	<u>Description</u>
EX1002	Excerpts from the Prosecution History of the '713 Patent ("the Prosecution History")
EX1004	U.S. Publication No. 2009/0035405 ("Leavitt")
EX1005	Dual extruder PLA printing (Oct. 29, 2012), <i>available at</i> https://www.okob.net/wp/index.php/2012/10/29/dual-extruder-pla-printing/ ("RepRap Article")
EX1006	x2 dual color print (Oct. 29, 2012), <i>available at</i> https://www.youtube.com/watch?v=ZAafPtKjZSc ("RepRap Video")
EX1007	U.S. Publication No. 2003/0004600 ("Priedeman")
EX1008	U.S. Publication No. 2014/0034214 ("Boyer")
EX1009	KickStarter Campaign For Dual Extruder (2012), <i>available at</i> https://reprap.org/forum/read.php?1,137362,137887#msg-137887
EX1010	KISSlicer Quick-Start Guide (2012), <i>available at</i> https://web.archive.org/web/20121224171520/http://kisslicer.com/files/KISSlicerQuickStart.pdf#expand ("KISSlicer")
EX1011	U.S. Patent No. 7,625,200 ("Leavitt-200")
EX1012	U.S. Patent No. 7,604,470 ("LaBossiere")
EX1013	Evans, <i>Practical 3D Printers, The Science And Art Of 3D Printing</i> (2012)
EX1014	whistle_x2_body.stl (2012), <i>available at</i> http://www.okob.net/wp/wp-uploads/2012/10/whistle_x2_body.stl
EX1015	whistle_x2_text.stl (2012), <i>available at</i> http://www.okob.net/wp/wp-uploads/2012/10/whistle_x2_text.stl

<u>Exhibit</u>	<u>Description</u>
EX1016	Declaration of Denis Bakin
EX1017	Declaration of Jonathan Dummer
EX1018	Declaration of Kathryn Talbot
EX1019	December 17, 2024 stipulation sent by Petitioner's counsel to Patent Owner's counsel
EX1020	Docket Control Order (Document 34), <i>Stratasys, Inc. v. Shenzhen Tuo Zhu Technology Co. Ltd. et al</i> , 2-24-cv-00644 (EDTX)

19. Although this declaration refers to selected portions of the cited references, it should be understood that these are examples, and I recognize that a POSITA would have viewed the references cited herein in their entirety and in combination with other references cited herein or cited within the references themselves.

V. LEGAL STANDARDS

20. I am not a lawyer and do not provide any legal opinions, but I have been advised that certain legal standards are to be applied by technical experts in forming opinions regarding meaning and validity of patent claims I have applied the legal standards described below, which were provided to me by counsel for the Petitioners.

21. It is my understanding that assessing the validity of a U.S. patent based on a prior art analysis involves two steps. First, one construes the terms of the patent claims to understand what meaning one of ordinary skill in the art would have given

the terms. Second, after the claim terms have been construed, one then assesses validity by comparing the patent claim properly construed to the “prior art.” I understand that the teaching of the prior art is viewed through the eyes of a POSITA as of the effective filing date of the ’713 Patent. My analysis as to what constitutes a POSITA is set forth above (§III).

A. Legal Standards for Prior Art

22. I understand that a patent or other publication must first qualify as prior art before it can be used to invalidate a patent claim. Counsel for Petitioners have informed me that Leavitt (EX1004), RepRap Article (EX1005), RepRap Video (EX1006), Priedeman (EX1007), Boyer (EX1008), and KISSlicer (EX1010) all qualify as prior art to the ’713 Patent. In particular, I was informed that all of these publications were published before the filing date of the ’713 patent (March 8, 2013), except for Boyer. I was informed that although Boyer was published after March 8, 2013, Boyer was nonetheless filed before March 8, 2013 and therefore qualifies as prior art.

B. Legal Standard for Anticipation

23. I have been informed that a patent claim is unpatentable as anticipated under 35 U.S.C. § 102 if each and every element of a claim is found either explicitly or inherently in a single prior art reference. Under the principles of inherency, if the

prior art necessarily functions in accordance with, or necessarily includes the claimed elements, it anticipates.

C. Legal Standard for Obviousness

24. I have been informed that a patent claim is invalid as “obvious” in light of one or more prior art references if it would have been obvious to a person of ordinary skill in the art at the time of the alleged invention (“POSITA”), taking into account (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so called “secondary considerations” of non-obviousness (e.g., evidence of “long felt need” for the claimed invention, commercial success attributable to the claimed invention, unexpected results of the claimed invention, and “copying” of the claimed invention by others).

25. While I do not know the exact date that the alleged invention of the ’713 patent was made, I do know that the ’713 patent’s earliest claimed priority date is March 8, 2013. For purposes of my obviousness analysis in the Grounds below, I have applied a date of March 8, 2013 as the date of the alleged invention, although my opinions expressed below would hold true even if the date of the alleged invention were earlier, such as any time in the earlier 2010s.

26. I have been informed that a claim can be obvious in light of a single prior art reference or multiple prior art references. To be obvious in light of a single

prior art reference or multiple prior art references, there must be a reason that would have prompted a POSITA to modify or supplement the single prior art reference, or to combine two or more references, in a manner that provides the elements of the claimed invention. This reason may come from a teaching, suggestion, or motivation to combine, or may come from the reference(s) themselves, the knowledge or “common sense” of a POSITA, or from the nature of the problem to be solved, and this reason may be explicit or implicit from the prior art as a whole. I have been informed that, under the law, the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. I also understand it is improper to rely on hindsight in making the obviousness determination.

27. To the extent that a party presents any evidence of alleged “secondary considerations” of non-obviousness (refer to ¶24 above), the evidence must demonstrate a “nexus” between that secondary consideration and the invention recited in the patent claim.

VI. OVERVIEW OF THE '713 PATENT

A. Subject Matter Overview

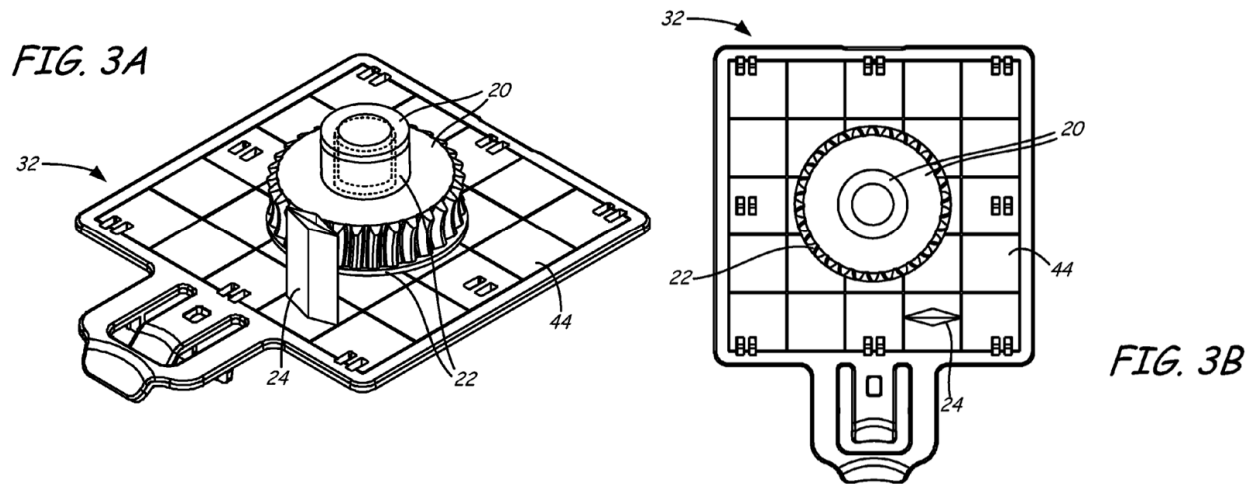
28. The '713 Patent is directed to an “Additive Manufacturing Method for Printing Three-Dimensional Parts With Purge Towers.” EX1001, Cover. I noticed that the '713 Patent generally describes an “additive manufacturing system” and

“method” for printing a 3D part 20 and support structure 22 using a “layer-based, additive manufacturing technique.” EX1001, 1:57-2:3, 3:41-51, 5:7-17, 5:60-67, 8:30-38, FIGS. 1, 3A-3B. For example, the ’713 patent explains that:

The part material is extruded through an extrusion tip or nozzle carried by a print head of the system, and is deposited as a sequence of roads on a substrate in an x-y plane. The extruded part material fuses to previously deposited part material, and solidifies upon a drop in temperature. The position of the print head relative to the substrate is then incremented along a z-axis (perpendicular to the x-y plane), and the process is then repeated to form a 3D part resembling the digital representation.

EX1001, 1:27-39.

29. Another notable feature of the system is that multiple print heads or deposition lines can deposit layers of a “part material” to print 3D part 20 and deposit layers of a “support material” to print support structure 22. EX1001, 2:4-33, 3:41-51, 5:18-43, 8:30-38, FIGS. 1, 3A-3B.



EX1001, FIGS. 3A-3B.

30. According to the '713 Patent, each print head or deposition line is a structure that can toggle between an “operating mode” (when heated and depositing material) and a “stand-by mode” (when cooled and idle). EX1001, 1:57-2:33, 4:1-62, 7:65-8:9, 8:30-38, 10:38-51. The '713 patent goes on to explain that in the stand-by mode, material located within the idle print head or deposition line can be cooled to prevent oozing from the output nozzle. EX1001, 4:1-11, 4:46-62. When a particular print head or deposition line is toggled from the stand-by mode to the operating mode, the structure can typically “purge” a portion of the material therein prior to depositing the next layer. EX1001, 4:39-62.

31. Notably, I noticed that The '713 Patent discusses an alleged improvement to such traditional purge operations that involves printing “a purge tower (or multiple towers)” directly on the build substrate “without requiring the use of a separate purge station” within the 3D printer. EX1001, 5:7-17, 8:39-53, FIGS.

3A-B, 6, 8-9. The '713 Patent explains that such a purge tower can be beneficial because it eliminates a need for a separate “purge station” in a way that increases “the useable build volume” within the 3D printer. EX1001, 4:63-5:17.

B. Interpretation of the '713 Patent Claims at Issue

32. For purposes of my analysis in this IPR proceeding, I understand that the terms that appear in the claims of the '713 Patent should be interpreted according to their “ordinary and customary meaning,” which is sometimes called the *Phillips* standard. In determining the ordinary and customary meaning, I understand that the words of a claim are first given their plain meaning that those words would have had to a POSITA at the time. I also understand that the structure of the claims, the specification, and the file history also may be used to better construe a claim insofar as the plain meaning of the claims cannot be understood. Moreover, I understand that even treatises and dictionaries may be used, albeit under limited circumstances, to determine the meaning attributed by a POSITA to a claim term at the time of filing. I have followed this approach in interpreting terms of the Challenged Claims herein.

33. One claim interpretation issue that I noticed in the claims of the '713 Patent is that Claim 1 requires a step of printing layers of a three-dimensional part and a support structure “from multiple print heads or deposition lines.” That is, Claim 1 requires a system that has *more than one print head or more than one deposition line*. As explained below, the plain meaning of this claim language in a

context consistent with the '713 patent specification leads to a first construction (identified below). I was also asked to consider an alternative construction (identified below) for purposes of this proceeding. In doing so, Grounds 1-2 (below) fall within the scope of claim 1 under the first construction, while Ground 3 would be excluded under the first construction. Yet, under the alternative construction, all of Grounds 1-3 would be applicable here.

34. According to the first construction, the step of printing “from multiple print heads [plural] or deposition lines [plural]” would involve a system that includes multiple deposition output ports. This is consistent with column 3 of the '713 Patent, which explains that the multiple output ports were “accomplished” either in the form of multiple print heads (each having a respective output nozzle/tip for depositing material) or in the form of a single head having multiple output nozzles/tips. EX1001, 3:52-67 (“separate print heads” like that of Swanson (EX1012), or “single deposition head having multiple deposition lines for printing” like that of Leavitt-200 (EX1011)); *see also* 5:31-35 and FIG. 1 (print head 18p and print head 18s). These 3D printer systems (cited in column 3 of the '713 Patent) were sometimes referred to as “dual-extruder” systems and were known to include multiple deposition output ports—one output port for each type of material to be deposited during the print task. I further note that this first construction is also consistent with the actual text in claim 1, which further describes that one “deposition line” (or a “print head”) can switch

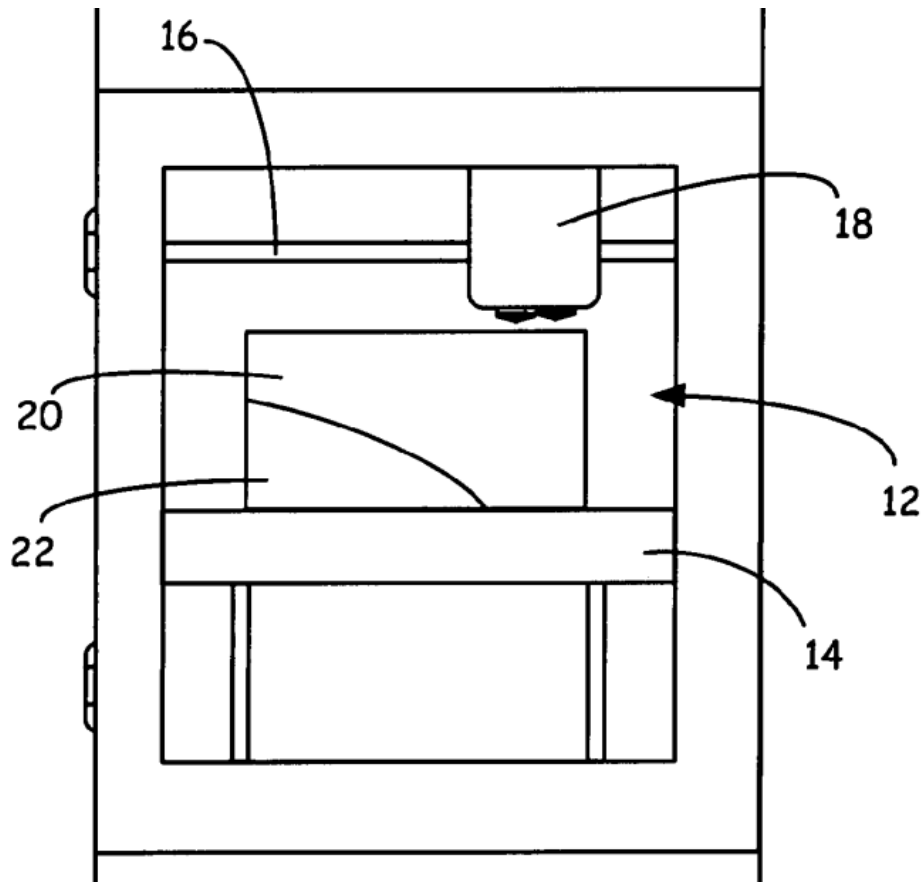
to a stand-by mode while another is switched an operating mode. EX1001, 15:49-58. Based upon my knowledge and experience in this field, a POSITA would have recognized that this first construction excludes any system with a single head having a single deposition output port (e.g., a single-extruder system), and therefore it is apparent that Ground 3 (detailed below) would be excluded from the claim scope under this first construction. However, the predictable dual-extruder systems described in Grounds 1-2 (detailed below) would be encompassed by claim 1 under this first construction.

35. I was also asked to consider, for purposes of assessing the prior art in this proceeding, an alternative claim construction. In this alternative construction, claim 1's step of printing "from multiple print heads [plural] or deposition lines [plural]" encompasses not only the types of systems having multiple deposition output ports described above, but also a single extruder head having a single deposition output port to print different materials *at different times*. I note that such single-extruder systems are different from the embodiment depicted in the '713 patent (e.g., FIG. 1, print head 18p and print head 18s), but I am nevertheless able to assess the prior art cited here under this alternative construction. As detailed below, under the alternative construction, all of Grounds 1-3 would fall within the scope of claim 1.

VII. OVERVIEW OF THE CITED REFERENCES

A. Leavitt (EX1004)

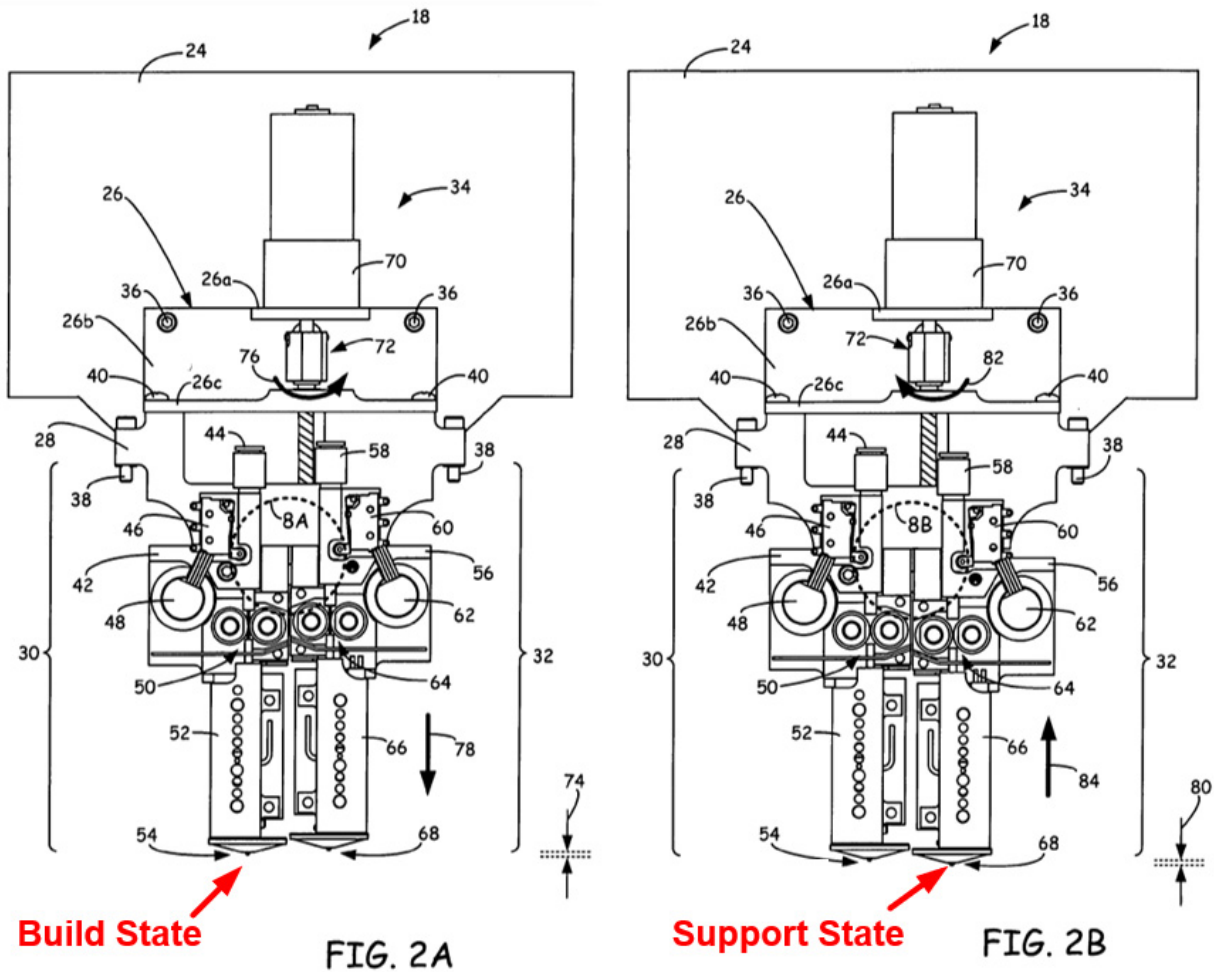
36. Leavitt describes a dual-extruder printing apparatus that is highly similar to that described in the '713 Patent. For example, Leavitt provides details of a dual-extruder head for a three-dimensional printer 18 that is configured to print a three-dimensional (3D) object 20 and support structure 22 on a build surface. EX1004, [0001]-[0006], [0020]-[0022], FIG. 1. Leavitt describes a “layer-by-layer manner by extruding a flowable build material” by operating the extrusion head 18 to print the 3D object 20 and support structure 22. EX1004, [0002], [0020]-[0022]. This additive manufacturing technique includes toggling between a “build state” in which build material is deposited from one nozzle of the print head and a “support state” in which support material is deposited from the second nozzle of the print head, as demonstrated, for example, in FIG. 1:



EX1004, [0020]-[0022], FIG. 1.

37. Leavitt describes that the two different extrusion nozzles of the extrusion head 18 are respectively components of two different deposition lines—a build liquefier pump 30 for extruding build material from the first nozzle and a support liquefier pump 32 for extruding support material from the second nozzle. EX1004, [0025]-[0039], FIGS. 2A-2B. Leavitt goes on to explain that extrusion head 18 toggles between the build state where support liquefier pump 32 is raised above build liquefier pump 30 and the support state where support liquefier pump 32 is lowered below build liquefier pump 30. EX1004, [0029], [0031], [0034],

[0035], FIGS. 2A-2B. One of these transitions between the state in which the support liquefier pump nozzle is positioned above the build liquefier pump nozzle to the state in which the support liquefier pump nozzle is positioned below the build liquefier pump nozzle is shown in Figures 2A and 2B:



EX1004, FIGS. 2A-2B (annotated).

38. Leavitt explains that when either nozzle of the extrusion head 18 is in an idle state while the other nozzle is extruding material, the idle nozzle can “ooze” material, which could potentially drip onto the object being fabricated and cause

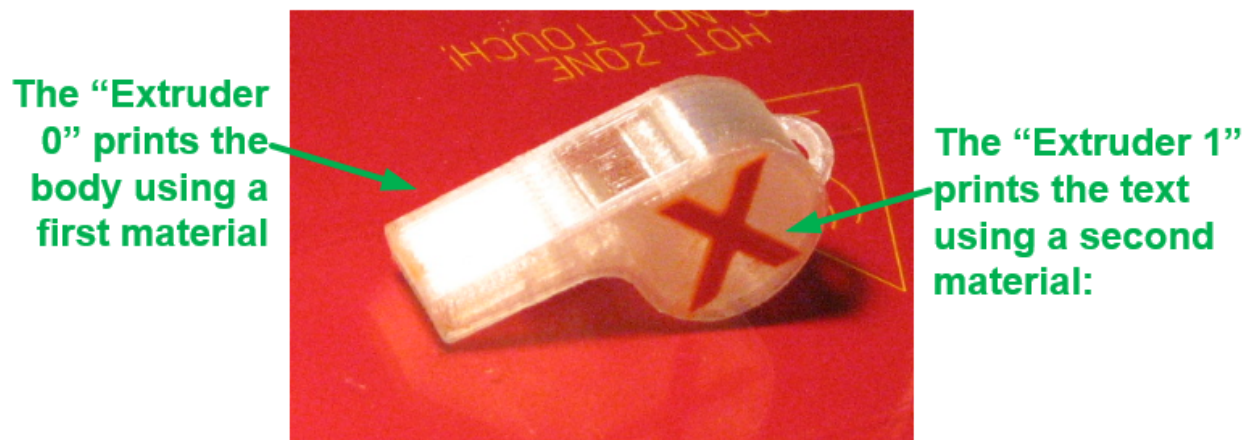
defects in the deposition process. EX1004, [0032]. This oozing could potentially lead to residual support material dripping onto layers of the 3D object 20. Conversely, such oozing by the build material nozzle could lead to build material unintentionally oozing onto the support structure.

39. Indeed, I noticed that Leavitt discloses that “positioning support tip 68 higher than build tip 54 by raised offset distance 74 reduces the risk that the residual support material comes into contact with the layer of 3D object 20 being formed,” thus indicating that residual material oozing out of an idle nozzle can drip onto a recently printed layer. EX1004, [0032]. Leavitt also indicates that a similar issue can arise when extrusion head 18 is disposed in the support state when residual build material drips onto layers of support structure 22. EX1004, [0035].

B. RepRap Article and RepRap Video (EX1005 and EX1006)

40. RepRap Article and RepRap Video both described a known improvement applied to a “RepRap” 3D printing apparatus, and RepRap Article linked to and instructed the reader to contemporaneously view RepRap Video for a visual demonstration of what is textually described in the written text of RepRap Article. EX1005, 1; EX1006. RepRap Article is similar to Leavitt and the ’713 Patent in that it describes a dual-extruder system for printing an object using two different materials. EX1004, [0022], [0023], [0025]-[0035], FIGS. 1-2B; EX1005, 1. In the specific example described in RepRap Article and depicted in the linked

video, the two different deposition materials are two different colors used to fabricate an object (in the example shown, a whistle). EX1005, 1. The dual-extruder system of RepRap Article comprises an “extruder 0” for printing a body of a 3D part using a first material and an “extruder 1” for printing text on the body of the 3D part using a second material. EX1005, 1. The 3D part printed by RepRap Article’s extruders—including the body and the text—is depicted below:



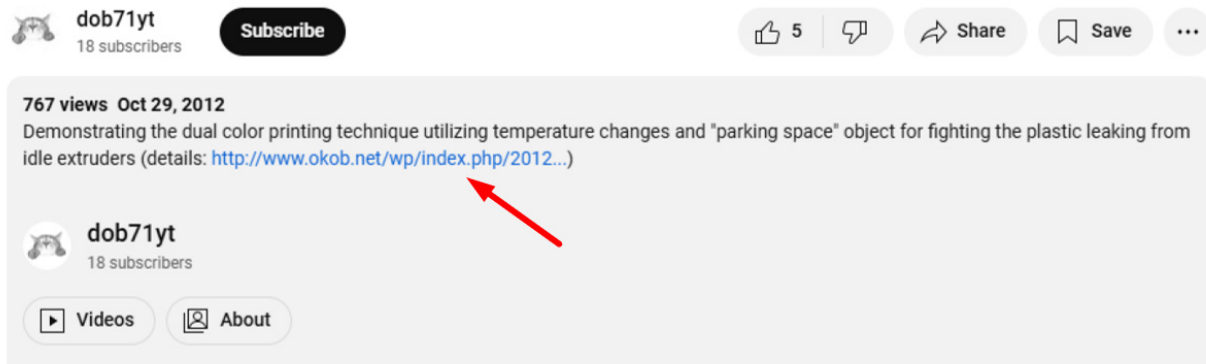
EX1005, 1(annotated). RepRap Article clearly explains that when one of these extruders is active and the other is idle, the idle extruder is cooled to prevent excess molten material from leaking out of the idle extruder nozzle. EX1005, 1 (“Lowering the temperature of the idle extruder while it is not needed...helps to deal with leaking”).

41. The dual-extruder system of RepRap Article performs a purge operation every time that an extruder is switched to an operating mode from an idle mode. EX1005, 1. This transition involves the idle extruder heating up from a cooler

temperature for preventing leaking to a warmer temperature for melting material to print the 3D object. EX1005, 1. In particular, RepRap Article clearly teaches that the system can print a purge tower—referred to as a “parking space” by the author—beside the dual color whistle. EX1005, 1. Although the author of refers to this purge tower as a “parking space,” it is clear that the parking space represents a purge tower because RepRap Article expressly teaches that printing the purge tower directly on the substrate serves to “prime” an idle extruder that is transitioning to an active state. EX1005, 1. Priming the extruder establishes a consistent flow and purges degraded material leftover from a previous active state, thus making it apparent that RepRap Article’s “parking space” is a purge tower. EX1005, 1.

42. RepRap Article (EX1005) expressly directs the reader to the RepRap Video (EX1006) to visually demonstrate the dual-extruder system in action in a way that depicts the process of printing the 3D part and purge tower in more detail. EX1005, 1 (“[y]ou can see the full size video,” which “demonstrates ... the described technique”). Based on this express direction in RepRap Article, I understand that the RepRap Article incorporates, or at least expressly suggests that the readers should view and learn from, the RepRap Video for purposes of understanding this prior art technique for printing a purge tower adjacent to the 3D part. Notably, The RepRap Video is a YouTube video uploaded on the same date as RepRap Article, and the YouTube page featuring the published video likewise includes a link back to the

RepRap Article, thus indicating that the author indicated RepRap Article and Rep Rap Video should be considered together:



EX1018, Appendix B (annotated). The RepRap Article and RepRap video are both describing/depicting the same fabrication process and furthermore, the RepRap Article incorporates and instructs the reader to contemporaneously view the RepRap Video for the demonstrative example of what is described in the written text of the RepRap Article. As such, I consistently refer to the respective exhibit numbers in my declaration but will sometimes refer to the RepRap Article and RepRap Video collectively herein as “RepRap.” *See also, infra*, Footnote 1.

43. The RepRap Video clearly indicates that the system uses a layer-by-layer additive manufacturing technique to print the 3D part (whistle) and the purge tower (referred to as a “parking space”) concurrently on the same substrate. EX1006, 0:03-4:59. When printing is complete, RepRap Video depicts the purge tower being located on the build substrate next to the 3D part, where the purge tower includes layers of the first material (translucent) and second material (orange). As can be seen

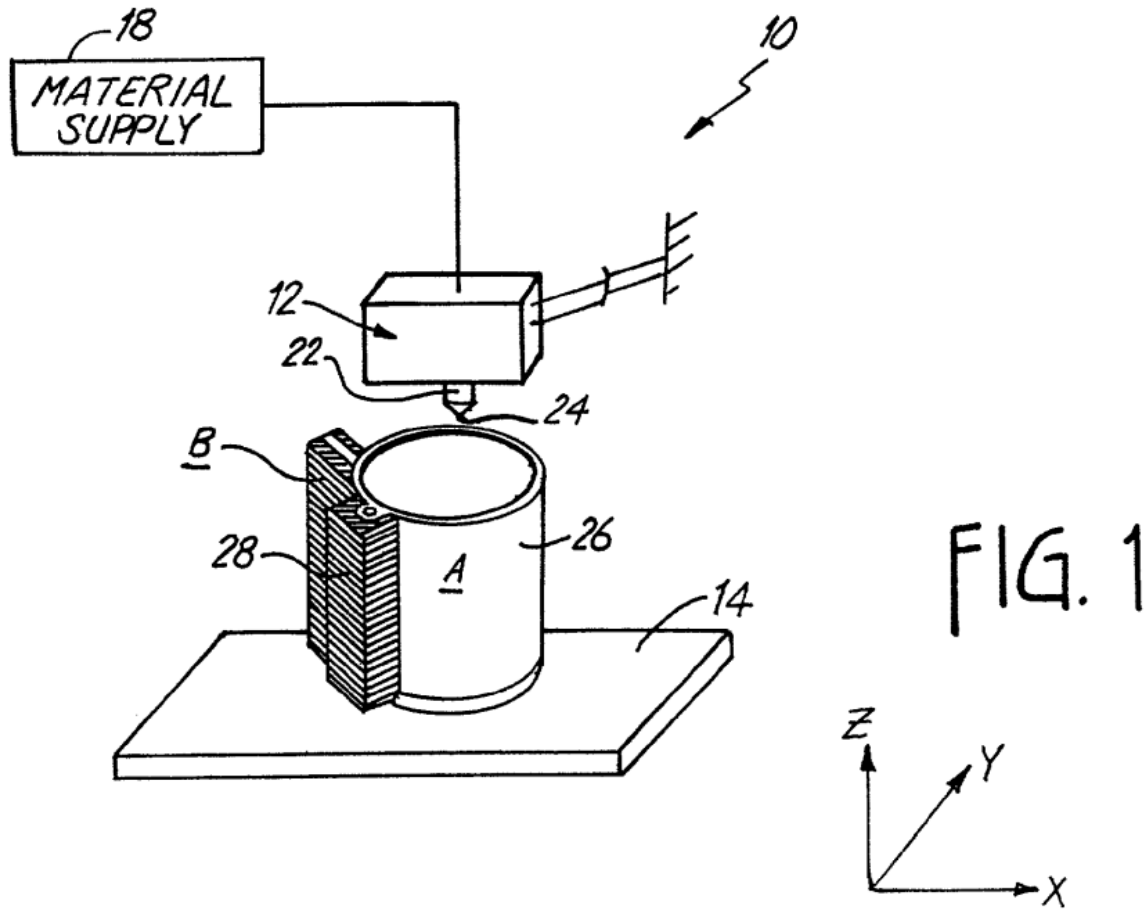
in RepRap Video, the geometry of the purge tower has different thicknesses at different heights and different X, Y locations. The purge tower also has different heights at different X, Y locations on the substrate.



EX1006, 5:04.

C. Priedeman (EX1007)

44. Priedeman, much like the '713 Patent, discloses an extrusion apparatus 10 for building a three-dimensional model 26 and a support structure 28. EX1007, [0002]-[0011], [0013], [0016]-[0018], FIG. 1. Priedeman's extrusion apparatus 10 uses "layered deposition modeling" to build model 26 and support structure 28. EX1007, [0013], see also [0017] ("The movement of the extrusion head is controlled So as to deposit material onto the base 14 in multiple passes and layers to build the three-dimensional model 26 and further to build the support structure 28.") Specifically, Priedeman explains that the extrusion apparatus 10 includes at least one extrusion head 12 for depositing "modeling material A" to print the model 26 and depositing "support material B" to print the support structure 28:

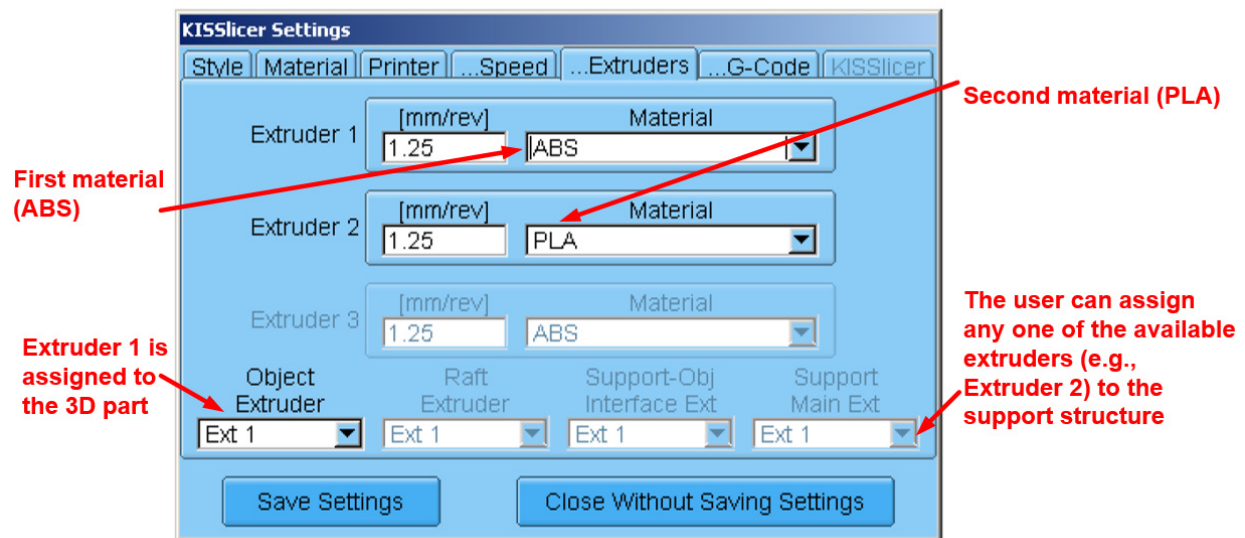


EX1007, [0016]-[0022], FIG. 1. For example, Priedeman discloses that a single extrusion head can include two separate nozzles, one depositing material A and the other depositing material B. EX1007, [0018].

D. KISSlicer (EX1010)

45. KISSlicer is a user manual describing software for controlling a multi-extruder system to print a three-dimensional part and support structure, much like Priedeman's extrusion apparatus 10 that includes multiple nozzles depositing multiple materials. EX1010, 1-11. I noticed that KISSlicer provides users with

granular control to set parameters for each extruder of a multi-extruder system through various user interfaces. EX1010, 2-8. Specifically, KISSlicer's software provides one user interface that allows a user to select a first material (e.g., ABS) for deposition by "Extruder 1" and a second material (e.g., PLA) for deposition by "Extruder 2":



EX1010, 5 (annotated). As depicted above, this same user interface provided by KISSlicer's software allows the user to select one extruder (e.g., Extruder 1) for printing the three-dimensional part and another extruder (e.g., "Extruder 2") to print the support structure. EX1010, 3.

46. Even though KISSlicer's user interface shows "Ext 1" as being selected for both of the "object" (3D part) and "support" (structure) it is apparent that KISSlicer provides the option for a user to select different extruders to print these items. For example, KISSlicer discloses that "[w]ith free version you can set one

extruder for all the print, while the pro version you can assign the head to part, raft, support and part/support interface.” EX1010, 5. This clearly indicates that the “pro version” of KISSlicer’s software permits different extruders to be selected for printing the 3D part and support structure. EX1010, 5. KISSlicer also describes transitioning each extruder between active and standby modes by adjusting the temperature of the extruders. For example, KISSlicer shows an active temperature for the extruder of 250°C and a “Keep-Warm” temperature for the standby mode of 160°C. EX1010, 3.

47. KISSlicer explains that when multiple extruders are used for printing, it is “extremely important” to clean the extruder tips “before every layer.” EX1010, 9. KISSlicer’s software controls the multi-extruder system by printing a purge tower—referred to as a “wipe pillar”—on the substrate next to the three-dimensional part and support structure at a position that “can be chosen” by the user. EX1010, 9.

The wipe pillar is a cylinder printed before every layer to clean the extruder tip. It reduces hairing and it is extremely important in dual head prints. Can be switched off, or the position with respect to the main part can be chosen.

EX1010, 9.

48. As discussed in the above reproduced excerpt, one reason that KISSlicer provides for printing this purge tower is that it “reduces hairing,” which in 3D printing technology means reducing a prevalence of oozed threads or fine

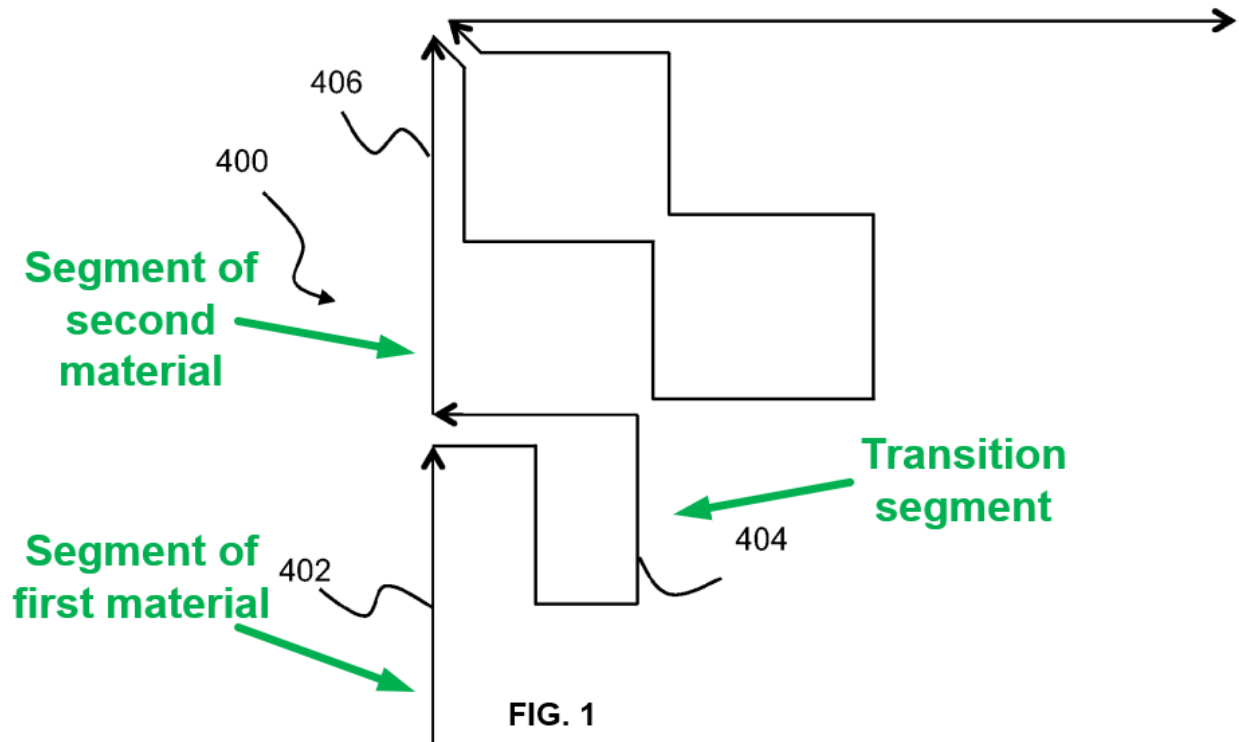
“hairs” that can form between different printed objects. EX1010, 9. Each layer of KISSlicer’s purge tower performs a “priming” (or “wipe”) operation to extrude some filament from the nozzle “after a warm up.” EX1010, 10.

E. Boyer (EX1008)

49. Boyer is similar to the ’713 Patent because it describes a printer including an extruder for printing three-dimensional parts using two different materials. EX1008, [0003], [0025]-[0029], FIG. 2. Boyer describes one embodiment of an extrusion head that includes a single output tip and deposits a first material and a second material *at different times*. EX1008, [0025]-[0029], FIG. 2. Boyer’s printer in the embodiment involving a single extrusion head can deposit a first material to print a three-dimensional part and a second material to print a support structure. EX1008, [0025]-[0029], [0032]-[0044], FIGS. 2, 4-5.

50. Boyer discloses that the extruder can alternate between depositing a segment of the first material and depositing a segment of the second material to print a 3D part and support structure using two different materials, with the first material corresponding to the 3D part and the second material corresponding to the support structure. EX1008, [0032]-[0034], FIG. 4. When Boyer’s printer alternates between materials, the printer can deposit a layer of purge material that Boyer refers to as a “transition segment” to dispose of material that adheres to the inside walls of the extruder. EX1008, [0032]-[0034], FIG. 4. After printing this layer of purge material,

Boyer's extrusion head can subsequently print a segment of the object or support structure. EX1008, [0032]-[0034], FIG. 4. An example of a tool path that can be printed by Boyer's extruder is depicted below in FIG. 4:



EX1008, FIG. 4 (annotated).

51. The successive segments of material depicted above in Boyer's FIG. 4 can be deposited by the extruder according to a two-dimensional tool path and using two different materials. EX1008, [0012], [0024], [003], [0034], FIG. 4. Boyer refers to the successive segments as a "cross section of a multi-material build. EX1008, [0032]. This means that layers such as the one depicted in FIG. 4 can be deposited on top of one another to create a 3D part and/or support structure. Furthermore, the

“transition segments” printed by Boyer’s extruder can form purge towers because the transition segments are printed on top of one another.

VIII. GROUND 1: LEAVITT IN COMBINATION WITH REPRAP ARTICLE AND REPRAP VIDEO WOULD HAVE RENDERED CLAIMS 1, 2, 5-7, 9, 16, AND 17 OBVIOUS

A. Overview of the Combination and Reasons to Combine

52. Based upon my knowledge and experience in the field and my review of Leavitt and RepRap, it is clear that a POSITA would have been motivated to implement Leavitt’s system to print a purge tower directly on the substrate in a layer-by-layer manner (as suggested by RepRap Article and RepRap Video) for purposes of achieving known benefits that I articulate in further detail below. For example, a POSITA would have been motivated to make this predictable combination in a way that advantageously allows Leavitt’s extruder head “prime” some material out of the nozzle, including any oozed or inconsistently heated material at the tip of the nozzle, in a position on the substrate that is near to the 3D part as taught by RepRap. EX1005, 1. Indeed, Multiple reasons would have motivated a POSITA to make this combination.

53. As a *first* reason, a POSITA would have been prompted to implement Leavitt’s system with the purge tower suggestion of RepRap because doing so would result in Leavitt’s deposition lines 30 and 32 “priming” their nozzles before printing the layers of 3D object 20 and support structure 22 to establish a “consistent flow of

plastic” in a way that prepares the nozzles for printing. EX1005, 1. It is apparent from Leavitt’s teachings that the material at the nozzle tip of the idle liquefier pump would have an inconsistent texture, especially if a portion of the material slightly oozes from the tip of the nozzle. EX1004, [0032] (“may potentially ooze”). It is apparent that a POSITA would have recognized from each of RepRap Article and RepRap Video that the “priming” of such material into the suggested purge tower would have advantageously avoided uneven deposition or defects imposed upon the 3D part.

54. As a *second* reason, RepRap’s suggestion to print a purge tower on the build substrate next to the 3D part would have beneficially allowed Leavitt’s extruder head to prime such material and prepare the deposition line for operating mode in a prompt and efficient manner, while limiting additional movement of the extruder head for the purpose of printing the purge tower. Because the suggested purge tower can be close to the 3D part on the build substrate, it is clear that Leavitt’s extrusion head 18 would not need to travel as far to perform the purge operation as compared with a distance required for other purging methods involving, for example, a purge bucket located outside the periphery of the build substrate. This means that printing a purge tower can reduce an amount of time required to complete a multi-material build as compared with other purge methods that require the extrusion head to repeatedly travel outside of the periphery of the build substrate.

55. As a *third* reason, a POSITA would have understood that implementing Leavitt's system with RepRap Article's suggestion to lower the temperature of an idle extruder would provide an improved approach for preventing the idle extruder from leaking oozed material onto the 3D part while positioned over the 3D part. For example, POSITA would have recognized that cooling Leavitt's deposition line 32 switched into the stand-by mode while deposition line 30 occupies the operating mode and extrusion head 18 is positioned above the 3D part would have advantageously decreased the likelihood of deposition line 32 dripping any oozed material along the 3D part, an issue that Leavitt expressly acknowledges in multi-material builds. EX1004, [0032]. A POSITA would have been prompted to cool Leavitt's deposition line 30 switched into the stand-by mode while deposition line 32 occupies the operating mode for similar reasons. Another reason that a POSITA would have recognized that it is beneficial to prevent such oozing from the extrusion head 18 of Leavitt is that the nozzles of build liquefier pump 30 and support liquefier pump 32 are positioned closely together. EX1004, [0025]-[0035], FIGS. 2A-2B. This means that the idle pump would routinely be positioned over the part and benefits of preventing oozing would be apparent.

56. *Fourth*, RepRap Video's teaching to print a purge tower on the substrate next to the 3D part would have provided an efficient way to concentrate waste material for rapid disposal in a compact purge tower. A POSITA would have

therefore understood that implementing Leavitt's system for using extruder head 18 to print a three-dimensional part and a support structure on a substrate with the purge tower teachings of RepRap would have provided an efficient way to dispose of waste material. Because RepRap's purge tower can be the same size or smaller than the 3D object, RepRap discloses a way to gather waste material in one place on the substrate so that the waste material can be rapidly collected (for disposal) when the 3D part is also collected.¹

57. Finally, Leavitt, RepRap Article, and RepRap Video are each directed to 3D printer systems that use additive manufacturing techniques to print objects with a dual extruder system and using multiple materials. In light of these similarities,

¹ As I noted above, it is apparent that the RepRap Article incorporates and directly links to the RepRap Video, and vice versa. EX1005, 1; EX1018, Appendix B. It is clear that a POSITA would have been motivated to consider one in view of the other and consider both of these references in view of Leavitt's dual-extruder teaching, especially because RepRap Article expressly suggests the reader should view the RepRap Video to see the improved dual-extruder technique in action. EX1005, 1 ("[y]ou can see the full size video"). A POSITA would have easily recognized the mutual links and context from these teachings in RepRap Article and RepRap Video.

a POSITA would have possessed ample skill to successfully implement the combination as I have described above. A POSITA would have been prompted to modify Leavitt's 3D printing system to include the additional functionality described by RepRap to print a purge tower for purging the printhead between depositing layers of different materials because doing so would be merely the application of a known technique (as suggested by RepRap) to a known system (e.g., Leavitt's 3D printing system) ready for improvement to yield predictable results. Here, RepRap provides straightforward evidence of a known technique printing a purge tower on the same substrate as the object being fabricated to prime the active extrusion nozzle of the device when transitioning the nozzle from a standby to active operating mode (including transitioning the temperature of the nozzle), and Leavitt's teaching provides a known system that would have been improved by application of RepRap's suggested technique for at least the reasons described above. Based upon my knowledge and experience in this field and my review of Leavitt and RepRap, I am confident a POSITA would have recognized that this modification would have yielded predictable results and required only routine adjustments to the mechanical components and software to provide the additional functionality disclosed by RepRap and as such a POSITA would have had a reasonable expectation of success in making such modifications. This modification would not have significantly altered or hindered the functions performed by Leavitt's system, and these

modifications would have been within the predictable and ordinary level of skill of a POSITA (certainly by a time frame as late as 2013).

B. Independent Claim 1

58. Independent claim 1 of the '713 Patent recites:

1. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:
printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;
switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;
performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.

59. As I explain in more detail below through my element-by-element analysis, the combination of Leavitt with RepRap renders claim 2 obvious.

[1pre] A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

60. To the extent that the preamble is treated as a limitation, my review of Leavitt and RepRap confirms that the Leavitt-RepRap combination provides “[a] method for printing a three-dimensional part with an additive manufacturing system.” For example, the “extrusion-based layered deposition system” (system 10) of Leavitt represents an ***additive manufacturing system***. EX1004, [0001], [0006], [0020],

[0022], FIG. 1. One reason for this is that Leavitt discloses that system 10 deposits material in a “layer-by-layer manner,” thus indicating that layers of material are *added* on top of one another to *manufacture* a part. EX1004, [0022]. System 10 can *print a three dimensional part* (e.g., 3D object 20) on a substrate. EX1004, [0020]-[0024], FIG. 1. Leavitt also describes aspects of a *method*, which is sometimes referred to by Leavitt as a “process,” for printing the *three-dimensional part*. EX1004, [0002], [0004], [0023].

61. Therefore, the Leavitt-RepRap combinations provides Element [1pre].

[1a] printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;

62. As I describe above in my analysis of Element [1pre], it is apparent that Leavitt’s system 10 can *print a three-dimensional part* (e.g., 3D object 20). EX1004, [0020]-[0024], FIG. 1. It is also clear that Leavitt’s system 10 can *print a support structure* 22 for 3D object 20. EX1004, [0020]-[0024], FIG. 1. Leavitt makes it clear that extrusion head 18 prints *layers* of 3D object 20 and support structure 22. EX1004, [0004], [0020], [0023] (“form a layer of 3D object 2,” “form a layer of Support structure 22.” Leavitt discloses that “[e]xtrusion head 18 is a dual-tip extrusion head...for building 3D object 20 and support structure 22 on substrate 14 in a *layer-by-layer* manner,” thus indicating extrusion head 18 prints multiple layers of both the 3D object 20 and the support structure 22. EX1004, [0020]. In another

example, Leavitt describes that “extrusion head 18 is initially positioned in the build state, which allows extrusion head 18 to deposit the build material in a sequence of roads to form a *layer* of 3D object 20... extrusion head 18 then toggles to the support state, which allows extrusion head 18 to deposit the support material in a sequence of roads to form a *layer* of support structure 22”. EX1004, [0020]. This configuration in which extrusion head 18 includes two deposition lines, with the first deposition line depositing build material to fabricate the 3D object 20 and the second deposition line depositing support material to fabricate support structure 22 is depicted below in FIG. 1:

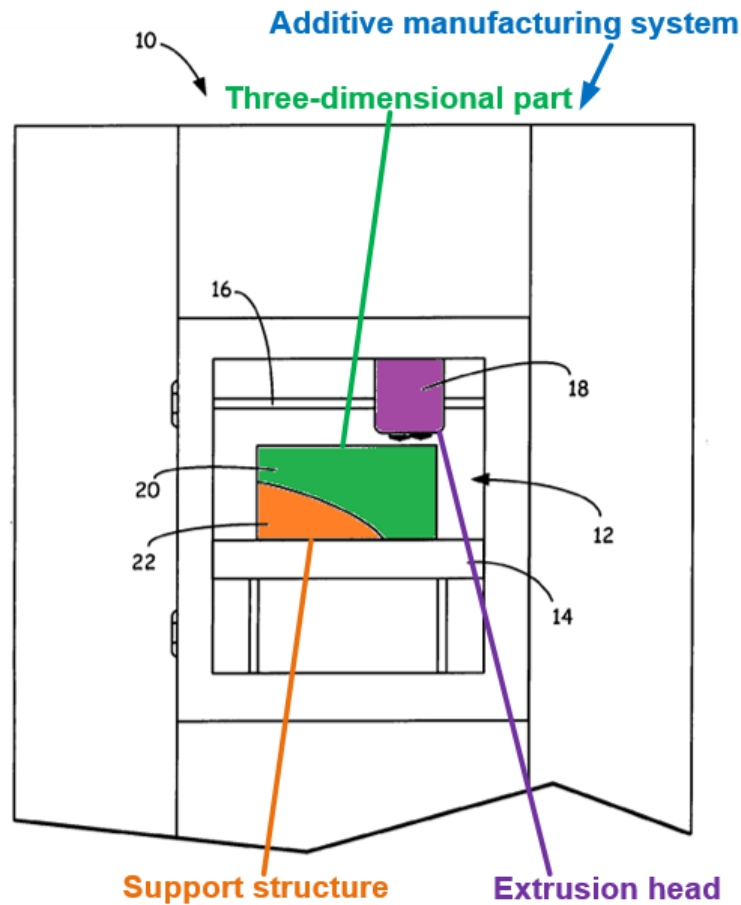


FIG. 1

EX1004, FIG. 1 (annotated).

63. Based on my review of Leavitt, it is clear that extrusion head 18 comprises *multiple deposition lines*, including a “build” *deposition line* with a first output nozzle from build liquefier pump 30 for printing 3D part 20 and a “support” *deposition line* including a second output nozzle from support liquefier pump 32 for printing support structure 22. EX1004, [0020]-[0023], [0025]-[0032], [0033] (“is then *deposited*”), [0037] (“is then *deposited*”), FIGS. 1-2B. Leavitt’s *multiple deposition lines* are depicted below in FIG. 2A:

material filament so that molten build material is extruded from build tip 54 to *print layers* of 3D object 20. EX1004, [0028], FIGS. 2A-2B. Because the build tip 54 deposits build material through extrusion, it is clear that build liquefier pump 30 represents a *deposition line*.

65. Also as depicted in FIG. 2A, the support *deposition line* of support liquefier pump 32 includes filament inlet 58, motor 62, drive wheel assembly 64, liquefier 66, and support tip 68. EX1004, [0029], FIGS. 2A-2B. Motor 62 powers drive wheel assembly 64 to feed a support material filament through filament inlet 58 to liquefier 66 to *print* the *support structure* 22. EX1004, [0030], FIGS. 2A-2B. Subsequently, liquefier 66 melts the support material filament so that molten support material is extruded from support tip 68 to *print layers* of support structure 22. EX1004, [0028], FIGS. 2A-2B. Because the support tip 68 deposits support material through extrusion, it is clear that support liquefier pump 32 represents a *deposition line*.

66. Therefore, the combination of Leavitt with RepRap provides Element [1a].

[1b] switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;

67. Leavitt makes it clear that extrusion head 18 is configured to *switch* between a “build state” for depositing a build material to print the *three-dimensional*

part (e.g., 3D object 20) and a “support state” for depositing a support material to print *support structure* 22, a process that Leavitt refers to as “toggling.” EX1004, [0022]-[0024], FIG. 1. It is apparent that this toggling between the build state and the support state occurs *in-between* printing *layers* of the *three-dimensional part* (3D object 20) and the *support structure* 22, for reasons that I discuss in further detail below. EX1004, [0022]-[0024], FIG. 1.

68. For example, I noticed that Leavitt describes each layer of a layer-by-layer process to build 3D object 20 and support structure 22, including the toggle actions that occur between printing 3D object 20 and support structure 22. For instance, Leavitt explains that “extrusion head 18 is initially positioned in the build state,² which allows extrusion head 18 to deposit the build material...to form a *layer* of 3D object 20.” EX1004, [0023]. After printing the *layer* of 3D object 20, Leavitt further explains that “extrusion head 18 then toggles to the support state, which

² This is merely one example of a starting point for Leavitt’s layer-by-layer deposition process. I noticed that extruder head 18 is not limited to initially being positioned in the build state. Indeed, Leavitt explains that extruder head 18 can be initially positioned in the support state in some embodiments to print a layer of support structure 22, subsequently toggling to the build state to print a layer of 3D object 20. EX1004, [0023].

allows extrusion head 18 to deposit the support material...to form a *layer* of support structure 22.” EX1004, [0023]. This support state involves moving the nozzle of the support liquefier pump 32 to “a lowered position.” EX1004, [0034]. Leavitt explains that “[w]hen support liquefier pump 32 reaches the lowered position, toggle motor 70 desirably continues to apply a low to moderate amount of rotational power to torque assembly 72 in the direction of rotational arrow 76 to retain support liquefier pump 32 in the lowered position. EX1004, [0034]. Leavitt further explains that “this prevents support liquefier pump 32 from moving horizontally or vertically relative to build liquefier pump 30 while extrusion head 18 moves around build chamber 12 (shown in FIG. 1) in the support state.” EX1004, [0034].

69. Extrusion head 18 then toggles back to the build state “[a]fter the layer of support structure 22 is complete” in order to print “a *subsequent layer* of 3D object 20.” EX1004, [0023]. Leavitt explains that as part of this transition, the tip 68 of support liquefier pump 32 is raised above the build tip of the build liquefier pump 30. EX1004, [0032] (“In the raised position, support tip 68 extends higher than build tip 54 along the z-axis by raised offset distance 74.”). Leavitt explains that the [r]aised offset distance 74 allows build liquefier pump 30 to extrude roads of build material to form a layer of 3D object 20 without interference from support tip 68. Moreover, raised offset distance 74 reduces the risk of support material becoming embedded in 3D object 20. EX1004, [0032]. Finally, Leavitt discloses that the

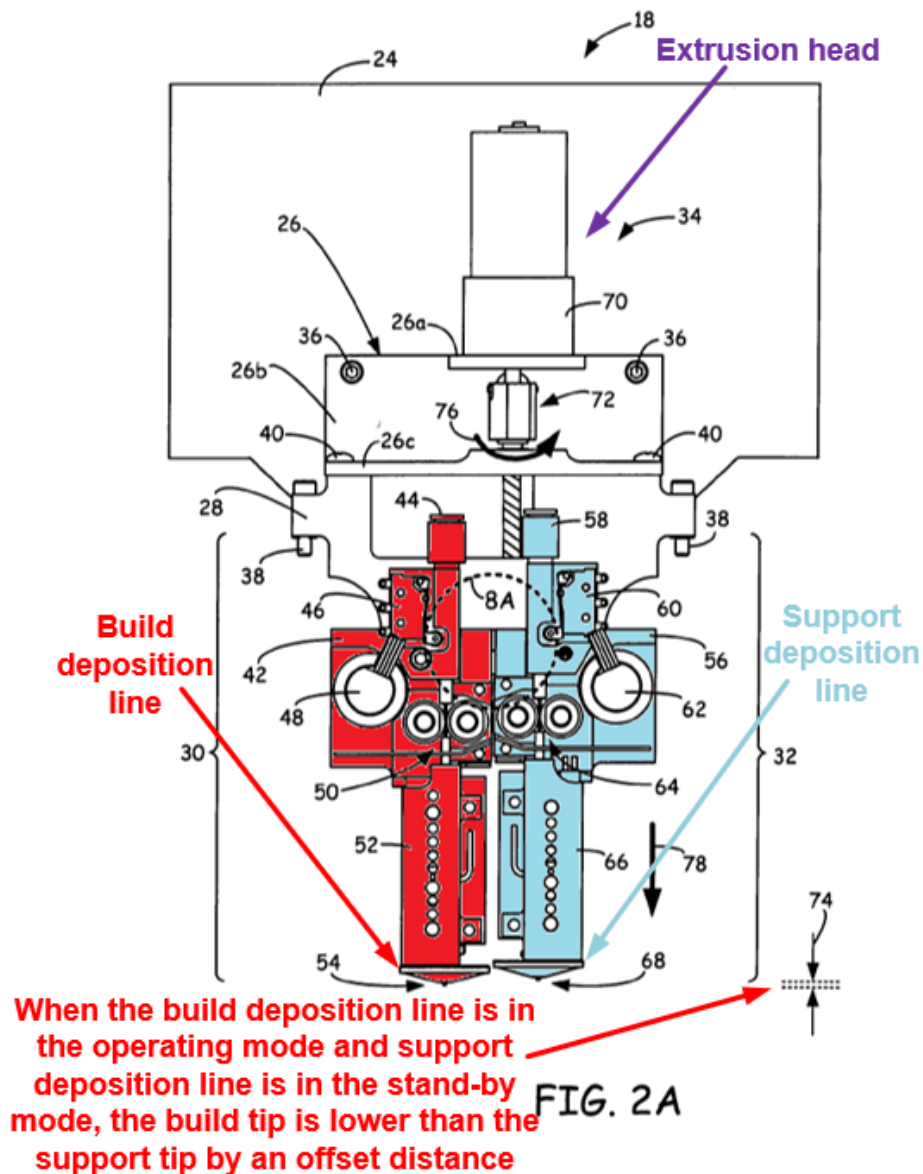
process of **switching** (“toggling”) between the build state and the support state “may be repeated until each layer of 3D object 20 and support structure 22 are complete.” EX1004, [0023], *see also* [0024] (“extrusion head 18 toggles...numerous times”).

70. This disclosure of Leavitt clearly indicates that the extrusion head 18 performs a toggle action ***in-between*** printing a layer of the 3D object 20 and printing a layer of support structure 22—throughout the process to print 3D object 20 and support structure 22. EX1004, [0023], [0024]. By indicating that the toggling actions occur between printing layers of the 3D object 20 and support structure 22 and also indicating that this process occurs “numerous times,” it is apparent that Leavitt’s ***multiple deposition lines*** each switch ***modes***. Specifically, Leavitt explains that toggling extrusion head 18 between the build state and the support state involves adjusting a relative position of support liquefier pump 32 and build liquefier pump 30 so that the pump actively extruding material is closer to the build surface than the idle pump. EX1004, [0025]-[0039], FIGS. 2A-2B.

71. As I discussed in further detail above in connection with my analysis of Element [1a], Leavitt’s extrusion head 18 includes ***multiple deposition lines***. EX1004, [0025]-[0039], FIGS. 2A-2B; *supra*, Element [1a]. Leavitt makes it clear that a build ***deposition line*** corresponding to build liquefier pump 30 can ***switch*** between an ***operating mode*** for depositing molten ***build material*** and a ***stand-by***

mode where build liquefier pump 30 sits idle.³ EX1004, [0032]-[0038], FIGS. 2A-2B. Specifically, Leavitt explains that when build liquefier pump 30 is in the *operating mode*, support liquefier pump 32 is in a raised position so that support tip 68 is higher than build tip 54 by an offset distance 74. EX1004, [0032]. According to Leavitt, this offset distance helps to ensure that support liquefier pump 32 does not interfere with build liquefier pump 30 as build liquefier pump 30 actively deposits build material in the *operating mode*. EX1004, [0032]. Leavitt's FIG. 2A, which depicts extrusion head 18 in the "build state" and build liquefier pump 30 in the *operating mode*, is reproduced below:

³ It is apparent build liquefier pump 30 is in the *operating mode* when extrusion head 18 occupies the build state and is in the *stand-by mode* when extrusion head 18 occupies the support state.

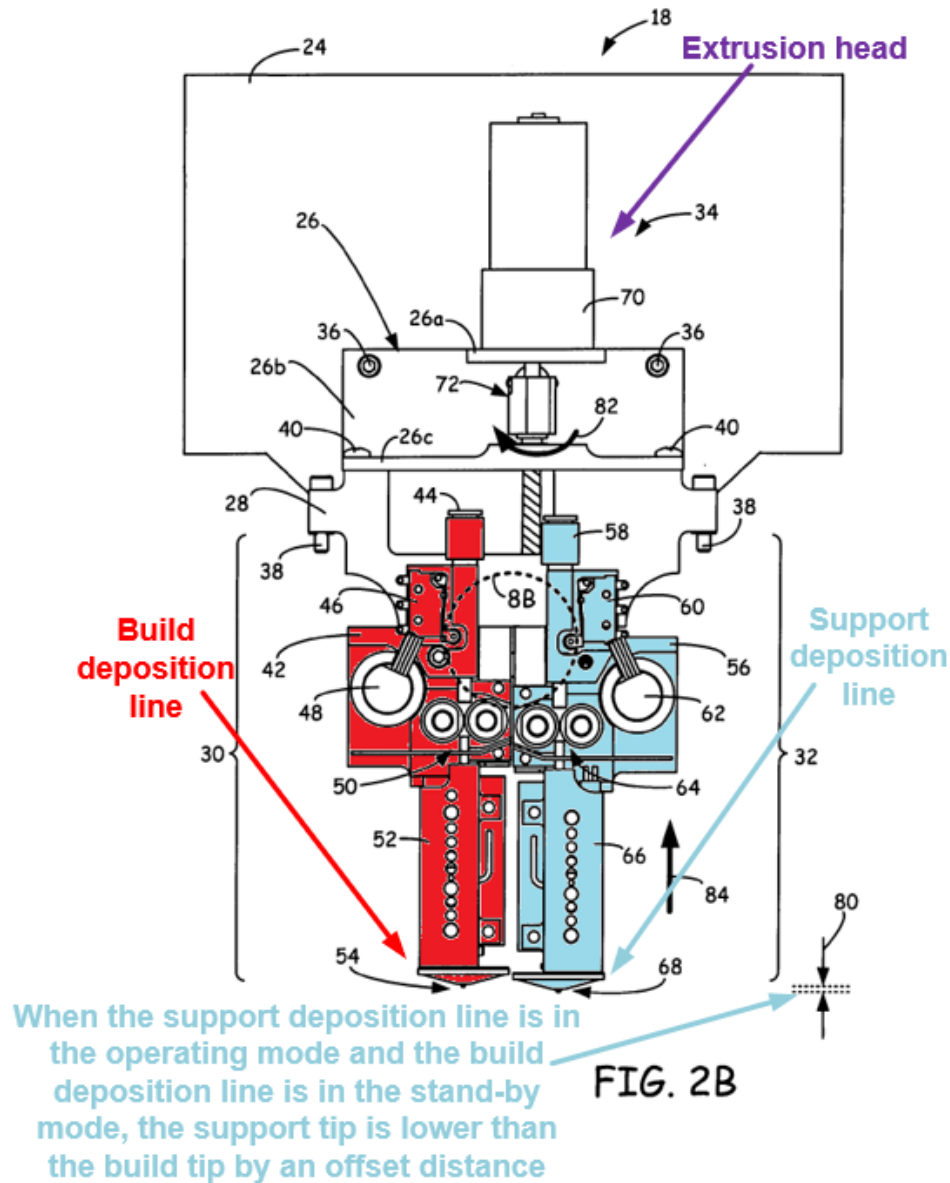


EX1004, FIG. 2A (annotated).

72. The support *deposition line* corresponding to support liquefier pump 32 is sitting idle in the *stand-by mode* when the *build deposition line* corresponding to build liquefier pump 30 is in the *operating mode* to “extrude roads of build material” as depicted above in FIG. 2A. EX1004, [0032]. Leavitt explains that after printing a layer of the 3D object 76, a toggle motor of the

extrusion head 18 causes support liquefier pump 32 transition to a lowered position where the support tip 68 extends below the build tip 54 by an offset distance.

EX1004, [0034]-[0035]. The position of extruder 18 which Leavitt refers to as the “support state” is depicted below in FIG. 2B:



EX1004, FIG. 2B (annotated).

73. Leavitt makes it apparent that transitioning the extrusion head 18 from the build state depicted in FIG. 2A to the support state depicted in FIG. 2A involves switching the support liquefier pump 32 from the *stand-by mode* to the *operating mode* and *switching* the build liquefier pump 30 from the *operating mode* to the *stand-by mode*. EX1004, [0034]-[0038], FIGS. 2A-2B. This allows support liquefier pump 32 to extrude roads of support material to *print a layer* of support structure 22 while build liquefier pump 30 sits idle so that build liquefier pump 30 does not interfere with the operation of support liquefier pump 32. EX1004, [0035]. The toggle motor of the extrusion head 18 causes the extrusion head 18 to transition from the support state back to the build state to *print* another *layer* of 3D object 20 *after* this *layer* of support structure 22 is complete and before printing another *layer* of 3D object 20. EX1004, [0035].

74. Furthermore, when Leavitt's extrusion head 18 is predictably implemented with RepRap's purge tower and temperature control teachings, extrusion head 18 would cool the idle *deposition line* and heat the active *deposition line*, further indicating that the *deposition lines* switch between an *operating mode* and *stand-by mode*. EX1005, 1; *supra*, §VIII.A. For example, RepRap expressly describes that a benefit of cooling an idle deposition line from a warmer temperature used during printing is to reduce a probability of "leaking" from the idle deposition line. EX1005, 1. A POSITA would have been motivated to implement these

temperature changes in Leavitt's extrusion head 18 as part of the *operating mode* and *stand-by mode* to prevent such leaking from build liquefier pump 30 and support liquefier pump 32, especially because Leavitt acknowledges that "oozing" from idle deposition lines is an issue. EX1005, 1; EX1004, [0032] *supra*, § VIII.A.

75. Therefore, the combination of Leavitt with RepRap Element [1b].

[1c] performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.

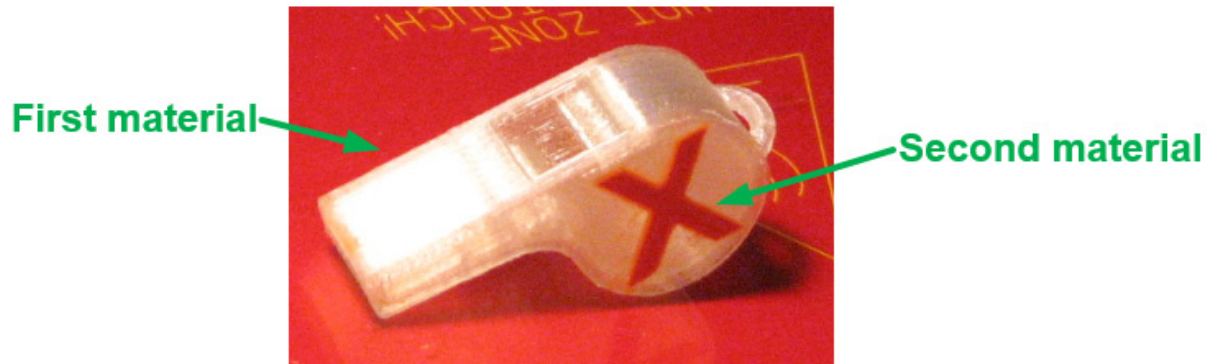
76. As I described above in my analysis of Element [1b], Leavitt discloses that extruder head 18 includes a build *deposition line* corresponding to build liquefier pump 30 and a support *deposition line* corresponding to support liquefier pump 32, each *deposition line* alternating between an *operating mode* and a *stand-by mode*. EX1004, [0025]-[0039], FIGS. 2A-2B. These *deposition lines* alternate inversely so that when the build *deposition line* switches to the *operating mode*, the support *deposition line* switches to the *stand-by mode*, and vice versa. EX1004, [0031]-[0035], FIGS. 2A-2B. This means that only one of the two deposition lines actively extrudes material at a given time, and the other deposition line remains idle.

77. As I described above in §VII.A of my declaration, Leavitt explains that transitioning the *deposition lines* between actively extruding material and sitting idle presents an issue where excess material can leak from the idle *deposition line* and

mix with material recently printed by the active *deposition line*. EX1004, [0032], [0035]. For example, Leavitt discloses that support liquefier pump 32 in the *stand-by mode* can “ooze” residual support material so that support material drips onto a recently printed layer of 3D object 20. EX1004, [0032]. It is clear that the same issue can arise when build liquefier pump 30 occupies the *stand-by mode*, with residual build material potentially becoming “embedded” in support structure 22. EX1004, [0035]. Leavitt fully acknowledges this problem and explains that positioning the idle pump above the active pump “reduces the risk” of leakage. EX1004, [0032], [0035].

78. RepRap discloses that a *purge operation* is performed for *each deposition line* switched to the *operating mode*, as I discussed above in section §VIII.A of my declaration. For instance, I noted that RepRap Article describes a 3D printer including an “extruder 0” that deposits one material and an “extruder 1” that deposits another material, meaning that RepRap’s printing includes *multiple deposition lines* each depositing a different material. EX1005, 1. It is apparent that RepRap Article’s extruders are configured to print a 3D part by depositing both of these materials using a *layer-by-layer* technique where the printer alternates between depositing one material using “extruder 0” and depositing the other material using “extruder 1.” EX1005, 1. One example of an object that can be printed by RepRap

Article's extruders using two different materials is a 3D part (whistle), as depicted below:



EX1005, 1 (annotated).

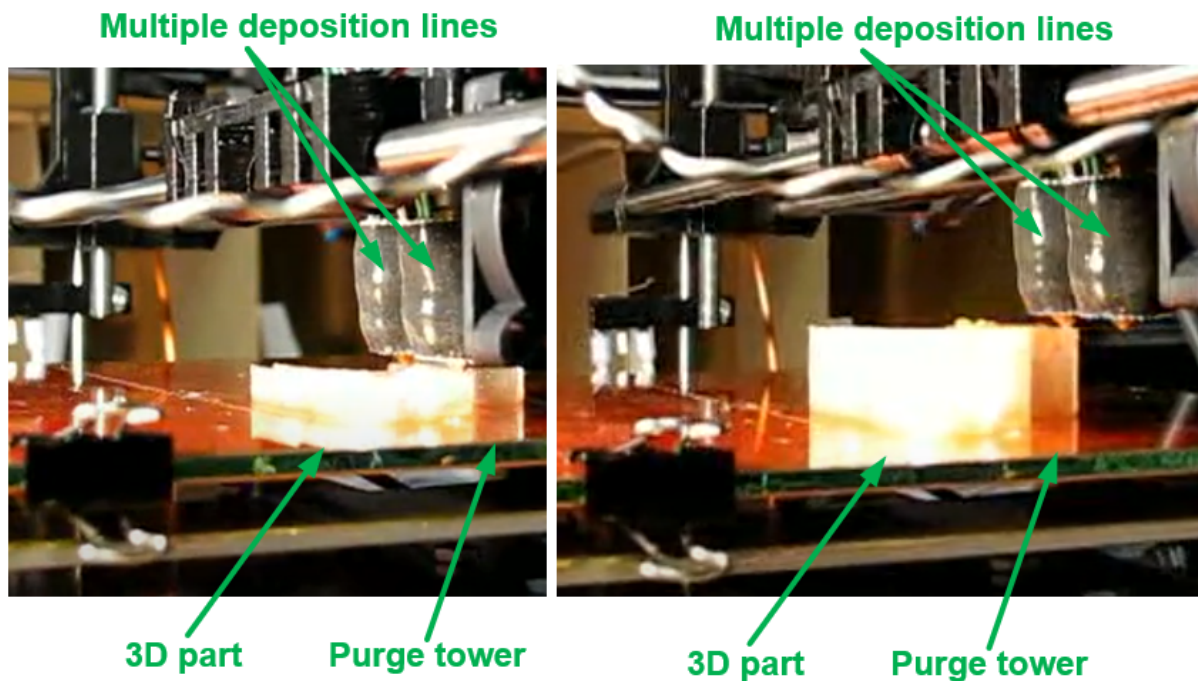
79. RepRap explains that the temperature of an idle extruder can be lowered to prevent leaking. EX1005, 1. According to RepRap Article, this leaking issue is “[o]ne of the most annoying problems with [] dual extruder printing.” EX1005, 1. Leavitt likewise acknowledges that such leaking is an issue, as residual material oozing from an idle nozzle can drip onto a recently printed layer of the part or support structure. EX1004, [0032], [0035]. This means that by moving the extruder head over the purge tower (away from the 3D part) and lowering the temperature within an idle extruder, RepRap Article addresses a problem that Leavitt expressly acknowledges and decreases a probability of dripping from idle extruders. EX1004, [0032], EX1005, 1.

80. When one of the extruders *switches* to an *operating mode* from the idle *stand-by mode*, RepRap makes it clear that the idle extruder performs a *purge*

operation by printing the purge tower to establish “consistent flow” of material within the extruder before printing the 3D object. EX1005, 1. At the same time, the other (idle) extruder can also be positioned over the purge tower and is cooled to prevent leaking. EX1005, 1. For example RepRap Article describes that the 3D printer “positions the nozzles above the ‘parking space’ object and change the active extruder while lowering the temperature of the idle.” EX1005, 1. RepRap Video clearly shows the 3D printer’s extruders print a purge tower next to the 3D object on the build plane. EX1005, 1. Specifically, based on my review of RepRap, “extruder 0” *performs a purge operation* upon switching to the *operating mode* by printing at least one layer of the purge tower prior to printing the 3D object. EX1005, 1. The “extruder 1” performs a similar *purge operation* upon switching to the *operating mode*. EX1005, 1.

81. RepRap Video, which is incorporated and linked within in RepRap Article as I describe in further detail above in §VII.B, depicts a printer including *multiple deposition lines* (e.g., “extruder 0” and “extruder 1”) simultaneously printing the 3D object and the purge tower using an *additive manufacturing technique*. EX1006, 0:03-4:59. It is apparent that A POSITA would have readily recognized that the 3D object and the purge tower are each printed in a *layer-by-layer manner* because RepRap Video depicts the extruders depositing layers of material so that the 3D object and the purge tower are gradually built upwards from

the print surface; EX1006, 0:03-4:59. This is a common feature of layer-based, additive manufacturing techniques. RepRap's extruders, 3D object, and purge tower are depicted below at two different points in the printing process as depicted by RepRap Video clearly indicating that the part and purge tower are built in a layer-by-layer manner:



EX1006, 3:22, 4:36 (annotated).

82. Another feature that I noticed in RepRap involves a *purge tower* that can be printed in a *layer-by-layer manner* through *purge operations* occurring when one of the extruders is switched to the *operating mode*. RepRap's *purge tower* is printed on the substrate directly next to the 3D part. RepRap Video depicts the completed 3D part and purge tower next to each other on the build substrate:

3D part printed
using multiple
materials



Purge tower
printed using
multiple materials

EX1006, 5:04 (annotated).

As shown in the above image of the RepRap Video, the purge tower is deposited in relatively close proximity to the three-dimensional part to beneficially minimize movement of the deposition head to make the most efficient use of fabrication time. When Leavitt's extruder head 18 is implemented with RepRap's purge tower teachings, it is apparent that Leavitt's extruder head 18 would predictably perform a *purge operation* between each use of build liquefier pump 30 and support liquefier pump 32 as suggested by RepRap, *supra*, §VIII.A. This *purge operation* would involve printing a *purge tower* in a *layer-by-layer manner* with build liquefier pump 30 and support liquefier pump 32 printing at least one layer of the *purge tower* in response to switching from a *stand-by mode* to an *operating mode*, as taught by RepRap, *supra*, §VIII.A.

83. RepRap thus demonstrates that performing *purge operations* to print a *purge tower* in a dual extruder system was well-known by the Critical Date of the '713 Patent (Mar. 8, 2013). EX1005, 1; EX1006, 0:01-5:15. Other sources corroborate that *purge towers* were well known in the art by 2012. For example, in

a 2012 internet thread discussing the RepRap dual extruder system, a user commented that the idle nozzle in a dual extruder system is often “dribbling” while the active nozzle is printing. EX1009, 2. Another user replied that the KISSlicer system can “draw a cylinder” next to this model to “wipe the nozzle on the cylinder on color/material changes.” EX1009, 2. Yet another user replied that one solution to the dribbling issue is to “prime” when changing extruders. EX1009, 3.

84. Therefore, for the reasons discussed above, the combination of Leavitt with RepRap provides Element [1c].

C. Claim 2

85. Claim 2 of the ’713 Patent recites:

<p>2. The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and wherein switching the deposition lines between the stand-by modes and the operating modes comprises:</p> <p>switching the first deposition line from the stand-by mode to the operating mode; and</p> <p>switching the second deposition line from the operating mode to the stand-by mode.</p>
--

86. As I explain in more detail below through my element-by-element analysis, the combination of Leavitt with RepRap renders claim 2 obvious.

[2a] The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and

87. As I describe in further detail above in connection with Element [1a], Leavitt's *multiple deposition lines* include a build liquefier pump 30 representing a *first deposition line* and a support liquefier pump 32 representing a *second deposition line*. EX1004, [0025]-[0032], FIGS. 2A-2B; *supra*, Element [1a].

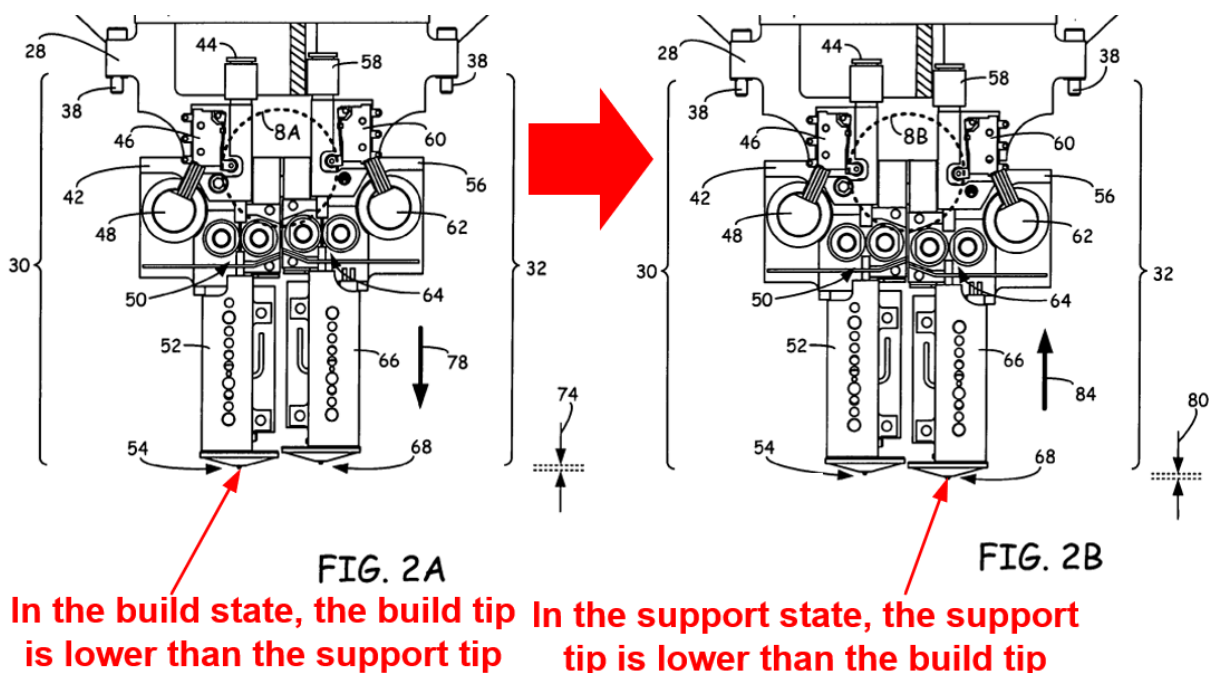
88. Therefore, the combination of Leavitt with RepRap provides Element [2a].

[2b] wherein switching the deposition lines between the stand-by modes and the operating modes comprises: switching the first deposition line from the stand-by mode to the operating mode; and switching the second deposition line from the operating mode to the stand-by mode.

89. As I describe in further detail above in connection with Element [1b], Leavitt explains that when extrusion head 18 occupies the "build state," build liquefier pump 30 occupies the *operating mode* for extruding build material and support liquefier pump 32 sits idle in the *stand-by* mode. EX1004, [0025]-[0039], FIGS. 2A-2B; *supra*, Element [1b]. Alternatively, Leavitt discloses that when extrusion head 18 occupies the "support state," build liquefier pump 30 occupies the *operating mode* for extruding build material, and support liquefier pump 32 sits idle in the *stand-by* mode. EX1004, [0025]-[0039], FIGS. 2A-2B; *supra*, Element [1b].

90. *Switching* Leavitt's *multiple deposition lines* between the *stand-by modes* and *operating modes* comprises toggling extrusion head 18 between the build state and the support state. For example, Leavitt explains that when extrusion head

18 toggles from the build state to the support state, the support liquefier pump 32 moves downward in the direction of arrow 78 from a raised position depicted in FIG. 2A to a lowered position depicted in FIG. 2B. EX1004, [0032], [0034], FIGS. 2A-2B.



EX1004, FIGS. 2A-2B (annotated).

91. Furthermore, when Leavitt's extruder head 18 is implemented with the purge tower and temperature control teachings of RepRap, it is apparent that extrusion head 18 would cool the idle *deposition line* when transitioning to *stand-by mode* and heat the active *deposition line* when transitioning to the *operating mode* per RepRap's teaching. EX1005, 1; *supra*, §VII.A. This temperature change could occur in addition to movement of support liquefier pump 66, meaning that *switching* between the *stand-by modes* and *operating modes* in the Leavitt-RepRap

combination involves both toggling the relative positions of build liquefier pump 30 and support liquefier pump 32 and changing the nozzle temperatures.

92. Leavitt explains that build liquefier pump 30 is in the *operating mode* to “extrude roads of build material” and support liquefier pump 32 is in the *stand-by mode* when extrusion head 18 occupies the build state. EX1004, [0032], [0033], FIG. 2A. Alternatively, Build liquefier pump 30 is in the *stand-by mode* and support liquefier pump 32 is in the *operating mode* to “extrude roads of support material” when extrusion head 18 occupies the support state. EX1004, [0035]-[0037], FIG. 2B. Based on my review of this disclosure in Leavitt, it is clear that when the extrusion head 18 toggles from the build state to the support state, the *first deposition line* corresponding to build liquefier pump 30 switches from the *stand-by mode* to the *operating mode* and the *second deposition line* corresponding to support liquefier pump 32 switches from the *operating mode* to the *stand-by mode*.

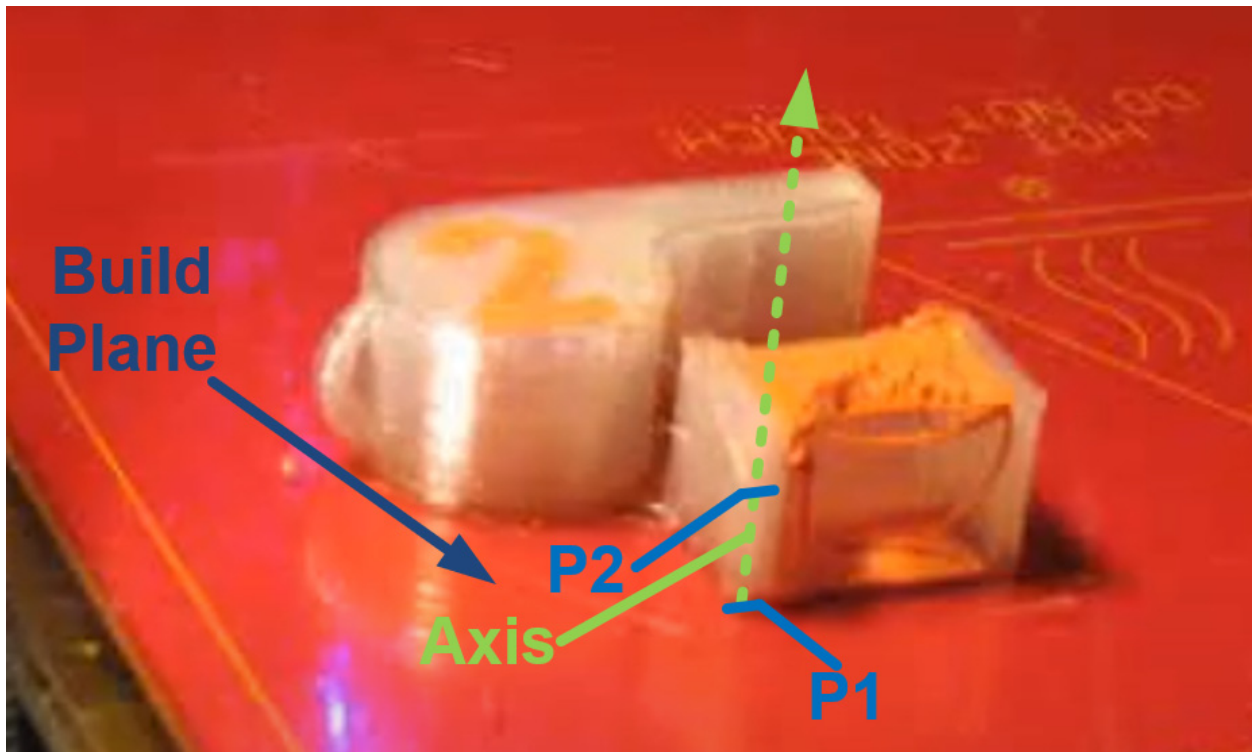
93. Therefore, the combination of Leavitt with RepRap provides Element [2b].

D. Claim 5

94. Claim 5 of the '713 Patent recites:

<p>5. The method of claim 1, wherein the at least one purge tower has a cross-sectional area that reduces in height along an axis that is perpendicular to a build plane.</p>

95. RepRap teaches that the *purge tower* can be printed next to a three-dimensional part such that a *cross-sectional area* of the *purge tower* reduces in height along an *axis* that is *perpendicular* to a *build plane* . EX1005, 1; EX1006, 5:01-5:05. As depicted below, it is apparent from RepRap Video that the *purge tower* has cross-sectional areas that differ between a first cross-sectional position (P1) at a base of the purge tower and a second cross-sectional position (P2) above P1 relative to the build plane:



EX1006, 5:04 (annotated).

96. Specifically, it is clear from RepRap video that the *cross-sectional area* of the purge tower at position P1 with the cross-section taken parallel to the build surface is greater than the *cross-sectional area* of the purge tower at position P2 with

the cross-section taken parallel to the build surface. EX1006, 5:04. This is because the cross-sectional area at position P1 includes a wide layer of orange material that fills most of the outer boundary of the purge tower. The cross-sectional area at position P2 does not include this wide layer of orange material, but rather includes a narrower layer of translucent material. RepRap video shows that a large portion of the area where orange material is located in the P1 cross-sectional area does not include such material in the P2 cross-sectional area. This means that between P1 and P2 along the axis perpendicular to the build plane, the cross-sectional area of the purge tower reduces in height.

97. The teachings of Leavitt and RepRap provide the additional feature recited in claim 5 and would have rendered claim 5 obvious in its entirety.

E. Claim 6

98. Claim 6 of the '713 Patent recites:

6. The method of claim 1, wherein the at least one purge tower is stopped at a highest layer at which there is a material change for the printed layers of the three-dimensional part and support structure.
--

99. As I described above in connection with Element [1c], the *purge operation* of RepRap involves *printing a purge tower* in a *layer-by-layer* manner as taught by RepRap. EX1005, 1; EX1006, 0:01-5:15. This means that in the Leavitt-RepRap combination, extrusion head 18 performs a *purge operation* for each *deposition line* switched to the *operating mode*. RepRap. EX1004, [0022]-[0039],

FIGS. 1-2B, EX1005, 1; EX1006, 0:01-5:15. That is, build deposition line 30 would perform a *purge operation* when it enters the operating mode and support deposition line 32 would perform a *purge operation* when it enters the operating mode. The purge operations would involve printing one or more layers of a *purge tower* before printing the 3D object 20 or support structure 22. EX1005, 1. As I discussed above in connection with Element [1c], the Leavitt-RepRap Combination provides that Leavitt's extrusion head 18 performs a purge operation for each deposition line corresponding to build liquefier pump 30 and support liquefier pump 32 switched to the operating mode. RepRap. EX1004, [0022]-[0039], FIGS. 1-2B, EX1005, 1; EX1006, 0:01-5:15.

100. In the predictable Leavitt-RepRap combination, it is apparent that extrusion head 18 would *stop* printing a *purge tower* at a *highest layer* at which there is a *material change* for the printed layers of the *three-dimensional part* (e.g., 3D object 20) and *support structure* 22. EX1004, [0022]-[0039], FIGS. 1-2B, EX1005, 1; EX1006, 0:01-5:15. This is because RepRap explains that when an extruder transitions out of an idle state upon a *material change*, the extruder prints one or more layers of the *purge tower* beside the *three-dimensional part* "before printing the actual object." EX1005, 1. It would not be necessary for extruder head 18 to continue printing the *purge tower* after the last *material change* is complete in the

predictable Leavitt-RepRap combination, because another purge operation would not be necessary to bring an idle extruder online.

101. It is apparent that Leavitt's extruder head 18 in the predictable Leavitt-RepRap combination would *stop* the *purge tower* at the *highest layer* at which extruder 18 *changes* between depositing the build material and depositing the support material just as the *purge tower* of RepRap *stops* with the last material that is used to print the 3D object. EX1004, [0022]-[0025], [0032]-[0039], FIGS. 1-2B, EX1005, 1; EX1006, 0:01-5:15. As I explained above, this is because once extruder 18 performs its final "toggle" to the build state for printing 3D object 20 or the support state for printing support structure 22, extruder 18 would not need to print another layer of the parking space to prime the idle extruder as taught by RepRap, as after the final toggle the print can be completed without using the idle extruder again.

Printing the 3D part concludes with "extruder 1" transitioning out of the idle mode to print the "2"



The highest layer of the parking space comprises the same material used for the "2"

EX1006, 5:04 (annotated).

102. The teachings of Leavitt and RepRap provide the additional feature recited in claim 6 and would have rendered claim 6 obvious in its entirety.

F. Claim 7

103. Claim 7 of the '713 Patent recites:

7. The method of claim 1, and further comprising:
generating tool path instructions for printing the layers of
the three-dimensional part and of the support structure;
and
generating tool path instructions for printing the layer of
the at least one purge tower.

104. As I explain in more detail below through my element-by-element analysis, the combination of Leavitt with RepRap renders claim 7 obvious.

***[7a] The method of claim 1, and further comprising:
generating tool path instructions for printing the layers of
the three-dimensional part and of the support structure;
and***

105. Leavitt discloses a controller for generating *tool path instructions* for printing *layers* of the *three-dimensional part* (e.g., 3D object 20) and of the *support structure* 22. EX1004, [0001]-[0006], [0020]-[0022]. In reviewing Leavitt, I noticed that Leavitt describes “[a]n extrusion-based layered deposition system...is used to build a 3D object from a computer-aided design (CAD) model in a layer-by-layer manner.” EX1004, [0002]. Leavitt also teaches that “[m]ovement of the extrusion head with respect to the substrate is performed under *computer control*, in accordance with build data” and “for each sliced *layer*, the host computer generates a *build path* for depositing roads of build material” to print a *three-dimensional part*. EX1004, [0003]. Furthermore, Leavitt discloses that system 10 includes a “gantry

16...configured to move extrusion head 18 in a horizontal x-y plane within build chamber 12 based on signals provided from the computer-operated controller.” EX1004, [0020]. Based on these disclosures in Leavitt, it is clear that Leavitt’s system can use a CAD model indicating characteristics of a part to generate tool path instructions for controlling extrusion head 18 to print the 3D object 20.

106. It is also clear that Leavitt’s system generates *tool path instructions* for printing a *support structure*. EX1004, [0004] (“[t]he host computer generates additional geometry acting as a support structure...support material is then deposited...pursuant to the generated geometry”). This is because to print support structure 22, the controller would need to control extrusion head 18 much like the system controls extrusion head 18 to print the 3D object 20. Furthermore, I noticed that Leavitt specifically teaches that a “computer-operated controller” generates *instructions* referred to in Leavitt as “signals” to cause extrusion head 18 to move within a “horizontal x-y plane” to print 3D object 20 and support structure 22 “in a layer-by-layer manner.” EX1004, [0020]-[0022].

107. Furthermore, RepRap expressly discloses “G-code” tool path instruction files that are generated based on “STL” files that define characteristics of a multi-material 3D object. RepRap teaches that the G-code tool path instructions are generated “layer-by-layer” to control the dual head extruder to print each layer of the part. G-code was well known in the art by the filing date of the ’713 Patent as

being a common form of tool path instructions. This is corroborated in one 2012 textbook which describes “G-code” as “an instruction set that’s been around for a while and appropriated for use with...3D printers.” EX1013, 29.

108. Therefore, the combination of Leavitt with RepRap provides Element [7a].

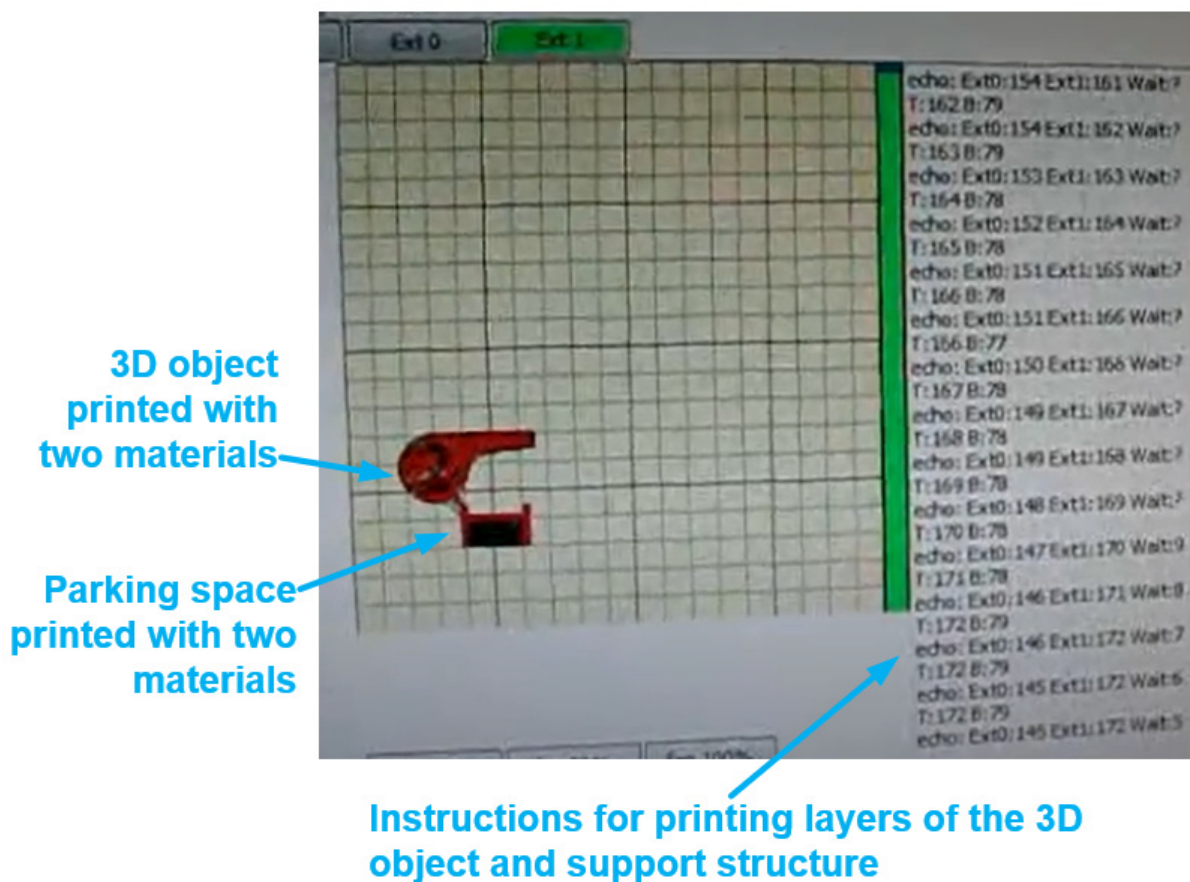
[7b] generating tool path instructions for printing the layer of the at least one purge tower.

109. It is clear that the resulting system would ***generate tool path instructions*** for controlling Leavitt’s extruder 18 to print ***layers*** of the ***at least one purge tower*** when Leavitt’s system is implemented with the purge tower teachings of RepRap. EX1004, [0020]-[0022]; EX1005, 1; EX1006; 0:01-4:59; *supra*, §VIII.A. For example, I noticed that RepRap Article teaches a process for using “STL files” to print a 3D object using two different materials and a corresponding ***purge tower***. EX1005, 1. These STL files described by RepRap can include one file for printing a body of the 3D object using a first material deposited by “extruder 0” and another file for printing text on the 3D object using another material deposited by “extruder 1.” EX1005, 1.

110. As I described above in connection with Element [7a], to generate the ***tool path instructions*** for printing a three-dimensional part and ***purge tower*** using multiple materials, RepRap discloses generating “G-code” for each of the STL files and merging the G-code “layer-by-layer.” EX1005, 1. This means that when

Leavitt's extrusion head 18 is implemented with RepRap's techniques for generating tool path instructions, the resulting system would generate G-code defining tool path instructions for printing each layer of the 3D object 20, support structure 22, and *purge tower*. EX004, [0020]-[0022]; EX1005, 1; EX1006; 0:01-4:59; *supra*, §VII.A.

111. Furthermore, RepRap Video depicts a computer file including a computer rendering of the 3D object a parking space and lines of computer code for controlling extruder 1 and extruder 0 to print the 3D object and parking space:



EX1006, 4:22 (annotated). This computer file includes at least some of the instructions for printing layers of the 3D object and support structure.

112. Therefore, the combination of Leavitt with RepRap provides Element [7b].

G. Claim 9

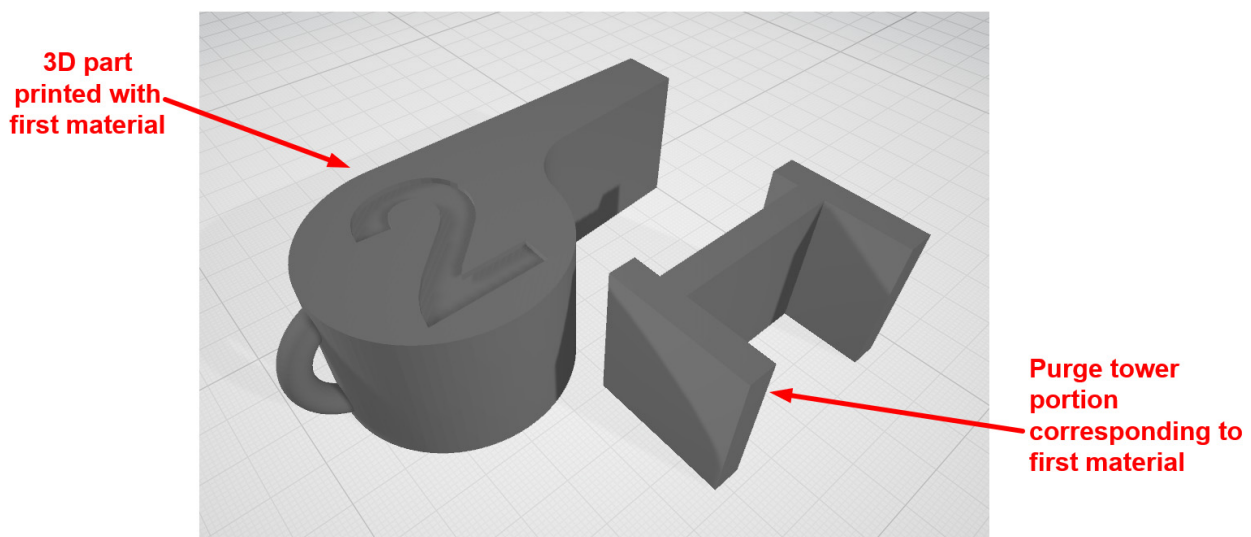
113. Claim 9 of the '713 Patent recites:

9. The method of claim 7, wherein the generating of the tool path instructions for printing the layer of the at least one purge tower is performed prior to printing the layers of the three-dimensional part and of the support structure.

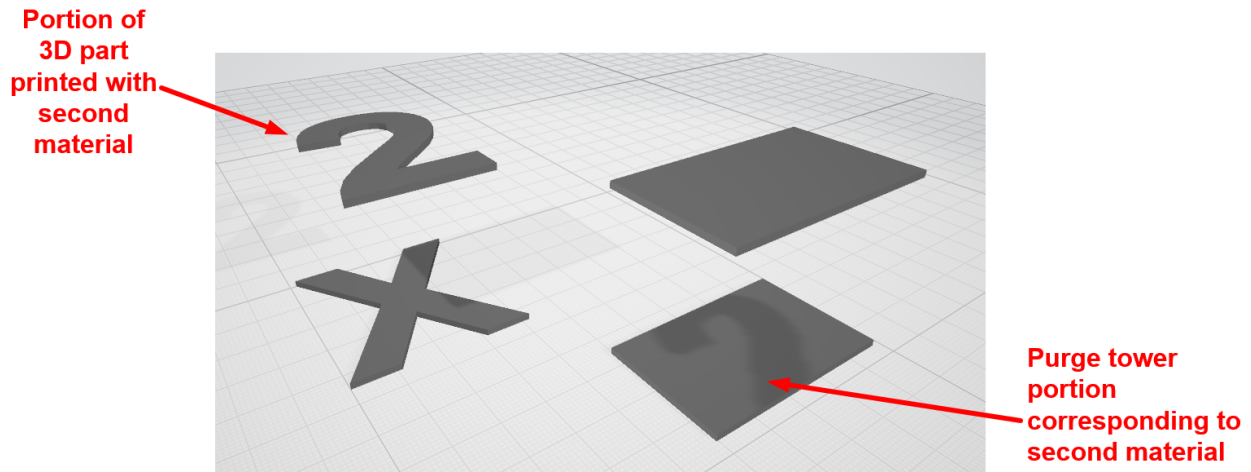
114. The system resulting from the predictable Leavitt-RepRap combination where Leavitt's extrusion head 18 is implemented with the teachings of RepRap would ***generate tool path instructions*** for printing layers of the ***at least one purge tower prior to printing layers of the three-dimensional part*** (e.g., 3D object 20) and the ***support structure*** 22. EX1004, [0002]-[0006], [0020]-[0022]; EX1005, 1; EX1006; 0:01-4:59; *supra*, §VII.A. Because Leavitt discloses a process for building a 3D object "from a computer-aided design (CAD) model" in a layer-by-layer manner" as I noted above in my declaration concerning Element [7a], Leavitt clearly discloses a system that accepts a CAD model of a part to be printed before the printing commences. EX1004, [0002]. Additionally, Leavitt discloses that printing the 3D object is "performed under computer control, in accordance with build data that represents the 3D object." EX1004, [0003]. To generate this build data, Leavitt's

Leavitt teaches that its system generates a “build path” for each “sliced layer” of the CAD model prior to deposition. EX1004, [0003].

115. Because Leavitt indicates that the build data is generated for each “sliced layer” of a CAD model, it is apparent that Leavitt therefore teaches that the tool path instructions for generating the 3D object 20 and support structure 22 are generated *prior* to *printing* the layers of 3D object 20 and support structure 22. EX1004, [0003], [0020]-[0022]. I noted above in my declaration concerning Element [7a] that RepRap Article teaches similar techniques for using STL files to generate “G-code” of tool path instructions for controlling a system to print a three-dimensional part and purge tower layer-by-layer using two different materials. EX1005, 1. RepRap article includes links to two STL files which corroborate that the G-code is generated from models that represent the entire part and purge tower corresponding to the part:



EX1014, 1 (annotated).



EX1015, 1 (annotated).

116. Furthermore, RepRap Article discloses techniques for *generating tool path instructions* by “slicing” STL files for the whistle body and the text to generate the “G-code” for each layer. EX1004, [0002], [0003]; EX1005, 1. Consequently, the system of the predictable Leavitt-RepRap combination generates *tool path instructions* for printing the *purge tower before* printing layers of 3D object 20 and support structure 22.

117. The teachings of Leavitt and RepRap provide the additional feature recited in claim 9 and would have rendered claim 9 obvious in its entirety.

H. Independent Claim 16

118. Independent claim 16 of the '713 Patent recites:

<p>16. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising: (a)</p>

printing a first layer of a support structure from a support material for the three-dimensional part; (b) printing a first layer of a purge tower from a part material; (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower; (d) printing a second layer of the purge tower from the support material; and (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.

119. As I explain in more detail below through my element-by-element analysis, the combination of Leavitt with RepRap renders claim 16 obvious.

[16pre] A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

120. The Leavitt-RepRap combination provides this claim element for at least the same reasons described above in connection with element [1pre]. *See supra*, Element [1pre].

121. Therefore, the Leavitt-RepRap combinations provides Element [1pre].

[16a] (a) printing a first layer of a support structure from a support material for the three-dimensional part;

122. As I described above in the analysis concerning element [1a], Leavitt discloses that extruder head 18 prints *layers* of a *support structure* 22 for a 3D object 20 using a *layer-based, additive manufacturing technique*. EX1004, [0004], [0020]-[0039], FIGS. 1-2B; *supra* Element [1a]. Leavitt expressly discloses that extruder head 18 prints each *layer* of the *support structure* 22 from a *support*

material. EX1004, [0022]-[0023], [0029]-[0030], [0032], [0035]-[0037]. For example, Leavitt discloses that extrusion head 18 deposits “a support material for support structure 22.” EX1004, [0022]. Because every layer of support structure 22 is printed from the support material, this means that Leavitt’s extruder head 18 prints a *first layer* of *support structure* 22 from the *support material* for the *three-dimensional part*.

123. Therefore, the combination of Leavitt with RepRap provides Element [16a].

[16b] (b) printing a first layer of a purge tower from a part material;

124. As I described above in connection with Element [1c], it is clear that a POSITA would have been motivated to implement Leavitt’s extruder head 18 with the teachings of RepRap so that extruder head 18 prints a layer of the *purge tower* each time that build liquefier pump 30 transitions from an idle state to an active state as taught by RepRap. EX1004, [0025]-[0027], [0032]-[0035], FIGS. 2A-2B; EX1005, 1; EX1006, 0:01-4:59; *supra*, Element [1c] *supra*, §VIII.A. Leavitt discloses that build liquefier pump 30 deposits a *part material* (e.g., “build material”) to print every layer of the *three-dimensional part* (e.g., 3D part 20). EX1004, [0022], [0027]-[0028], [0032]-[0033], [0035]. For example, Leavitt discloses that “extrusion head 18 deposits a build material for 3D object 20.” EX1004, [0022]. Because every layer of Leavitt’s 3D part 20 is printed from the *part material*, in the predictable

Leavitt-RepRap combination, extruder head 18 prints a *first layer* of the *purge tower* from the *part material* when the build liquefier pump 30 transitions from the idle state to the active state. As such, the *first layer* of the *purge tower* is deposited prior to printing a *first layer* of the *three-dimensional part*.

125. Therefore, the combination of Leavitt with RepRap provides Element [16b].

[16c] (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower;

126. It is clear Leavitt's extruder head 18 prints *layers* of a *three-dimensional part* (e.g., 3D object 20) using a *layer-based, additive manufacturing technique*. EX1004, [0004], [0020]-[0039], FIGS. 1-2B. For example, Leavitt expressly discloses that extruder head 18 prints each *layer* of 3D object 20 from a *part material*, which Leavitt refers to as a "build material." EX1004, [0022]-[0023], [0027]-[0028], [0032]-[0033], [0035]. Because every layer of 3D object is printed from the *part material*, it follows that a *first layer* of 3D object 20 is printed from the *part material*.

127. Leavitt explains that extrusion head 18 toggles between a "build state" depositing the build material and a "support state" depositing the support material to build print object 20 and support structure 22 on the build surface. EX1004, [0022]. It is also clear that Leavitt explains that extrusion head 18 can toggle between the

build state and the support state in a layer-by-layer manner such that extrusion head 18 deposits a layer of support material after depositing a layer of build material and deposits another layer of build material after depositing the layer of support material. EX1004, [0023]. That is, it is clear that the extrusion head 18 only prints one of 3D object 20 and support structure 22 at the same time and extrusion head 18 does not print both at the same time.

128. Furthermore, Leavitt discloses that a layer of support structure 22 “may [] be used to vertically support subsequent layers of deposited build...materials.” EX1004, [0023]. Consequently, the *first layer* of the *three-dimensional part* can be printed on *at least a portion* of the *first layer of the support structure* so that the first layer of the support structure vertically supports the first layer of the three-dimensional part as expressly disclosed by Leavitt. This is because for a support structure to vertically support a portion of a 3D part, at least one layer of the 3D part must be printed on a layer of the support structure so that the support structure is positioned below the 3D part for support.

129. In the predictable Leavitt-RepRap combination, extruder head 18 prints the *first layer* of the *three-dimensional part after* printing the *first layer* of the *purge tower* with the part material to ensure a consistent flow of material in the build liquefier pump 30 as taught by RepRap. As I discussed above in my declaration in connection with Element [1c], the extrusion head 18 of Leavitt performs a purge

operation with a particular material before commencing to print 3D part 20 or support structure 22 for to achieve this consistent flow.

130. Therefore, the combination of Leavitt with RepRap provides Element [16c].

[16d] (d) printing a second layer of the purge tower from the support material; and

131. As I explained in further detail in §VIII.A, a POSITA would have been motivated to implement Leavitt's extruder head 18 with the teachings of RepRap so that Leavitt's extruder head 18 prints a layer of the ***purge tower*** each time that support liquefier pump 32 transitions from an idle state to an active state as taught by RepRap. EX1004, [0029]-[0036], FIGS. 2A-2B; EX1005, 1; EX1006, 0:01-4:59; *supra*, Element [1c], *supra*, §VIII.A. Leavitt discloses that support liquefier pump 32 deposits a ***support material*** to print each layer of support structure 22. EX1004, [0029]-[0030], [0032], [0035]-[0037]. Consequently, in the predictable Leavitt-RepRap combination, extruder head 18 can print a ***second layer*** of the ***purge tower*** from the ***support material*** when the support liquefier pump 32 transitions from the idle state to the active state, just as extruder head 18 does in every instance of the support liquefier pump 32 transitioning from the idle state to the active state.

132. Furthermore, as I explained above in §VII.B, RepRap teaches that a dual extruder system can print a 3D part and purge tower that both include more than one material. EX1005, 1; EX1006, 5:04. This means that in the predictable Leavitt-

RepRap combination, extruder head 18 can print a *second layer* of the *purge tower* from the *support material*, even when extruder head 18 prints a first layer of the purge tower from the part material which is different from the support material.

133. Therefore, the combination of Leavitt with RepRap provides Element [16d].

[16e] (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.

134. Leavitt discloses that extruder head 18 prints *layers* of a *support structure* 22 using a *layer-based, additive manufacturing technique*, as I described above in connection with Element [1a]. EX1004, [0004], [0020]-[0039], FIGS. 1-2B; *supra*, Element [1a]. It is clear that Leavitt discloses that extruder head 18 prints each *layer* of *support structure* 22 from a *support material*. EX1004, [0022], [0023], [0029], [0030], [0032], [0035]-[0037]. Because every layer of support structure 22 is printed using the *support material*, it follows that that extruder head 18 can print a *second layer* of support structure 22 from the *support material*.

135. Furthermore, Leavitt explains that extrusion head 18 toggles between a “build state” depositing the *build material* and a “support state” depositing the *support material* to build print object 20 and support structure 22. EX1004, [0022]. Leavitt also explains that extrusion head 18 can toggle between the build state and the support state in a layer-by-layer manner such that extrusion head 18 deposits a

layer of support material after depositing a layer of build material and deposits another layer of build material after depositing the layer of support material. EX1004, [0023]. Leavitt explains that this toggling process can be “repeated until each layer of 3D object 20 and support structure 22 are complete.” EX1004, [0024].

136. Furthermore, Leavitt discloses that a layer of support structure 22 “may [] be used to vertically support subsequent layers of deposited build and/or support materials.” EX1004, [0023]. This means Leavitt teaches that the *second layer* of the *support structure 22* can be printed on *at least a portion* of the *first layer of the three-dimensional part* that is vertically supported by the *first layer* of the *support structure 22* so that the *first layer* of the *support structure* vertically supports the *first layer* of the *three-dimensional part*. In the predictable Leavitt-RepRap combination, extruder head 18 prints the *second layer* of the *support structure 22* *after* printing the *second layer* of the *purge tower* with the *support material* to ensure a consistent flow of material in the support liquefier pump 32 as taught by RepRap.

137. Therefore, the combination of Leavitt with RepRap provides Element [16e].

I. Claim 17

138. Claim 17 of the '713 Patent recites:

<p>17. The method of claim 16, and further comprising repeating steps (b)-(e) for at least a portion of the three-dimensional part and support structure.</p>

139. As I described above in connection with Element [1b], Leavitt's extrusion head 18 alternates between using a build material to print 3D part 20 and using a support material to print support structure 22. EX1004, [0004], [0022]-[0024], [0027]-[0029], [0032], [0033]; *supra*, Element [1b]. For example, it is clear that Leavitt discloses that extrusion head 18 can extrude a layer of 3D object 20 in the build state, toggle to the support state to print a layer of support structure 22, toggle back to the build state to print another layer of 3D object 20 and repeat this process "until each layer of 3D object 20 and support structure 22 are complete." EX1004, [0023]. This means that Leavitt expressly discloses *repeating steps (a), (c), and (e)* which involve printing layers of the *three-dimensional part* (e.g., 3D part 20) and *support structure* 22. Based on the disclosure of Leavitt referenced above, these steps can be repeated for at least a portion of the three-dimensional part (e.g., 3D object 20) and the support structure 22 up until 3D object 20 and support structure 22 are complete.

140. Furthermore, RepRap discloses printing one or more layers of a *purge tower* next to a three-dimensional part each time the 3D printer switches deposition lines/material. EX1005, 1; *supra*, Element [1c]. When Leavitt's extruder head 18 is implemented with the teachings of RepRap, extruder head 18 prints a layer of a

purge tower each time that extruder head 18 toggles between the build state and the support state to switch printing materials as taught by RepRap. EX1004, [0022]-[0024], [0027]-[0029], [0032], [0033]; EX1005, 1. This means that when Leavitt's extruder 18 *repeats steps (a), (c), and (e)*, it is apparent that extruder 18 would also *repeat steps (b) and (d)* of claim 16 to "prime" each *deposition line* before printing the 3D object 20 and support structure 22 in the combination. This is because RepRap makes clear that priming occurs before each material change, so the system resulting from the predictable Leavitt-RepRap combination would perform step (b) each time that the system performs steps (a) and (c) and would perform step (d) each time that the system performs steps (c) and (e). Doing so would provide the purging described in RepRap.

141. The teachings of Leavitt and RepRap provide the additional feature recited in claim 17 and would have rendered claim 17 obvious in its entirety.

IX. GROUND 2A: PRIEDEMAN IN COMBINATION WITH KISSLICER WOULD HAVE RENDERED CLAIMS 1, 2, 6, 7, 9, 16, AND 17 OBVIOUS

A. Overview of the Combination and Reasons to Combine

142. Based on my review, multiple reasons would have prompted a POSITA to implement Priedeman's system to print a purge tower next to a three-dimensional part and support structure, as suggested by KISSlicer. EX1007, [0016]-[0022]; EX1010, 3, 5, 8-11.

143. For example, a POSITA would have implemented Priedeman's extruder to print a purge tower on the same substrate as the 3D part as suggested by KISSlicer for multiple reasons. As a *first* reason to implement Priedeman's extruder with the purge tower ("wipe pillar") taught by KISSlicer, such an implementation of Priedeman's 3D printing apparatus would have advantageously primed Priedeman's nozzles when transitioning between materials before printing the layers of the 3D object being fabricated and corresponding support structure to establish a consistent flow of deposition material in a way that prepares the nozzles/print heads for printing. As would have been recognized by a POSITA, the material at the nozzle tip of the idle nozzle/print head of Priedeman's 3D printer would have an inconsistent texture, especially if a portion of the slightly material oozes from the tip of the nozzle. It is apparent that a POSITA would have recognized from KISSlicer that performing a priming action by printing such material into the suggested purge tower ("wipe pillar") would have advantageously avoided uneven deposition or defects imposed upon the 3D part being fabricated.

144. As a *second* reason, KISSlicer's suggestion to print a purge tower on the build substrate next to the 3D part would have beneficially allowed Priedeman's system to prime such material and prepare the deposition line/print head for the operating mode in a prompt and efficient manner by quickly disposing of the priming material with limited additional movement in a compact purge tower. For example,

such an implementation would have limited additional movement of the extruder head for the purpose of printing the purge tower. Because the suggested purge tower can be close to the 3D part on the build substrate, it is clear that Priedeman's extrusion head would not need to travel as far to perform the purge operation as compared with a distance required for other purging methods involving, for example, a purge bucket located outside the periphery of the build substrate. This means that printing a purge tower (i.e., KISSlicer's cylindrical "wipe pillar") can reduce an amount of time required to complete a multi-material build as compared with other purge methods that require the extrusion head to repeatedly travel outside of the periphery of the build substrate.

145. As a *third* reason, a POSITA would have understood that implementing Priedeman's system with KISSlicer's suggestion to lower the temperature of an idle extruder would provide an improved approach for beneficially decreasing the likelihood of molten material oozing from the idle nozzle onto the 3D part. A POSITA would have recognized that cooling the inactive deposition nozzle/head of Priedeman's system (e.g., to the "Keep-Warm" temperature of 160°C) while the active deposition nozzle/head is priming by printing a layer of the wipe pillar (not positioned over the 3D part) would have advantageously decreased the likelihood of dripping any oozed material along the 3D part, an issue that Priedeman expressly acknowledges in multi-material builds. EX1010, 3. Furthermore, a POSITA would

have recognized that it is beneficial to prevent such oozing from the extrusion head the extrusion nozzles in implementations of Priedeman's 3D printing apparatus in which the extrusion heads/nozzles are positioned in close proximity such that the idle head/nozzle would routinely be positioned over the part. EX1004, [0025]-[0035], FIGS. 2A-2B

146. As I explained above in relation to the Leavitt-RepRap combination, these known benefits were also previously explained in §VIII.A, *supra*.

147. Additionally, beyond these three reasons articulated above, the predictable combination would have advantageously allowed user selection/customization of parameters related to the purging operation. For instance, a POSITA would have recognized that the Priedeman-KISSlicer combination would have achieved more flexible user customization of parameters affecting the main part and the purge tower, such as "layer thickness," the "position" of the purge tower relative to the "main part," and temperature within the extruders. All of these selections would allow a user to customize a print depending upon the desired build time/quality of a particular print project. EX1010, 3, 9.

148. Furthermore, a POSITA would have implemented Priedeman's extruder based on KISSlicer's suggestions because doing so would be the application of known techniques to a known system to achieve predictable results. A POSITA would have been prompted to modify Priedeman's 3D printing system

to include the additional functionality described by KISSlicer to print a purge tower (“wipe pillar”) for purging the printheads/nozzles between depositing layers of different materials because doing so would be merely the application of a known technique (as suggested by KISSlicer) to a known system (e.g., Priedeman’s 3D printing system) ready for improvement to yield predictable results. Here, KISSlicer provides straightforward evidence of a known technique printing a purge tower on the same substrate as the object being fabricated to prime the active extrusion nozzle of the device when transitioning the nozzle from a stand-by to active operating mode (including transitioning the temperature of the nozzle), and Priedeman’s teaching provides a known system that would have been improved by application of KISSlicer’s suggested technique for at least the reasons described above. Based upon my knowledge and experience in this field and my review of Priedeman and KISSlicer, I am confident a POSITA would have recognized that this modification would have yielded predictable results and required only routine adjustments to the mechanical components and software to provide the additional functionality disclosed by KISSlicer and as such a POSITA would have had a reasonable expectation of success in making such modifications. This modification would not have significantly altered or hindered the functions performed by Priedeman’s system, and these modifications would have been within the predictable and ordinary level of skill of a POSITA (certainly by a time frame as late as 2013).

B. Independent Claim 1

149. Independent claim 1 of the '713 Patent recites:

1. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:
printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;
switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;
performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.

150. As I explain in more detail below through my element-by-element analysis, the combination of Priedeman with KISSlicer renders claim 1 obvious.

[Ipre] A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

151. To the extent that the preamble is treated as a limitation, the Priedeman-KISSlicer combination provides “[a] method for printing a three-dimensional part with an additive manufacturing system.” Priedeman discloses an extrusion apparatus 10 including an extrusion head 12 which operates as an ***additive manufacturing system*** according to “***additive*** process techniques” by printing a three-dimensional model 26 and support structure 28 layer-by-layer. EX1007, [0006], [0015]-[0019]. In another example, Priedeman describes that extrusion apparatus 10 can apply a

“*method* for using...material to build” a *three-dimensional part* including model 26.

EX1007, [0013], [0016]-[0018].Priedeman describes in more detail:

The movement of the extrusion head is controlled so as to deposit material onto the base 14 in multiple passes and layers to build the three-dimensional model 26 and further to build the support structure 28 defined so as to physically support the model 26 as it is being built. The model 26 and its support structure 28 are build up on the base 14 within a build chamber (not shown) having an environment controlled so as to promote thermal solidification. A first layer of the deposited material adheres to the base 14 so as to form a foundation, while subsequent layers of material adhere to one another.

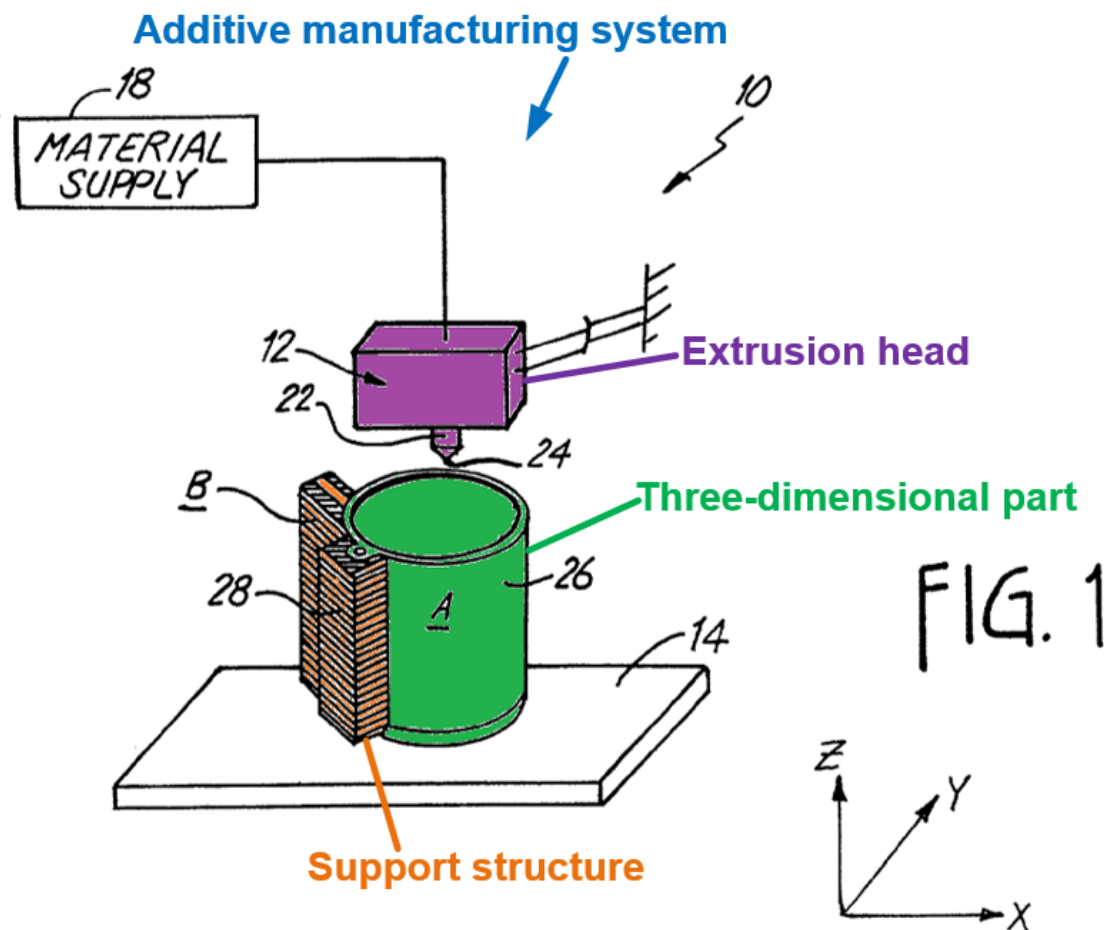
EX1007, [0017].

152. Therefore, the combination of Priedeman with KISSlicer provides Element [1pre].

[1a] printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;

153. The Priedeman-KISSlicer combination provides Element [1a]. As I described in more detail above in connection with Element [1pre], Priedeman’s system 10 can *print layers* of a *three-dimensional part* (e.g., model 26) and a *support structure* 28. EX1007, [0006], [0013], [0015]-[0019]. For example, I noticed that Priedeman expressly discloses that extrusion head 12 can “deposit material onto the base 14 in multiple...*layers* to build” model 26 and support

structure 28. EX1007, [0017]. As such, “[a] first layer of the deposited material adheres to the base 14 so as to form a foundation, while subsequent layers of material adhere to one another.” In another example, Priedeman describes that, “the modeling material A and the support material B are deposited... in horizontal *layers* from an extrusion head.” EX1007, [0019]. Priedeman’s extrusion head 12 for printing three-dimensional model 26 and support structure 28 is depicted below in FIG. 1:



EX1007, FIG. 1 (annotated).

154. In one embodiment described in Priedeman, extrusion apparatus 10 includes a single extrusion head that includes a first ***deposition line*** (“nozzle”) for printing ***layers*** of three-dimensional model 26 and a second ***deposition line*** (“nozzle”) for printing ***layers*** of support structure 28. EX1007, [0018]-[0022]; *supra*, §IX.A. It is clear that Priedeman’s extrusion apparatus 10 uses a ***layer-based, additive manufacturing technique*** to print these ***layers*** of the ***three-dimensional part*** and the ***support structure***. EX1007, [0003]-[0008], [0016]-[0019], FIG. 1. For example, Priedeman discloses techniques for “creating three-dimensional objects by ***additive*** process techniques, such as by depositing layers of solidifiable material.” EX1007, [0006]. Priedeman also discloses that “[s]upport material is deposited in layered fashion at the interface between the object and its support structure, or it is deposited in a layered fashion to form the support structure.” EX1007, [0008].

155. Therefore, the combination of Priedeman with KISSlicer provides Element [1a].

[1b] switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;

156. The Priedeman-KISSlicer combination provides Element [1b]. Namely, it is apparent that Priedeman’ extrusion apparatus 10 deposits modeling material A and support material B “in coordination” to print model 26 and support structure 28 using ***multiple deposition lines***, referred to as “nozzles” in Priedeman. EX1007,

[0016]-[0018]; *supra*, Element [1a]. Priedeman makes it clear that the modeling and support materials are deposited in horizontal **layers** from respective extrusion heads or nozzles during the process to print model 26 and support structure 28. EX1007, [0028]. EX1007, [0028], [0029].

157. It is apparent that Priedeman's extrusion apparatus 10 is configured to alternate between depositing modeling and support materials in order to print the model 26 and support structure 28, because in Priedeman's embodiment where a single extrusion includes two deposition lines ("nozzles"), one nozzle would need to be idle while the other nozzle is active in order to successfully print each of the model 26 and support structure 28. EX1007, [0018]. In other words, Priedeman's single extruder head would not be able to deposit layers of the model 26 and support structure 28, because the nozzles are attached to one another and moving one nozzle could interfere with a position of another nozzle. Furthermore, Priedeman also discloses that heated material can be "sitting idle" in an inactive extruder, indicating that such alternation between active and idle states causes some issues. EX1007, [0022]. Priedeman explains that such issues include that material can decompose in the idle extruder and "ooze" or potentially "drain uncontrollably" into the build envelope. EX1007, [0022]. Thus, it is clear that Priedeman suggests that the deposition lines ("nozzles") of the extrusion head 12 can occupy a **stand-by mode** when sitting idle or occupy an **operation mode** when extruding material, and that

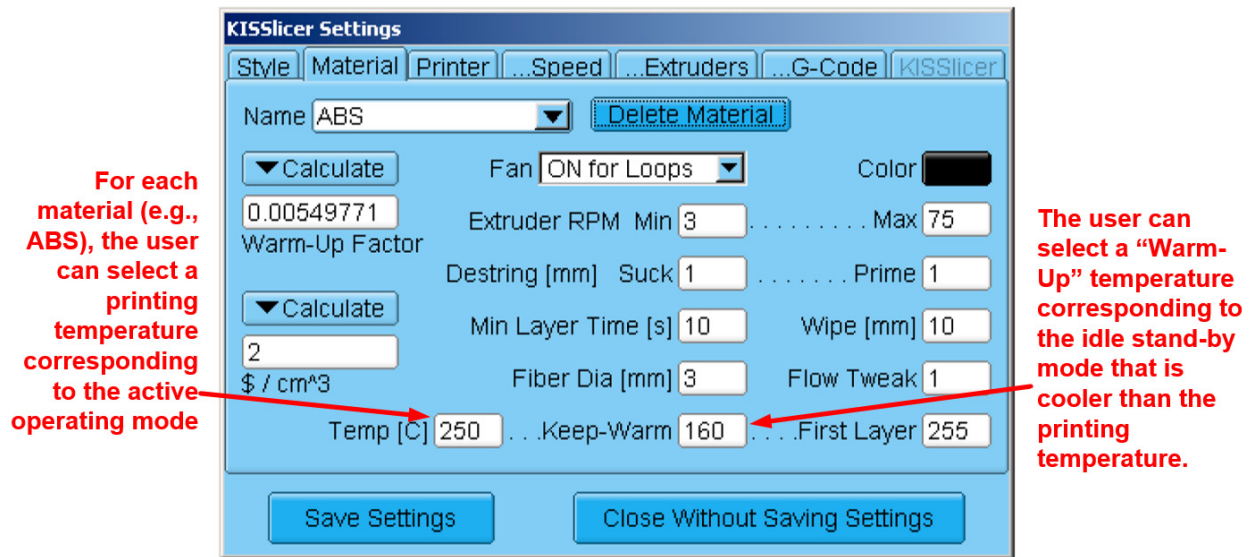
only one of the nozzles is active at a given time. Indeed, Priedeman acknowledges that idling is a problem that causes material to decompose in the idle extruder and “ooze” or potentially “drain uncontrollably” into the build envelope. EX1007, [0022].

158. Much like Priedeman’s extrusion apparatus 10 can use one nozzle to deposit modeling material A and use another nozzle to deposit support material B, KISSlicer discloses software that can control a multi-extruder system to print a *three-dimensional part* with a first material using one extruder (e.g., “Extruder 1”) and a *support structure* with a second material using another extruder (e.g., “Extruder 2”). EX1010, 5, 8, 11; *supra*, §IX.A. Further, as I explained above in §IX.A, the user can select one of these extruders to print the *three-dimensional part* and another one of these extruders to print the *support structure*. EX1010, 3 (“you can assign the head to part, raft, support and part/support interface”).

159. A user of KISSlicer’s software can select the exact materials that “Extruder 1” and “Extruder 2” deposit, thus providing customization for the user to pick an appropriate material for depositing *layers* of the *three-dimensional part* and an appropriate material for depositing *layers* of the *support structure*, as I described in more detail above in §IX.A. EX1010, 3 (“You can select the material in the extruder.”). KISSlicer provides “ABS” and “PLA” as examples of materials that can be selected, but does not indicate that the software is limited to permitting selection

of only these materials. EX1010, 3 (“ABS and PLA default profiles are provided.”), 5. In any case, different materials can be selected for each extruder, and different extruders can be selected to print the 3D part and support structure.

160. One important feature of KISSlicer’s software is the ability of the user to select temperature parameters. For example, KISSlicer’s extruders can *switch* between an active *operating mode* corresponding to a higher temperature (e.g., 250 °C) for melting the material during use and an idle *stand-by mode* for maintaining the material at a lower “Keep-Warm” temperature (e.g., 160 °C). EX1010, 3, 10. KISSlicer explains that Keep-Warm is an “idle temperature” used “when printing with multiple materials.” EX1010, 3, 10. The “Temp (C)” setting allows the user to select a higher temperature for melting material to print the “main part,” such as *layers* of the *three-dimensional part* and/or *support structure*. These temperatures can be customized, as indicated below in the user interface corresponding to the user-selected “ABS” material:



EX1010, 3 (annotated).

161. KISSlicer explains *switching* multiple extruders between the *operating mode* and the *stand-by mode* in detail. For example, KISSlicer explains that each of the extruders transitions out of the *stand-by mode* and into the *operating mode* to prepare the extruder for printing one or more layers of the *three-dimensional part* or *support structure*. EX1010, 10 (“*after a warm up* the printer will...prime...to ensure the printer is ready”). According to KISSlicer, this priming occurs “before every layer to clean the extruder tip.” EX1010, 9. Because priming follows an increase in temperature representing a *switch* from the *stand-by mode* to the *operating mode*, such a *switch* occurs before each layer printed by either one of “Extruder 1” or “Extruder 2.”

162. As described above in connection with Element [1b], in Priedeman’s extruder embodiment where a single extrusion head includes multiple deposition

lines (“nozzles”), only one of the deposition lines would deposit material at a given time while the other deposition line sits idle. EX1007, [0016]-[0018]; *supra*, Element [1b]. This means that to switch between one of the nozzles depositing layers of the 3D model 26 to the other nozzle depositing layers of support structure 28, the first nozzle would switch to the stand-by mode and the second nozzle would switch to the operating mode in-between printing layers of the 3D model 26 to the other nozzle depositing layers of support structure 28. Consequently, when Priedeman’s extrusion apparatus 10 is implemented with KISSlicer’s techniques for temperature control and nozzle priming, the resulting extrusion heads or nozzles would switch between a lower temperature in the *stand-by mode* and a higher temperature in the *operating mode in-between* the printing of the layers of the *three-dimensional part* (e.g., model 26) and *support structure* 28. EX1007, [0016]-[0022]; EX1010, 3, 5, 9, 10; *supra*, §IX.A.

163. Switching an idle extruder head or nozzle to the *stand-by mode* by cooling after printing the model 26 or support structure 28 as taught by KISSlicer would decrease a likelihood of material “draining uncontrollably...into the build envelope,” which is a problem acknowledged by Priedeman. EX1007, [0022]; *supra*, §IX.A. Furthermore, transitioning an extruder head or nozzle to the *operating mode* by re-heating prior to printing the model 26 or support structure 28 would beneficially allow the nozzle to melt the material for deposit.

164. Therefore, the combination of Priedeman with KISSlicer provides Element [1b].

[1c] performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.

165. Priedeman acknowledges printing material can “ooze” or “drain uncontrollably” from an idle extruder when the temperature is too high. EX1007, [0022]. To the extent Priedeman does not disclose changing temperatures between stand-by modes and operating modes, Priedeman expressly discloses that a viscosity of materials depends on a temperature within the extruder. EX1007, [0022] (“Melt viscosity is lowered by increasing the temperature at which the material is extruded.”). Thus, Priedeman recognizes that oozing and uncontrollable draining are problems in 3D printing, and one way to solve these problems is to change the temperature within idle extruders.

166. KISSlicer discloses techniques for controlling the temperature within extruders of a multi-extruder system. For example, as described above in Element [1b], *supra*, KISSlicer explains that a temperature of an extruder is decreased in the idle ***stand-by mode*** and subsequently increased when transitioning to the active ***operating mode*** in a way that that would address the oozing and uncontrollable draining issues recognized by Priedeman. EX1010, 3, 5, 9, 10. For example,

KISSlicer discloses that the *stand-by mode* temperature (“Keep-Warm”) is an “idle temperature” that is used “when printing with multiple materials.” EX1010, 3, 10. The *operating mode* temperature (“Temp (C)”) is higher than the stand-by mode temperature that is used for melting build materials. Implementing Priedeman’s extruder apparatus 10 to lower the temperature of idle extruders as suggested by KISSlicer would decrease a likelihood of build material draining uncontrollably onto base 14 from an idle *deposition line* in Priedeman’s single extrusion head embodiment. *supra* §IX.A.

167. KISSlicer teaches that it is “extremely important in dual head prints” to print one or more layers of a *purge tower* “before every layer” of the 3D part or support structure as part of a *purge operation*. EX1010, 9. This *purge operation* occurs “after a warm up” when the extruder *switches* from the idle *stand-by mode* at a lower temperature to the active *operating mode* at a higher temperature. EX1010, 10. KISSlicer describes this purge operation as “priming” the extruder for subsequent printing. EX1010, 10. KISSlicer also discloses that the purge operation decreases a probability “hairing”—a kind of oozing from the extruder nozzle that can cause “hairs” to form between build sections in some cases. EX1010, 10.

168. KISSlicer explains that priming the extruder is done “to ensure the printer is ready” to print the three-dimensional part or support structure. EX1010, 10. This means that it is clear that KISSlicer’s software prints a *purge tower* in a

layer-by-layer manner as “Extruder 1” and “Extruder 2” each transition to the *operating mode* by warming up. Each time that one of “Extruder 1” or “Extruder 2” heats up to *switch* to the *operating mode*, that extruder prints one or more layers of the *purge tower* before printing the *three-dimensional* part or *support structure*. Consequently, when extruder apparatus 10 is implemented with the nozzle priming teachings of KISSlicer, the resulting system would perform a *purge operation* by printing a *purge tower* in a *layer-by-layer manner*, the layers of the purge tower printed by a nozzle previously switched to the operating mode. EX1010, 3, 5, 9, 10; *supra* §IX.A.

169. Furthermore, KISSlicer makes it clear that the wipe pillar is a singular “cylinder” printed on the build surface next to the part and support structure, where layers of the cylinder are printed as part of KISSlicer’s *purge operations* whenever one of the extruders transitions to the *operating mode*. EX1010, 2, 3, 8-10. KISSlicer discloses that the position of the purge tower on the build surface can be chosen by the user. EX1010, 9 (“Can be switched off, or the position with respect to the main part can be chosen.”). Because KISSlicer’s “wipe pillar” is a cylindrical “tower” that is printed as part of purge operations to prime extruders, the pillar is a *purge tower*.

170. Therefore, the combination of Priedeman with KISSlicer provides Element [1c].

C. Claim 2

171. Claim 2 of the '713 Patent recites:

2. The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and wherein switching the deposition lines between the stand-by modes and the operating modes comprises:
switching the first deposition line from the stand-by mode to the operating mode; and
switching the second deposition line from the operating mode to the stand-by mode.

172. As I explain in more detail below through my element-by-element analysis, the combination of Priedeman with KISSlicer renders claim 2 obvious.

[2a] The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and

173. As I describe in further detail above in connection with Element [1a], Priedeman discloses at least one embodiment where extrusion apparatus 10 comprises a single extrusion head with ***multiple deposition lines***—including a ***first deposition line*** “nozzle” for dispensing the model material A to build model 26 and a ***second deposition line*** “nozzle” for dispensing the support material B to build the support structure 28. EX1007, [0016]-[0018]; *supra*, Element [1a]. Therefore, the Priedeman-KISSlicer combination provides Element [2a].

[2b] wherein switching the deposition lines between the stand-by modes and the operating modes comprises: switching the first deposition line from the stand-by mode to the operating mode; and switching the second deposition line from the operating mode to the stand-by mode.

174. In applying KISSlicer’s teachings regarding switching the deposition nozzles between active and standby modes, including heating the active nozzle to an active temperature of 250°C and cooling the inactive nozzle to a “Keep-Warm” temperature for the standby mode of 160°C to Priedeman’s extrusion apparatus 10 a POSITA would have recognized that Priedeman’s first and second *deposition line* alternate between an idle *stand-by mode* corresponding to a lower nozzle temperature for preserving material during nonuse and an active *operating mode* corresponding to a higher nozzle temperature for melting material during use. EX1007, [0016]-[0022]; EX1010, 3, 5, 9-11; *supra*, Elements [1b]-[1c]; *supra*, §IX.A. This is because, for example, Priedeman’s extruder head 12 includes two nozzles that cannot move around the build plane independently of one another, meaning that extruder head 12 must alternate between printing layers of the model 26 and printing layers of the support structure 28 to achieve the multi-material build. This means that when one of Priedeman’s *deposition line* nozzles *switches* from the *stand-by mode* to the *operating mode* to deposit material, the other *deposition line* nozzle *switches* from the *operating mode* to the *stand-by mode* to sit idle. EX1007, [0016]-[0018]; EX1010, 3, 5, 9-11.

175. As I discussed above, A POSITA would have recognized that cooling the inactive deposition nozzle/head of Priedeman’s system (e.g., to the “Keep-Warm” temperature of 160°C) while the active deposition nozzle/head is priming by printing

a layer of the wipe pillar (not positioned over the 3D part) would have advantageously decreased the likelihood of dripping any oozed material along the 3D part, an issue that Priedeman expressly acknowledges in multi-material builds. EX1010, 3. Furthermore, a POSITA would have recognized that it is beneficial to prevent such oozing from the extrusion head the extrusion nozzles in implementations of Priedeman's 3D printing apparatus in which the extrusion heads/nozzles are positioned in close proximity such that the idle head/nozzle would routinely be positioned over the part. EX1004, [0025]-[0035], FIGS. 2A-2B.

176. Therefore, the combination of Priedeman with KISSlicer provides Element [2b].

D. Claim 6

177. Claim 6 of the '713 Patent recites:

<p>6. The method of claim 1, wherein the at least one purge tower is stopped at a highest layer at which there is a material change for the printed layers of the three-dimensional part and support structure.</p>

178. KISSlicer describes that “[t]he wipe pillar is a cylinder *printed before every layer* to clean the extruder tip.” EX1010, 9. Based on this disclosure of KISSlicer, a POSITA would have recognized that the predictable combination of Priedeman with KISSlicer would have operated the extrusion head 18 to *stop* printing a *purge tower* at a *highest layer* at which there is a *material change* for the printed layers of the *three-dimensional part* (e.g., model 26) and *support structure*

28, because this is the last point at which extrusion head 18 would need to prime an extruder to prepare it for use. EX1007, [0016]-[0022], FIG. 1; EX1010, 9, 10. As mentioned above, KISSlicer explains that “before every layer” when an extruder warms up as part of a *material change*, the extruder prints a portion of a *purge tower* beside the *three-dimensional part* and *support structure*. EX1010, 9, 10. KISSlicer’s purging occurs when there is *a transition* between using a first extruder (e.g., “Extruder 1”) to print the 3D part and using a second extruder (e.g., “Extruder 2”) to print the support structure that causes one of the extruders to transition to the *operating mode* and the other extruder to transition to the *stand-by mode*, as I discussed above in connection with Element [1c]. EX1010, 3, 5, 9, 10; *supra*, Element [1c]. In the predictable Priedeman-KISSlicer combination, it would not be necessary for extrusion apparatus 10 to continue printing the *purge tower* after the last *material change* is complete.

179. The teachings of Priedeman and KISSlicer provide the additional feature recited in claim 6 and would have rendered claim 6 obvious in its entirety.

E. Claim 7

180. Claim 7 of the ’713 Patent recites:

<p>7. The method of claim 1, and further comprising: generating tool path instructions for printing the layers of the three-dimensional part and of the support structure; and generating tool path instructions for printing the layer of the at least one purge tower.</p>
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181. As I explain in more detail below through my element-by-element analysis, the combination of Priedeman with KISSlicer renders claim 7 obvious.

***[7a] The method of claim 1, and further comprising:
generating tool path instructions for printing the layers of
the three-dimensional part and of the support structure;
and***

182. Priedeman expressly discloses that an extrusion head can be “controlled so as to deposit material...in multiple passes and layers to build the ***three-dimensional*** model 26 and further to build the ***support structure*** 28.” EX1007, [0017]. Based on this disclosure and other descriptions in Priedeman, a POSITA would have recognized that Priedeman’s extrusion apparatus 10 ***generates tool path instructions*** to cause the extrusion head to deposit material according to these “multiple passes and ***layers***” for printing the model 26 and support structure 28. EX1007, [0016]-[0018]. Priedeman teaches techniques for ***generating tool path instructions*** using a CAD model, the instructions defining areas for controlling Priedeman’s extruders to deposit material. EX1007, [0003], [0004].

183. KISSlicer provides complimentary disclosure, describing that ***tool path instructions*** for printing material layers (such as the model and support structure layers of Priedeman) are generated from an “STL file.” EX1010, 6. KISSlicer further discloses that its software can position a three-dimensional part based on the STL file in a virtual print area so that the user can configure printer parameters based on printing needs for the particular part. EX1010, 7, 8. After the

user has selected print parameters, KISSlicer's software creates a "print file" by "slicing" the STL file to generate *tool path instructions* for each layer. EX1010, 9. A POSITA would have recognized that slicing an STL file to generate tool path instructions was a known technique by 2012. EX1013, 28.

184. Therefore, the combination of Priedeman with KISSlicer provides Element [7a].

[7b] generating tool path instructions for printing the layer of the at least one purge tower.

185. A POSITA would have recognized that application of KISSlicer's suggestions to Priedeman's system would have beneficially resulted in a system the *tool path instructions* ("print file") is generated for controlling Priedeman's extrusion apparatus 10 to print *layers* of the at least one *purge tower*. EX1007, [0002]-[0004], [0016]-[0022]; EX1010, 9, 10. KISSlicer discloses that its software can control a dual extruder system to print one or more layers of a *purge tower* "before every layer" of the three-dimensional part and support structure "to clean the extruder tip." EX1010, 9. KISSlicer also indicates that the position of this purge tower with respect to the three-dimensional part "can be chosen." EX1010, 9. To control the dual extruders to print the *purge tower*, KISSlicer's software would generate *tool path instructions* for printing each layer of the *purge tower* just as the software generates *tool path instructions* for printing layers of the *three-dimensional part* and *support structure*.

186. Therefore, the combination of Priedeman with KISSlicer provides Element [7b].

F. Claim 9

187. Claim 9 of the '713 Patent recites:

<p>9. The method of claim 7, wherein the generating of the tool path instructions for printing the layer of the at least one purge tower is performed prior to printing the layers of the three-dimensional part and of the support structure.</p>
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188. Priedeman makes clear that its extrusion apparatus 10 prints three-dimensional parts and support structures by depositing material in a predetermined pattern according to a three-dimensional CAD model that defines characteristics of the printed object. EX1007, [0003], [0004], [0015]-[0018]; *supra*, Element [7a]. A POSITA would have understood from Priedeman's disclosure that the "predetermined pattern" for each layer is defined by the CAD model for the entire object that the extrusion apparatus 10 generates the tool path instructions prior to printing model 26 and support structure 28. KISSlicer discloses a similar process for generating a "print file" for the tool path of each layer of a *three-dimensional part*, *support structure*, and *purge tower* based on an STL file. EX1010, 6, 7. Consequently, the system of the Priedeman-KISSlicer combination *generates tool path instructions* for printing *layers* of a *purge tower prior* to printing *layers* of a *three-dimensional part* and *support structure*.

189. The teachings of Priedeman and KISSlicer provide the additional feature recited in claim 9 and would have rendered claim 9 obvious in its entirety.

G. Independent Claim 16

190. Independent claim 16 of the '713 Patent recites:

<p>16. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising: (a)</p> <p>printing a first layer of a support structure from a support material for the three-dimensional part; (b) printing a first layer of a purge tower from a part material; (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower; (d) printing a second layer of the purge tower from the support material; and (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.</p>
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191. As I explain in more detail below through my element-by-element analysis, the combination of Priedeman with KISSlicer renders claim 16 obvious.

[16pre] A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

192. The Priedeman-KISSlicer combination provides this claim element for at least the same reasons described above in my analysis of Element [1pre]. *See supra*, Element [1pre]. For example, the Priedeman-KISSlicer combination provides “[a] method for printing a three-dimensional part with an additive manufacturing system.” Priedeman discloses an extrusion apparatus 10 including an extrusion head 12 which operates as an ***additive manufacturing system*** according to “***additive***

process techniques” by printing a three-dimensional model 26 and support structure 28 layer-by-layer. EX1007, [0006], [0015]-[0019]. In another example, Priedeman describes that extrusion apparatus 10 can apply a “*method* for using...material to build” a *three-dimensional part* including model 26. EX1007, [0013], [0016]-[0018]. Priedeman describes in more detail:

The movement of the extrusion head is controlled so as to deposit material onto the base 14 in multiple passes and layers to build the three-dimensional model 26 and further to build the support structure 28 defined so as to physically support the model 26 as it is being built. The model 26 and its support structure 28 are build up on the base 14 within a build chamber (not shown) having an environment controlled so as to promote thermal solidification. A first layer of the deposited material adheres to the base 14 so as to form a foundation, while subsequent layers of material adhere to one another.

EX1007, [0017].

193. Therefore, the combination of Priedeman with KISSlicer provides Element [16pre].

[16a] (a) printing a first layer of a support structure from a support material for the three-dimensional part;

194. Priedeman discloses that one of the extrusion heads or nozzles of extrusion apparatus 10 deposits a *part material* (e.g., “modeling material A”) to print each layer of the *three-dimensional part* (e.g., model 26). EX1007, [0018]-[0022]. Because Priedeman discloses that every layer of the *three-dimensional part* (e.g.,

model 26) is printed using the deposits a *part material*, in the this means that in the predictable Priedeman-KISSlicer combination, extrusion apparatus 10 prints a *first layer* of the *purge tower* from the *part material* when the print head or nozzle depositing modeling material A transitions from the idle state to the active state.

195. Therefore, the combination of Priedeman with KISSlicer provides Element [16a].

[16b] (b) printing a first layer of a purge tower from a part material;

196. It is clear that a POSITA would have been motivated to implement Priedeman's extrusion apparatus 10 with the teachings of KISSlicer so that extrusion apparatus 10 prints a layer of the *purge tower* each time that a *deposition line* ("nozzle") transitions from an idle state to an active state as taught by KISSlicer. EX1007, [0016]-[0018], FIG. 1; EX1010, 9, 10; *supra*, Element [1c], *supra*, §IX.A. As KISSlicer explains:

The wipe pillar is a cylinder printed before every layer to clean the extruder tip. It reduces hairing and it is extremely important in dual head prints. Can be switched off, or the position with respect to the main part can be chosen.

EX1010, 9.

197. Priedeman discloses that one of the extrusion heads or nozzles of extrusion apparatus 10 deposits a *part material* (e.g., "modeling material A").

EX1007, [0018]-[0022] for each layer of the model 26. Consequently, in the predictable Priedeman-KISSlicer combination, extrusion apparatus 10 prints a *first layer* of the *purge tower* from the *part material* when the print head or nozzle depositing modeling material A transitions from the idle state to the active state to print a layer of model 26. After the printing of the *first layer* of the *purge tower* from the *part material*, the “printer is ready” to deposit the modeling material A in the predictable Priedeman-KISSlicer combination.

198. Therefore, the combination of Priedeman with KISSlicer provides Element [16b].

[16c] (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower;

199. As I described above in Element [16a], Priedeman’s extrusion apparatus 10 deposits *layers* of three-dimensional model 26 using a *part material* (“modeling material A”). EX1007, [0018], [0019], [0022]; *supra*, Element [16a]. Because each layer of the three-dimensional model 26 is deposited using the part material (e.g., modeling material A), this means that extrusion apparatus 10 prints the *first layer* of the *three-dimensional part* (e.g., model 26) from the *part material* (e.g., modeling material A).

200. In the Priedeman-KISSlicer combination, it is apparent that extrusion apparatus 10 alternates between depositing the modeling material A to build model

26 and the depositing the support material B to build support structure 28 so that model 26 and support structure 28 are built in a *layer-by-layer manner* concurrently with the *purge tower*. EX1007, [0016]-[0022], FIG. 1; EX1010, 9, 10. When the extrusion apparatus 10 switches to depositing the *part material* (e.g., modeling material A), extrusion apparatus 10 prints a *first layer* of a *purge tower* before printing the *first layer* of model 26. EX1010, 9, 10; *supra*, Element [1c]. This ensures that the nozzle depositing the *part material* is ready to print.

201. Consequently, in the predictable Priedeman-KISSlicer combination, extrusion system 10 prints the *first layer* of the *three-dimensional part* (e.g., model 26) *after* printing the *first layer* of the *purge tower*. Priedeman describes “additional geometry acting as a support structure for the overhanging or free-space segments of the object being formed.” EX1007, [0007]. Priedeman therefore teaches that the *first layer* of the *three-dimensional part* can be printed on *at least a portion* of the *first layer* of the *support structure* so that *support structure* vertically supports the *three-dimensional part* (e.g., model 26). Thus, Priedeman’s *support structure* can vertically support a portion of the *three-dimensional part* that overhangs the *support structure*.

202. Therefore, the combination of Priedeman with KISSlicer provides Element [16c].

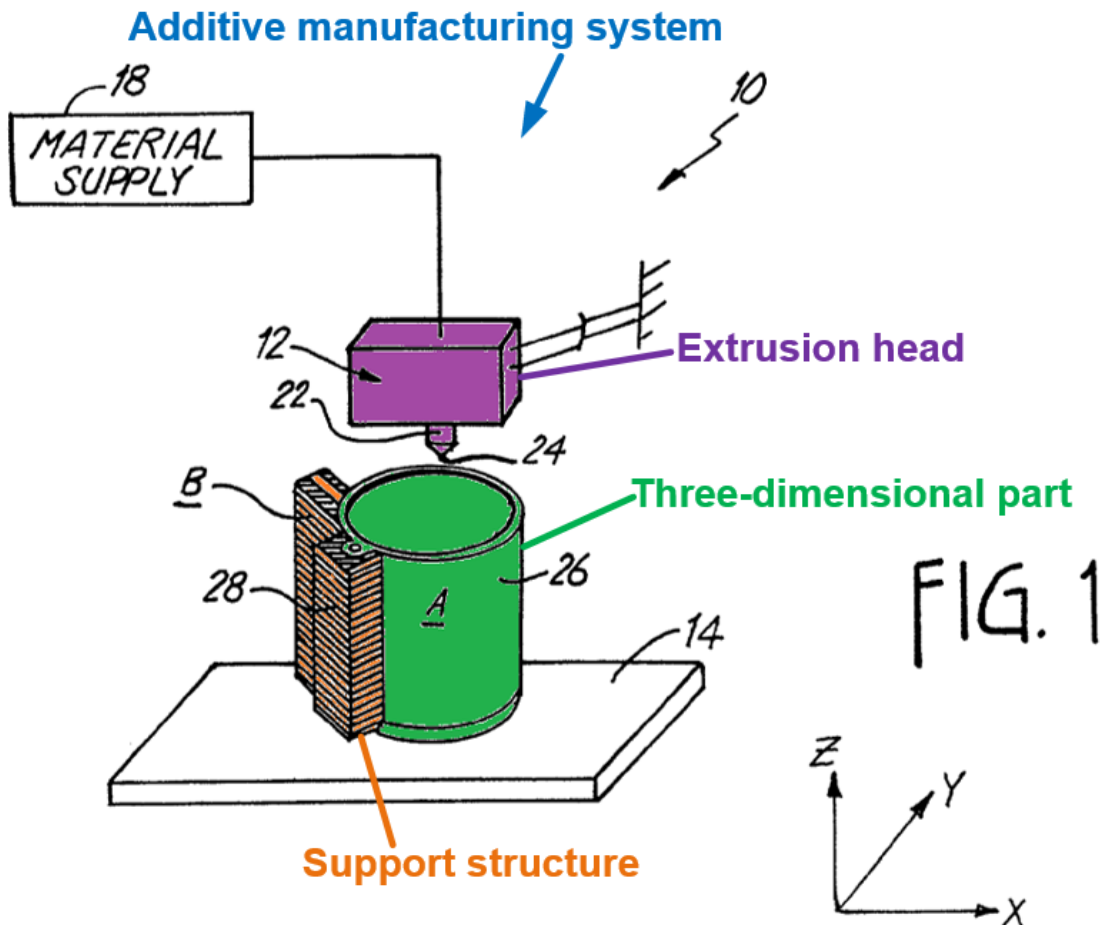
[16d] (d) printing a second layer of the purge tower from the support material; and

203. As I described above in my discussion of the predictable combination of Priedeman with KISSlicer and the reasons that would have prompted a POSITA to apply KISSlicer's suggestions to Priedeman (§IX.A), a POSITA would have predictably applied KISSlicer's suggestions to Priedeman's extrusion apparatus 10 such that in the resulting 3D printing system, the extrusion apparatus 10 prints a layer of a ***purge tower*** each time that a ***deposition line*** ("nozzle") transitions from an idle state to an active state as taught by KISSlicer. EX1007, [0016]-[0018], FIG. 1; EX1010, 9, 10; *supra*, Element [1c], *supra*, §IX.A. Priedeman discloses that one of the extrusion heads or nozzles of extrusion apparatus 10 deposits a ***support material B***. EX1007, [0018]-[0022]. As such, when applying KISSlicer's teaching to print a layer of the purge tower ("wipe pillar") when switching between deposition materials, in the resulting Priedeman-KISSlicer combination, extrusion apparatus 10 prints a ***second layer*** of the ***purge tower*** from the ***support material B*** when the print head or nozzle depositing ***support material B*** transitions from the idle state to the active state.

204. Therefore, the combination of Priedeman with KISSlicer provides Element [16d].

[16e] (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.

205. It is clear that Priedeman's extrusion apparatus 10 deposits *layers* of support structure 28—including a *second layer*—using a *support material* B as the system fabricates a completed object. EX1007, [0018], [0019], [0022]; *supra*, Element [16a]. This is shown, for example, in FIG. 1 of Priedeman, in which the support structure is shown as having a layer for each layer of the object being fabricated, which demonstrates that Priedeman's extruder apparatus 10 deposits a layer of *support material* for each layer of *part material*:



EX1007, FIG. 1 (annotated). A POSITA would have recognized based on the example of FIG. 1, and Priedeman's teachings as a whole, that the extrusion apparatus 10 alternates between depositing the modeling material A to print model 26 and the depositing the support material B to print support structure 28 in a *layer-by-layer manner* concurrently with printing *purge tower*. EX1007, [0016]-[0022], FIG. 1; EX1010, 9, 10. When the extrusion apparatus 10 switches to depositing the *support material* after depositing the *part material*, a POSITA would have been motivated to implement extrusion apparatus 10 to print a *second layer* of the *purge tower* before printing the *second layer* of *support structure* 28 as suggested by KISSlicer to prime the extruder head or nozzle for printing, to avoid undesirable oozing, as I described above. EX1010, 9, 10; *supra*, Element [1c]; *supra*, §IX.A. When the teachings of KISSlicer are predictably applied to Priedeman, the resulting system would function such that the extrusion system 10 would print the *second layer* of the *support structure* 28 *after* printing the *second layer* of the *purge tower* because, based on KISSlicer's suggestion, a layer of the purge tower is printed each time the device switches deposition materials, and therefore the system would print a layer of the purge tower (using support structure material) prior to printing this second layer of the support structure 28.

206. Priedeman describes “additional geometry acting as a support structure for the overhanging or free-space segments of the object being formed.” EX1007,

[0007]. Specifically, Priedeman describes one example where the 3D model is a cave prototype extending from a cave floor to a cave ceiling, with a stalactite hanging from the ceiling. EX1007, [0006]. In this example, there would need to be a support structure between the part cave floor and the stalactite to provide vertical support for the stalactite until the cave ceiling is finished. EX1007, [0006]. This means Priedeman teaches that the *second layer* of the *support structure* 28 can be printed on *at least a portion* of the *first layer* of the *three-dimensional part* (e.g., model 26) so that *support structure* 28 vertically supports other material above the *first layer* of the *three-dimensional* model 26.

207. Therefore, the combination of Priedeman with KISSlicer provides Element [16e].

H. Claim 17

208. Claim 17 of the '713 Patent recites:

17. The method of claim 16, and further comprising repeating steps (b)-(e) for at least a portion of the three-dimensional part and support structure.
--

209. The extrusion apparatus 10 of Priedeman uses a “modeling material A” and “support material B” to print three-dimensional model 26 and corresponding support structure 28, respectively. EX1007, [0018]-[0022]. As I described above, when the extrusion apparatus 10 of Priedeman is implemented with the idle cooling and purge teachings of KISSlicer, the resulting system alternates between depositing

the modeling material A to print the build model 26 and depositing the support material B to print support structure 28. One reason for this is because in the extruder embodiment of KISSlicer where a single extrusion head includes multiple nozzles, the nozzles must alternate between the idle and active states in an inverse fashion so that only one nozzle is depositing material at a given time. EX1007, [0018].

210. This means that the Priedeman-KISSlicer combination provides *repeating* steps (a), (c), and (e) which involve printing layers of the *three-dimensional part* (e.g., model 26) and *support structure* 28 in an alternating fashion. EX1007, [0016]-[0022]. Because extruder head 10 alternates between using one nozzle to deposit the modeling material A to print model 26 and another nozzle to deposit support material B to print support structure 28, there could be many instances in the course of printing model 26 support structure 28 where these steps repeat. EX1007, [0016]-[0022]. This is demonstrated, for example, in the example fabrication object and support structure shown in FIG. 1, which shows that both the object and the support structure are printed to include multiple levels. Furthermore, as I discussed above in my analysis of Element [16e], the system deposits a layer of support structure for each layer of part material, as demonstrated by the equal heights of the part and support structure, and therefore the resulting system repeats the process of alternating between part material and support material layers. *supra*, Element [16e].

211. As I discussed above in my analysis of Element [1c], KISSlicer discloses a process for printing a *purge tower* next to a *three-dimensional part* and *support structure* specifically to “prime” an extruder that is transitioning out of an idle state and into an active state to print the *three-dimensional part* or *support structure*. EX1010, 9-11. When Priedeman’s extrusion apparatus 10 is implemented with the teachings of KISSlicer, extrusion apparatus 10 prints a one or more layers of a *purge tower* each time that the extrusion apparatus 10 transitions between materials as taught by KISSlicer. EX1010, 9, 10. This means that when Priedeman’s extrusion apparatus 10 repeats steps (a), (c), and (e), extrusion apparatus 10 would also repeat steps (b) and (d) of claim 16 to “prime” a nozzle for depositing the part material and a nozzle for depositing the support material. That is, each material switch that occurs in a repeat of steps (a), (c) would prompt the system to repeat step (b) and each material switch that occurs in a repeat of steps (c), (e) would prompt the system to repeat step (d).

212. The teachings of Priedeman and KISSlicer provide the additional feature recited in claim 17 and would have rendered claim 17 obvious in its entirety.

X. GROUND 2B: PRIEDEMAN IN COMBINATION WITH KISSLICER, REPRAP ARTICLE, AND REPRAP VIDEO WOULD HAVE RENDERED CLAIM 5 OBVIOUS

A. Overview of the Combination and Reasons to Combine

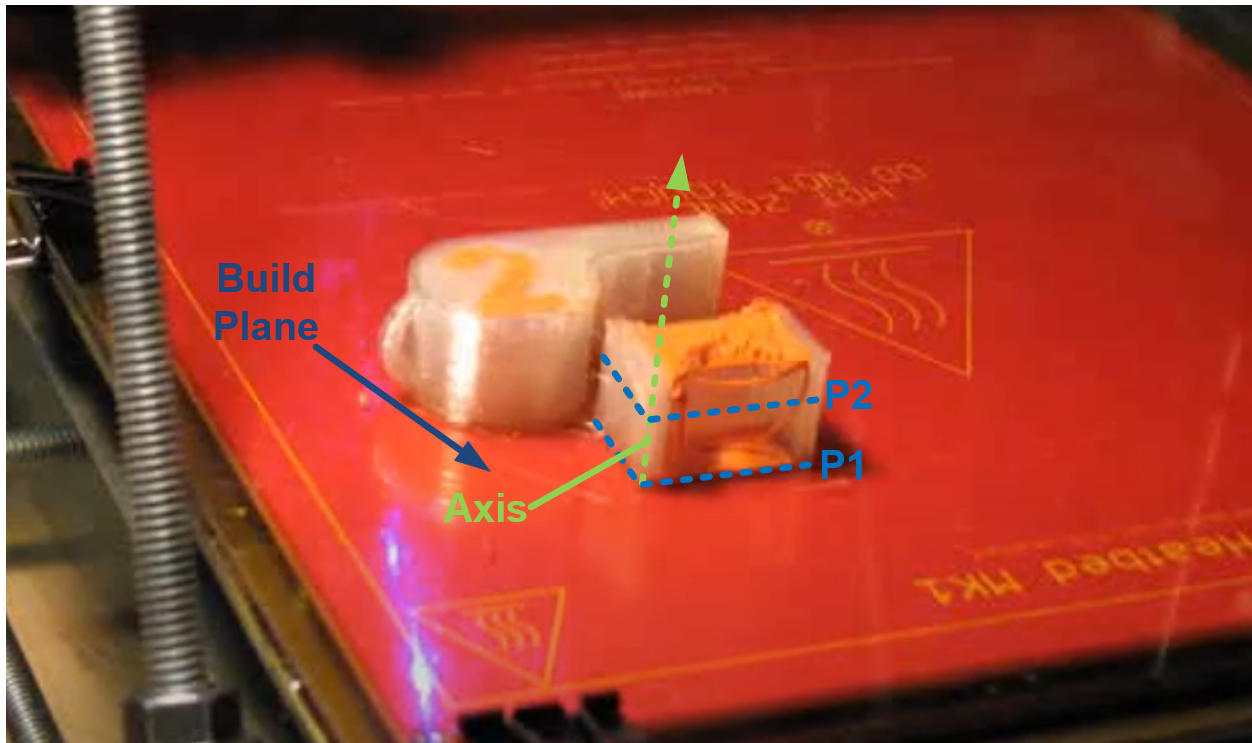
213. As I discussed above with respect to my analysis of Claim 5 in Ground 1, , it is clear that RepRap plainly suggested a conventional purge tower having a cross-sectional area at the base that is larger than an area in other regions (above the base). *Supra*, Ground 1 Claim [5] (citing EX1005, 1; EX1006, 5:01-5:05). Based on RepRap's suggestion, a POSITA would have been motivated to implement the resulting purge tower of the Priedeman-KISSlicer combination (*supra*, Ground 2A) in this manner to advantageously construct a more stable, less top-heavy tower. *Intel*. Specifically, a POSITA would have recognized that narrowing the purge tower as the purge tower increases in height (as suggested by RepRap) would have made the resulting purge tower more stable and acted to prevent the resulting purge tower from potentially tipping over and making contact with the actual object being fabricated and/or support structure, thus interrupting the fabrication process in a potentially unrecoverable manner. A POSITA would have recognized the potential stability of a cylinder shape (as disclosed by KISSlicer) for the purge tower in situations in which a particularly tall object and support structure (and therefore, a particularly tall purge tower) is being fabricated. As such, a POSITA would have been prompted to apply RepRap's teachings to form a more stable purge tower in which the lower layers of the purge tower have a cross-sectional area that is wider than later (higher) layers of the purge tower.

B. Claim 5

214. Claim 5 of the '713 Patent recites:

5. The method of claim 1, wherein the at least one purge tower has a cross-sectional area that reduces in height along an axis that is perpendicular to a build plane.

215. Priedeman-KISSlicer-RepRap combination would have provided this predictable option based on RepRap teaching that the *purge tower* printed next to a three-dimensional part can have cross-sectional areas that differ between a larger cross-sectional area at a base and a reduced cross-sectional area at a higher position. *Supra*, Ground 1 analysis of [5] (annotating position (P1) and (P2)). For example, based on RepRap's teachings, a POSITA would have implemented the Priedeman-KISSlicer-RepRap combination such that KISSlicer's purge tower ("wipe pillar") is printed next to a three-dimensional part such that a cross-sectional area of the purge tower reduces in height along an axis that is perpendicular to a build plane . EX1005, 1; EX1006, 5:01-5:05. As shown in the example from RepRap Video, the *purge tower* has cross-sectional areas that differ between a first cross-sectional position (P1) at a base of the purge tower and a second cross-sectional position (P2) above P1 relative to the build plane:



EX1006, 5:04 (annotated).

216. Specifically, it is clear from RepRap video that the *cross-sectional area* of the purge tower at position P1 with the cross-section taken parallel to the build surface is greater than the *cross-sectional area* of the purge tower at position P2 with the cross-section taken parallel to the build surface. EX1006, 5:04. This is because the cross-sectional area at position P1 includes a wide layer of orange material that fills most of the outer boundary of the purge tower. The cross-sectional area at position P2 does not include this wide layer of orange material, but rather includes a narrower layer of translucent material. RepRap video shows that a large portion of the area where orange material is located in the P1 cross-sectional area does not include such material in the P2 cross-sectional area. This means that between P1 and

P2 along the axis perpendicular to the build plane, the cross-sectional area of the purge tower reduces in height.

XI. GROUND 3: BOYER ANTICIPATES CLAIMS 1, 2, 6, 7, AND 9

A. Independent Claim 1

217. Independent claim 1 of the '713 Patent recites:

1. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:
printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;
switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;
performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.

218. As I explain in more detail below through my element-by-element analysis, Boyer anticipates claim 1 because Boyer expressly teaches each and every element of claim 1.

[1pre] A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

219. Boyer provides “[a] method for printing a three-dimensional part with an additive manufacturing system.” For example, Boyer discloses a printer that can “build a three-dimensional object by depositing lines of build material in successive

layers.” EX1008, [0018], [0024]-[0029], FIGS. 1-2. This represents *printing a three-dimensional part* using an *additive manufacturing system*, because successive layers are *added* to one another to manufacture the *three-dimensional part*. In several cases, Boyer discloses that its printer can perform a *method* for using multiple build materials to print a three-dimensional part. EX1008, [0012], [0029] (“application of the systems and methods described herein”), [0035] (“method for using multiple build materials”).

220. Therefore, Boyer provides Element [1pre].

[1a] printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;

221. As I described above in my analysis of Element [1pre], Boyer discloses that the printer “can *build a three-dimensional object* by depositing lines of build material in *successive layers*—two-dimensional patterns derived from the cross-sections of the three-dimensional object. As described below, three-dimensional printing may be augmented to *accommodate multi-material builds*.”. EX1008, [0024]. Each layer represents a “two-dimensional pattern” derived from a cross-section of the three-dimensional part. EX1008, [0024]. (In another example, Boyer describes that “object 112 may be fabricated in three dimensions by depositing successive layers of material in two-dimensional patterns.” EX1008, [0018]. To deposit these successive layers, Boyer’s extruder deposits “*multiple* build materials.”

EX1008, [0015]-[0018], [0025]-[0029], [0032]-[0044], FIGS. 2, 4-5. Boyer clearly discloses that the printer is configured to print layers of the *three-dimensional part* using a first build material (“main structure”) and print layers of a “sacrificial *support structure*” for the three-dimensional part using a second build material. EX1008, [0044] (“build materials may be deposited in an object”).

222. According to the alternative claim construction that I discussed in connection with §VI.B, *supra*, Boyer discloses an extruder 200 including *multiple deposition lines* that use a *layer-based additive manufacturing technique* to print *layers* of the *three-dimensional part* and the *support structure*. EX1008, [0025]-[0029], FIG. 2, *supra* §VII.E. Namely, extruder 200 includes a first *deposition line* corresponding to a first feed 210 for *depositing* the first build material 214 and a second *deposition line* corresponding a second feed 212 for *depositing* the second build material 216. EX1008, [0025], [0026], FIG. 2. For example, “[t]he filament changer 208 may, for example include a first feed 210 and a second feed 212 that receive a first build material 214 and a second build material 216 respectively.” EX1008, [0026]. Boyer’s extruder 200 is depicted below in FIG. 2 (annotated):

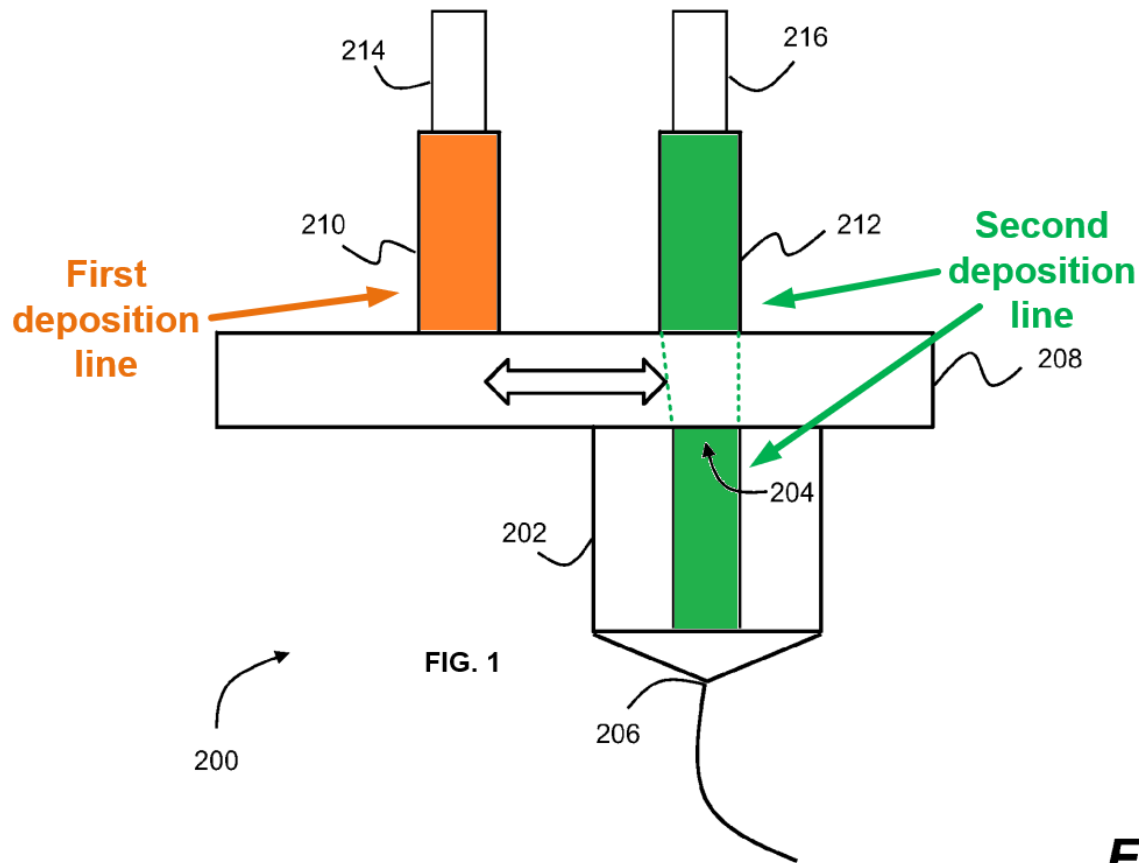


Fig. 2

223. Again, consistent with the alternative claim construction that I discussed in connection with §VI.B, *supra*, Boyer expressly discloses that extrusion head 202 can transition between the first feed 210 of the first *deposition line* and the second feed 212 of the second *deposition line* by sliding along filament changer 208. EX1008, [0025]. For example, as Boyer describes, “[t]he filament changer 208 may, for example slide horizontally over a blade or other cutting edge to cut one of the build materials 214, 216 that is being moved away from the feed 204 of the extruder 200 while moving the other one of the build materials 214, 216 into the feed 204 of the extruder 200.” EX1008, [0026]. Although Boyer’s figures do not depict the

example where extrusion head 202 is aligned with first feed 210, the modified version of FIG. 2 below depicts this example consistent with Boyer's description in paragraph [0025]:

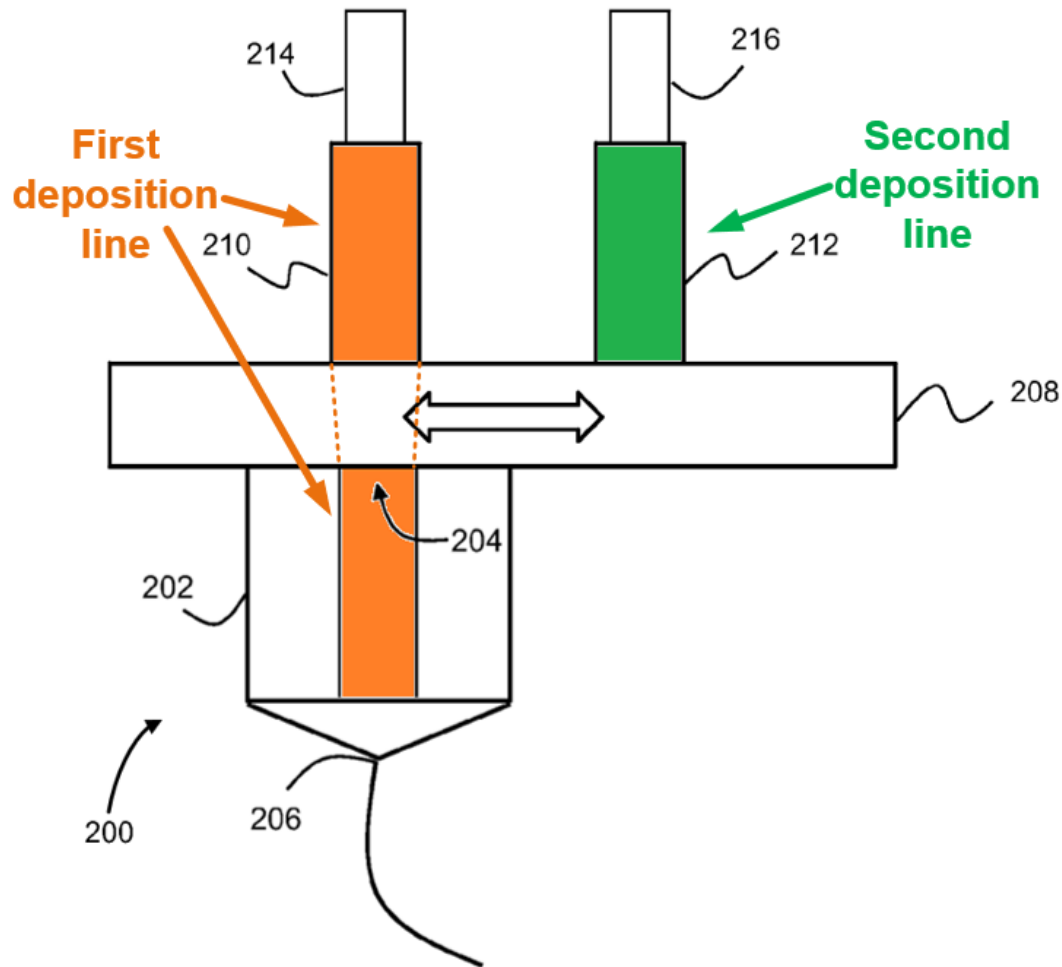


Fig. 2

224. EX1008, FIG. 2 (modified and annotated). Consequently, Boyer's extruder 200 includes *multiple deposition lines* that can fabricate a *three-dimensional part* and *support structure* object by changing between "two different build materials." EX1008, [0025], [0028], [0032]. Furthermore, Boyer discloses that extruder 200 can deposit *layers* of the first build material 214 to print a *three-*

dimensional part and deposit *layers* of the second build material 216 to print a sacrificial *support structure*. EX1008, [0025]-[0029], [0044].

225. Therefore, Boyer provides Element [1a].

[1b] switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;

226. As I described above in connection with Element [1a], *supra*, Boyer discloses that extrusion head 202 can transition between being aligned with first feed 210 corresponding to a first *deposition line* and being aligned with second feed 212 corresponding to a second *deposition line*. EX1008, [0025]-[0027]. This transition occurs when extrusion head 202 slides along filament changer 208 from first feed 210 to second feed 212, and vice versa. EX1008, [0026].

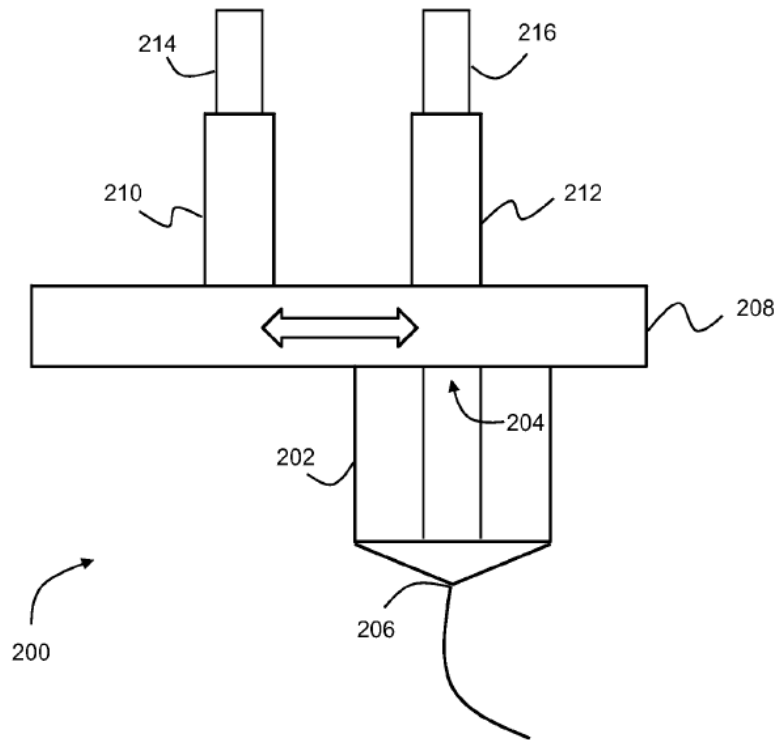


Fig. 2

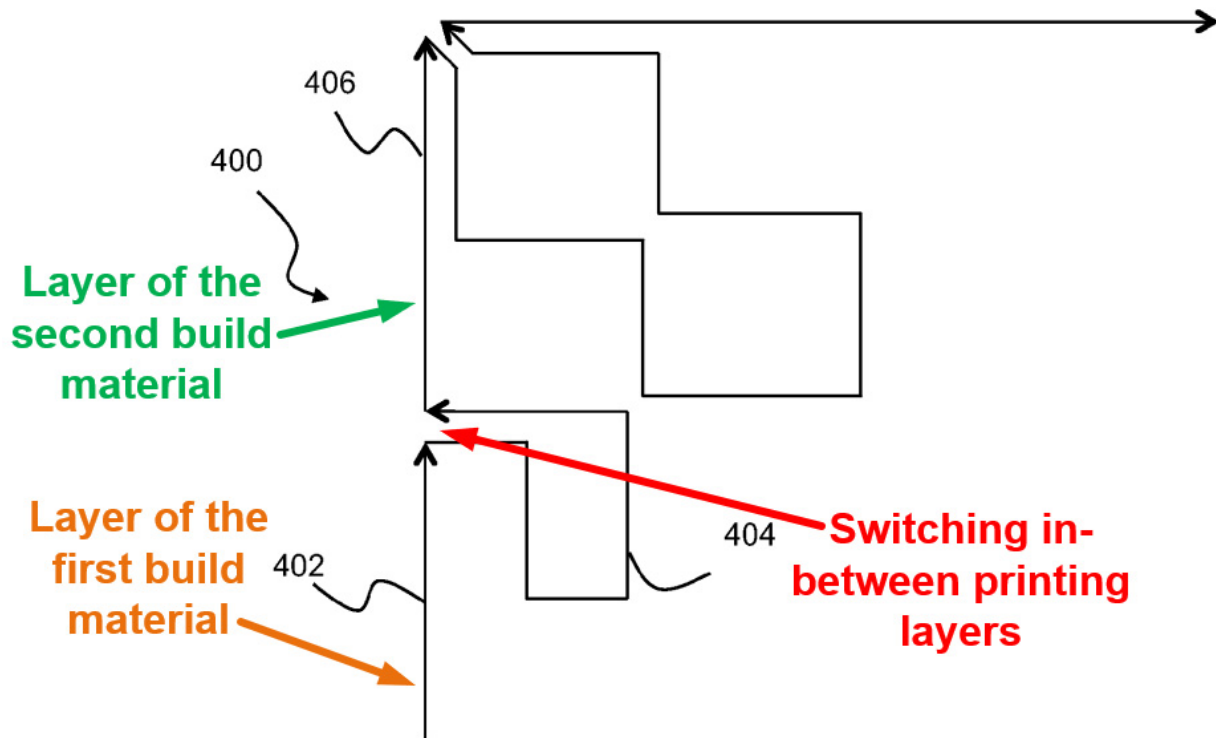
EX1008, FIG. 2.

227. According to the alternative claim construction (*supra* §IV.A), the transition of extrusion head 202 between alignment with first feed 210 and alignment with second feed 212 causes the **multiple deposition lines** of extruder 200 to **switch** between **stand-by** modes and **operating modes**. EX1008, [0025]-[0027], FIG. 2. Boyer discloses that extruder 200 can deposit **layers** of the first build material 214 to print a **three-dimensional part** and deposit **layers** of the second build material 216 to print a sacrificial **support structure** so that no more than one material is deposited at a given time. EX1008, [0025]-[0029], [0044]. This is because the **deposition line** in alignment with extrusion head 202 is configured to actively extrude build material

via nozzle 206 in the *operating mode*, whereas the *deposition line* not in alignment with extrusion head 202 sits idle in the *stand-by mode*.

228. When extrusion head 202 transitions from alignment with first feed 210 to alignment with second feed 212, for example, the first *deposition line* corresponding to first feed 210 *switches* from an *operating mode* to a *stand-by mode* where first build material 214 is not deposited, and the second *deposition line* corresponding to second feed 212 *switches* from a *stand-by mode* to an *operating mode* to actively deposit second build material 216 (support structure material). EX1008, [0026]. The opposite occurs when extrusion head 202 transitions from alignment with second feed 212 to alignment with first feed 210. EX1008, [0026].

229. Boyer discloses that this *switching* of the multiple deposition lines between *stand-by modes* and *operating modes* occurs *in-between* printing layers of “multiple build materials.” EX1008, [0026], [0032]-[0037], FIGS. 4-5. For example, Boyer discloses that the printer can fabricate three-dimensional parts by “depositing successive layers of material in two-dimensional patterns.” EX1008, [0018]. In another example, Boyer describes that its 3D printer “build[s] a three-dimensional object by depositing lines of build material in successive layers—two-dimensional patterns derived from the cross-sections of the three-dimensional object.” EX1008, [0024]. FIG. 4 of Boyer shows an example of just such a two-dimensional pattern representing a layer of an object printed with multiple materials:



EX1008, FIG. 4 (annotated).

230. To print according to the tool path of FIG. 4, Boyer's extruder 200 prints first segment 402 by extruding first build material 214 from the first *deposition line* when extruder head 202 is aligned with first feed 210. EX1008, [0025]-[0029], [0032], FIG. 2, FIG. 4. Boyer's extruder 200 prints third segment 406 from the second *deposition line* when extruder head 202 is aligned with second feed 212. EX1008, [0025]-[0029], [0032], FIG. 2, FIG. 4. *In-between* printing the first segment 402 and the third segment 406, the first *deposition line switches* from the *operating mode* to the *stand-by mode* and the second *deposition line switches* from the *stand-by mode* to the *operating mode* when extruder head 202 transitions

from alignment with first feed 210 to alignment with second feed 212. EX1008, [0025]-[0029], [0032], FIG. 2, FIG. 4.

231. Finally, although Boyer uses “different colors” as an example of materials that can be used in the example of FIG. 4, Boyer also discloses other “multi-material” builds such as using one material for a *three-dimensional part* and another material for a *support structure*. EX1008, [0032]-[0034], [0044]. That is, Boyer’s extruder 200 can extrude a build material to print the segment 402 when extruder head 202 is aligned with first feed 202. Next, Boyer’s extruder head 202 can switch to align with second feed 212 and extrude support material to print transition segment 404. Boyer’s extrusion head 202 can print the segment 406 including support material after printing transition segment 404.

232. Therefore, Boyer provides Element [1b].

[1c] performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.

233. Each time that the first *deposition line* or the second *deposition line* of extruder 200 switches to the *operating mode*, that *deposition line* performs a *purge operation* by printing at least one layer of a *purge tower*. EX1008, [0025]-[0028], [0032]-[0034], FIG. 2, FIG. 4. For example, Boyer’s FIG. 4 shows an example “cross section of a multi-material build” where the first segment 402 is printed from

a first material and the third segment 406 is printed from a second material. EX1008, [0032]. It is apparent that Boyer's extruder 200 prints the first segment 402 with first build material 214 using the first *deposition line* when extruder head 202 is aligned with the first feed 210. EX1008, [0025]-[0029], [0034], FIG. 2, FIG. 4. After printing the first segment 402, it is clear that Boyer's first *deposition line* switches to the *stand-by mode* and Boyer's second *deposition line* switches to the *operating mode* when extrusion head 202 transitions from alignment with first feed 210 to alignment with second feed 212. EX1008, [0025]-[0029], [0034], FIG. 2, FIG. 4.

234. Upon the second *deposition line* switching to the *operating mode*, extruder 200 performs a *purge operation* by printing transition segment 404 using the second *deposition line*. EX1008, [0032]. This is confirmed by the fact that in FIG. 4, the beginning of the arrow for transition segment 404 begins where the head of the arrow for first segment 402 ends. EX1008, FIG. 4. When the *purge operation* is complete, extruder 200 prints the third segment 406 with second build material 216 using the second *deposition line* in which extruder head 202 is aligned with the second feed 212. EX1008, [0025]-[0029], [0034], FIG. 2, FIG. 4. Boyer discloses that more than one material change can occur in each layer printed by the extruder 200. EX1008, [0034]. Based on these disclosures, a POSITA would have recognized that Boyer's extruder 200 is configured to perform a *purge operation* each time there

is a material change where one of the *deposition lines* transitions from the *stand-by mode* to the *operating mode*. EX1008, [0032]-[0034], [0037]-[0043], FIGS. 4-5.

235. FIG. 4 of Boyer also depicts multiple transition segments (purge towers). For example, in addition to transition segment 404 corresponding to one material change (e.g., change from first material 214 to second material 216), Boyer's FIG. 4 depicts another transition segment corresponding to another material change (e.g., a change from second material 216 back to first material 214):

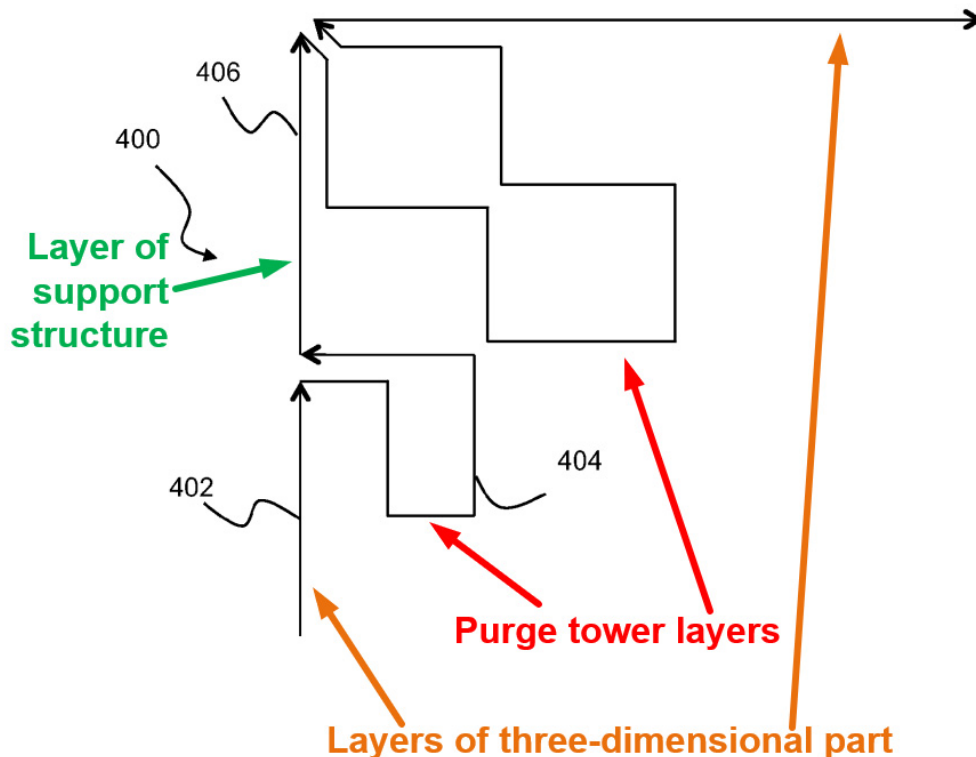


Fig. 4

EX1008, FIG. 4 (annotated).

236. As Boyer explains, after extruder 200 prints the third segment 406, the extruder head 202 can slide back to alignment with first feed 210 so that the first

deposition line transitions back to the first operating mode for depositing the first build material 214; EX1008, [0025]-[0029], [0032]-[0034], FIG. 2, FIG. 4. Following this material switch, the extruder 200 can perform another *purge operation* as depicted in FIG. 4 before printing another segment of the *three-dimensional part*. EX1008, FIG. 4. This means that there are two transition segments on the same two-dimensional pattern—one transition a cross-section of a purge tower resulting from switches from a first material to a second material and another resulting from switches from the second material to the first material.

237. As described above, Boyer discloses that the printer fabricates three-dimensional parts by “depositing successive layers of material in two-dimensional patterns.” EX1008, [0018], *see also supra*, Elements [1pre]-[1b]. For example, Boyer describes that “the above system can build a three-dimensional object by depositing lines of build material in successive layers—two-dimensional patterns derived from the cross-sections of the three-dimensional object. As described below, three-dimensional printing may be augmented to accommodate multi-material builds.” EX1008, [0024]. By describing tool path 400 as a “cross section” of a multi-material build, Boyer teaches that layers printed using a similar two-dimensional tool path can exist above and/or below FIG. 4’s cross section. EX1008, [0018], [0024], [0032]-[0034], FIG. 4. To form a three-dimensional part, two-dimensional layers such as the one depicted in FIG. 4 are stacked on top of one another so that

the transition segments of FIG. 4 correspond to *purge towers* printed in a *layer-by-layer* manner. EX1008, [0032]-[0044], FIGS. 4-5.

238. Therefore, Boyer provides Element [1c].

B. Claim 2

239. Claim 2 of the '713 Patent recites:

<p>2. The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and wherein switching the deposition lines between the stand-by modes and the operating modes comprises:</p> <p>switching the first deposition line from the stand-by mode to the operating mode; and</p> <p>switching the second deposition line from the operating mode to the stand-by mode.</p>
--

240. As I explain in more detail below through my element-by-element analysis, Boyer anticipates claim 2.

[2a] The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and

241. Boyer discloses techniques for using a printer to build three-dimensional parts by depositing multiple build materials in successive layers. EX1008, [0002], [0003], [0024], [0025], [0029], [0032]-[0034], FIG. 2, FIG. 4. For example, Boyer describes that “the above system can build a three-dimensional object by depositing lines of build material in successive layers—two-dimensional patterns derived from the cross-sections of the three-dimensional object. As

described below, three-dimensional printing may be augmented to accommodate multi-material builds.” EX1008, [0024]. As I described above in §VII.E, Boyer discloses one embodiment where the printer comprises a single extruder 200 including **multiple deposition lines**. EX1008, [0025]-[0029], FIG. 2; *supra*, Element [1a]; *supra*, §VII.E. These **multiple deposition lines** include a first **deposition line** where extrusion head 202 is aligned with first feed 210 for depositing first build material 214 and a second **deposition line** where extrusion head 202 is aligned with second feed 212 for depositing second build material 216. EX1008, [0025]-[0029], FIG. 2

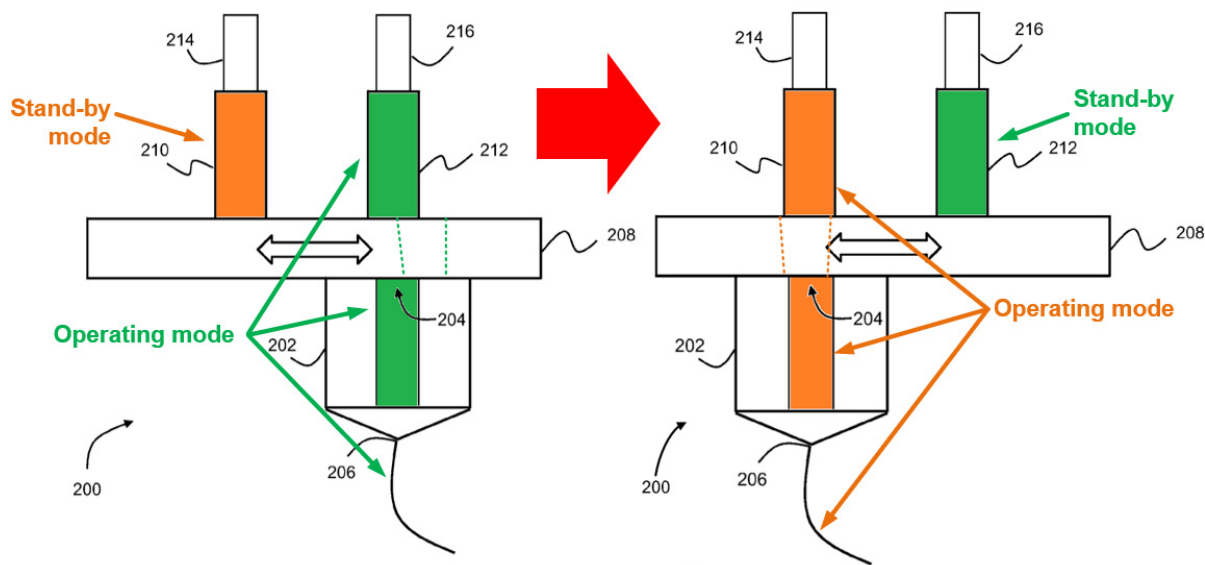
242. Therefore, Boyer provides Element [2a].

[2b] wherein switching the deposition lines between the stand-by modes and the operating modes comprises: switching the first deposition line from the stand-by mode to the operating mode; and switching the second deposition line from the operating mode to the stand-by mode.

243. Boyer describes that the process of building a three-dimensional part by depositing multiple build materials includes transitioning the extruder 200 between using the first **deposition line** to deposit the first material 214 and using the second **deposition line** to deposit the second build material 216. EX1008, [0025]-[0029], FIG. 2; *supra*, Element [1a]; *supra*, §VII.E. For example, “[t]he filament changer 208 may, for example slide horizontally over a blade or other cutting edge to cut one of the build materials 214, 216 that is being moved away from the feed

204 of the extruder 200 while moving the other one of the build materials 214, 216 into the feed 204 of the extruder 200.” EX1008, [0026] This transition occurs when the extrusion head 202 slides horizontally over filament changer 208 to change between alignment with first feed 210 and alignment with second feed 212 to **switch** the **deposition lines** between the **stand-by modes** and the **operating modes**. EX1008, [0026]. Both of the **deposition lines** switch modes simultaneously in this transition.

244. For instance, when extrusion head 202 slides horizontally from being aligned with second feed 212 (as depicted in FIG. 2) to being aligned with first feed 210 (as depicted in a modified version of FIG. 2), the first deposition line **switches** from the **stand-by mode** to the **operating mode** for depositing the first material 214 and the second deposition line **switches** from the **operating mode** for depositing the second material 216 to the **stand-by mode**:



EX1008, FIG. 4 (modified and annotated). Because there is only one nozzle in this embodiment of Boyer, only one deposition line can be in the *operating mode* at a given time.

245. Therefore, Boyer provides Element [2b].

C. Claim 6

246. Claim 6 of the '713 Patent recites:

6. The method of claim 1, wherein the at least one purge tower is stopped at a highest layer at which there is a material change for the printed layers of the three-dimensional part and support structure.

247. As I described above in connection with Element [1c], Boyer discloses that the printer performs a *purge operation* by printing a transition segment every time a there is a change of build material (e.g., a change from a first material for printing a *three-dimensional part* to a second material for printing a *support structure*, or vice versa). EX1008, [0032]-[0034], [0037]-[0040], FIGS. 4-5; *supra*, Element [1c]. Transition segment 404, for example, represents a cross section of a *purge tower* that is printed when a first *print head* or *deposition line* finishes printing the first segment 402 using a first build material and a second *print head* or *deposition line* switches to the operating mode to deposit a second build material. Consequently, Boyer discloses that transition segments are printed in response to a change in materials (e.g., a change from a first material for printing a *three-*

dimensional part to a second material for printing a *support structure*). EX1008, [0032]-[0034], [0037]-[0040], [0044], FIGS. 4-5.

248. Because Boyer discloses that the printer deposits a transition segment in response to each *material change*, this means that the printer stops printing transition segments at the *highest layer* at which there is a *material change* for printed layers of the *three-dimensional part* and *support structure*. EX1008, [0032]-[0044], FIGS. 4-5. Therefore, it is clear that the *at least one purge tower* is *stopped* at the *highest layer* at which there is a *material change* prompting the printer to deposit a *transition segment* representing a cross-section of the at least one purge tower. After the last material change occurs, there is not a need to perform another transition segment.

249. Therefore, Boyer anticipates Claim [6].

D. Claim 7

250. Claim 7 of the '713 Patent recites:

7. The method of claim 1, and further comprising: generating tool path instructions for printing the layers of the three-dimensional part and of the support structure; and generating tool path instructions for printing the layer of the at least one purge tower.
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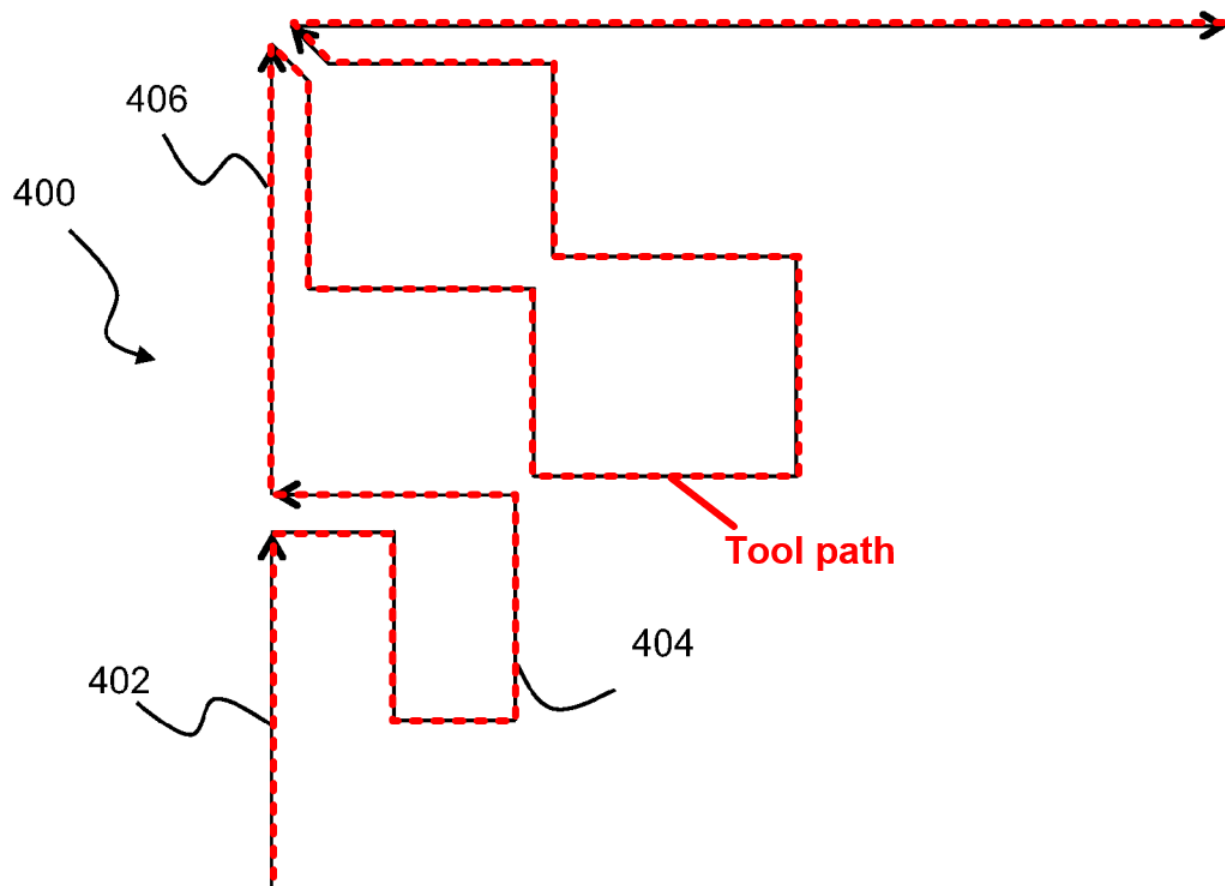
251. As I explain in more detail below through my element-by-element analysis, Boyer anticipates claim 7.

***[7a] The method of claim 1, and further comprising:
generating tool path instructions for printing the layers of
the three-dimensional part and of the support structure;
and***

252. Boyer's printer can generate *tool path instructions* for printing one or more three-dimensional parts. EX1008, [0013], [0019], [0020], [0028], [0032]-[0034], [0036]-[0044], FIGS. 1, 2, 4-5. Specifically, Boyer discloses that "[t]he processor may...control an x-y-z positioning assembly...along with the extruder 200 and the filament changer 208 to fabricate an object from a three-dimensional model." EX1008, [0028]. Boyer also discloses that the x-y-z positioning assembly can independently control a position of an extruder within a "working volume along each of an x-axis, a y-axis, and a z-axis." EX1008, [0018]. This indicates that the positioning assembly can control an extruder to follow a tool path to print *layers* of a *three-dimensional part* and *support structure*, because the positioning assembly can control the exact position of the nozzle relative to the part and support structure. That is, the positioning assembly can control the extruder to follow a path along parts of the three-dimensional part and support structure according to a path (e.g., a *tool path*).

253. Furthermore, Boyer expressly discloses a process for printing a three-dimensional part using multiple materials that begins "by determining a tool path for an extruder to fabricate an object from a three-dimensional model." EX1008, [0036]-[0040], FIG. 5. I also noticed that Boyer acknowledges that "[t]echniques for

determining tool paths are well known in the art.” EX1008, [0036]. Boyer discloses that the multiple materials used to print the object can include separate materials for a *three-dimensional part* and a *support structure*. EX1008, [0044]. One example of a *tool path* that Boyer’s extruder can use to print a three-dimensional part and support structure using multiple materials is depicted in FIG. 4 of Boyer:



EX1008, FIG. 4 (annotated).

254. Consequently, Boyer discloses that the printer can generate *tool path instructions* for printing the *layers* of the *three-dimensional part* and *support structure*.

255. Therefore, the Boyer provides Element [7a].

[7b] generating tool path instructions for printing the layer of the at least one purge tower.

256. Boyer also discloses generating *tool path instructions* for printing at least one *layer* of a *purge tower* from a *print head* or *deposition line* switched to the operating mode. EX1008, [0032]-[0040], FIGS. 4-5. As I described above in connection with Element [1c], *supra*, Boyer discloses a process for printing a transition segment (e.g., transition segment 404) that represents a *layer* of a *purge tower*. EX1008, [0032]-[0040], FIGS. 4-5. Boyer describes a process for “identifying a transition including a beginning and an end along the tool path for a change from a first color of the pattern of colors to a second color of the pattern of colors that results in a portion of the pattern of colors on the surface.” EX1008, [0037]. This involves determining a “length” of the transition and altering the tool path to “accommodate” the length of the transition. EX1008, [0038]-[0039]. Thus, Boyer describes a process for determining the portion of the tool path corresponding to a transition segment.

257. As I described above in connection with Element [7a], *supra*, Boyer’s multi-material build is not limited to materials having different colors. Boyer expressly discloses that the multiple materials used to print the object can include separate materials for a *three-dimensional part* and a *support structure*. EX1008, [0044]. Consequently, Boyer discloses *generating tool path instructions* for

printing the *layer* of the *at least one purge tower*. These instructions can cause extruder 200 to print transition segments (e.g., transition segment 404), which represent the *layer* of the *at least one purge tower*.

258. Therefore, the Boyer provides Element [7b].

E. Claim 9

259. Claim 9 of the '713 Patent recites:

9. The method of claim 7, wherein the generating of the tool path instructions for printing the layer of the at least one purge tower is performed prior to printing the layers of the three-dimensional part and of the support structure.

260. Boyer discloses that generating the tool path instructions for the three-dimensional part, the support structure, and the at least one purge tower occurs prior to printing layers of the three-dimensional part and the support structure. EX1008, [0035]-[0044], FIG. 5. For example, Boyer discloses that “a print may be initiated based upon tool instructions including the tool path and transitions described above.” EX1008, [0041]. Thus, it is clear that printing the layers of the three-dimensional part and the support structure (“initiat[ion]” of the print job) occurs after the tool path instructions for the object (part and support structure) and the transitions (purge tower(s)) are generated.

261. Therefore, Boyer anticipates Claim [9].

XII. ADDITIONAL REMARKS

262. I currently hold the opinions expressed in this declaration. But my analysis may continue, and I may acquire additional information and/or attain supplemental insights that may result in added observations.

263. I hereby declare that all statements made are of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of the Title 18 of the United States Code and that such willful false statements may jeopardize the validity of this proceeding.

Dated: Dec. 17, 2024

By: 

Michael A. Hickner, PhD
East Lansing, MI

Appendix A

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Professional Preparation

Virginia Tech	Chemical Engineering	Ph.D. 2003 Dissertation Advisor: J. E. McGrath, Chemistry (deceased)
Virginia Tech	Chemical Engineering	M.Eng. 2002
Michigan Technological University	Chemical Engineering	B.S. 1999

Appointments

2023-present	Craig A. Rogerson Endowed Professor Department of Chemical Engineering and Materials Science Michigan State University, East Lansing, MI
2023-present	Adjunct Professor, Department of Materials Science and Engineering Pennsylvania State University, University Park, PA
August 2018-present	Associate Editor, ACS Applied Energy Materials, American Chemical Society
July 2018-Dec 2022	Professor, Materials Science and Engineering Professor by courtesy, Department of Chemistry and Department of Chemical Engineering The Pennsylvania State University, University Park PA
Sept. 2017-Dec 2022	Co-Director, Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D) The Pennsylvania State University, University Park PA
Nov. 2016-Dec 2022	Associate Director, Materials Research Institute The Pennsylvania State University, University Park PA
Oct. 2016-July 2018	Associate Professor by courtesy, Department of Chemistry The Pennsylvania State University, University Park PA
Feb. 2014-July 2018	Associate Professor by courtesy, Department of Chemical Engineering The Pennsylvania State University, University Park PA
July 2013-July 2018	Associate Professor, Department of Materials Science and Engineering The Pennsylvania State University, University Park PA Corning Faculty Fellow (2016-2019)
July 2007-June 2013	Assistant Professor, Department of Materials Science and Engineering The Pennsylvania State University, University Park, PA Virginia S. and Philip L. Walker, Jr. Faculty Fellow (2010-2013)
2005-June 2007	Senior Member of the Technical Staff

Sandia National Laboratories, Albuquerque, NM

2003-2005

Postdoctoral Appointee
Sandia National Laboratories, Albuquerque, NM

2002, 2000

Graduate Research Assistant
Los Alamos National Laboratory, Los Alamos, NM

Research Interests and Expertise

My research interests focus on the coupling of polymer composition and nanophase structure, water diffusion in membranes, and ion transport. My research group strives to understand the self-assembly of polymers with attached ions, the binding of water to the polymer matrix through hydration and nanoscale confinement, and how this water-polymer framework sets the stage for the transport of ions and small molecules through the material. To achieve basic understanding of the properties of ionic polymer systems, we undertake the synthesis of new polymers and perform measurements of their solution and solid-state structure. We elucidate water-polymer interactions using spectroscopic methods and study the effects of chemical composition, phase-separated domain structure, grain boundaries, and surface interactions on polymer membrane properties. Through this fundamental work, we strive to develop new materials for membrane and electrochemical processes including applications in batteries, fuel cells, and water purification. A recent facet of my work has been on measuring and controlling the surface properties of new polymers to combat fouling in marine environments and microbial fuel cells. We have also broken new ground in additive manufacturing of unique materials, assemblies, composites, and polymer-derived ceramics. My group also draws on its core expertise in polymer synthesis and polymer function to devise new polymers for basic studies of polymer thin films and control of interfaces and transport processes in organic electronics.

Professional Service

- Presiding Session Organizer, “Cooperative Research Award: Symposium in Honor of Enrique Gomez, Manish Kumar, Abhishek Roy, Mou Paul, Jeffrey Wilbur, and Tyler Culp” American Chemical Society Spring National Meeting, March 26-30, 2023.
- Co-organizer (with Brian Benicewicz, U. South Carolina) American Chemical Society Polymer Chemistry Division Workshop, “Polymers for Fuel Cells, Energy Storage, and Conversion” Napa CA, February 15-18, 2022.
- Co-organizer (with Rob Hickey, Penn State) Penn State EMS 125th Polymer Symposium, University Park, PA April 10, 2021.
- Co-organizer (with Peter Pintauro and Michael Guiver) North American Membrane Society 2019 National Meeting, Session on Fuel Cells and Batteries, Pittsburgh, PA, May 11-15, 2019.
- Co-organizer (with Brian Benicewicz, U. South Carolina) American Chemical Society Polymer Chemistry Division Workshop, “Polymers for Fuel Cells, Energy Storage, and Conversion” Asilomar CA, February 15-18, 2019.
- Co-organizer (with Stephen Paddison UTK, Mark Tuckerman NYU, and Chulsung Bae RPI) 19th International Conference on Solid State Protonic Conductors (SSPC-19), Stowe, VT, Sept. 16-21, 2018.
- Co-organizer (with Rigoberto Andvina CWRU) for session on Membranes and Blends, 4th US-Mexico Symposium on Advances in Polymer Science – MACROMEX 2017, Cabo San Lucas, Mexico, December 9, 2017.
- Co-organizer (with Corky Mittlesteadt) for session on Ionic Membranes, International Conference on Membranes – ICOM, San Francisco, California July 30, 2017.
- Co-organizer (with Andrew Herring, Patrik Jannasch, and Peter Pintauro) for session on Anion and Cation Exchange Membranes, 21st Conference on Solid State Ionics, June 19, 2017.
- MRS Bulletin Volume Editor – 2017-2018.
- Electrochemical Society Journals Editorial Advisory Committee, 2016-present.
- Guest Editor (with Geoff Geise, U Virginia, and Abhishek Roy, Dow) *Polymer* Special Issue on Using the Tools of Polymer Science to Impact Water Treatment Membranes.
- International Advisory Board – International Symposium on Polymer Electrolytes, 2013-present.
- International Advisory Board – Solid State Ionics, 2016-present.
- Membrane Session Chairperson – Department of Energy Workshop on Alkaline Membranes, Phoenix, AZ, April 1, 2016.
- Co-organizer (with Benny Freeman, UT Austin) for session on Energy - Membranes, Batteries, and Fuel Cells at Pacific Polymer Conference, Kauai, Hawaii, December 2015.
- Co-organizer (with Kenji Miyatake and Bryan Pivovar) – Pacificchem 2015 session on “Current Status and Future Prospect of Polymer Electrolyte Fuel Cells”, Honolulu, Hawaii, December 2015.
- Co-organizer (with Jeff McCutcheon, UConn and Lauren Greenlee, NIST) for American Chemical Society Polymer Chemistry Division Workshop Advances in Materials and Processes for Polymeric Membrane Mediated Water Purification, Asilomar CA, February 15-18, 2015.

- Co-organizer (with Benny Freeman, UT Austin) for session on Symposium on Advanced Polymer Materials: Membranes at 3rd US-Mexico Symposium on Advances in Polymer Science – MACROMEX 2014, Nuevo Vallarta, Mexico, December 6, 2014.
- Lead investigator on American Chemical Society Technical Division Innovative Project Grant on “Strengthening Division Activities by Outreach to Meeting Attendees and Engaging Students”. A \$5,000 society grant for innovative ideas in division activities.
- 2012-2015 – Elected by the division members to the POLY Executive Council as “Alternate Councilor” for the Polymer Division of the American Chemical Society.
- 2013-2016 – Selected by the Editor-in-Chief Tim Lodge to serve on Macromolecules and ACS Macro Letters Editorial Advisory Boards.
- 2011-2013 - Elected to the Center for Nanophase Materials Sciences User Executive Committee by vote of the user group at Oak Ridge National Laboratory.
- Co-organizer 6th international fuel cell workshop (IFCW) August 2nd and 3rd, 2012 Kofu Japan.
- Co-Organizer (with Michael Eikerling and Stephen Paddison) Pacifichem 2010 session on “The Chemistry, Structure, and Properties of Fuel Cell Membranes” Honolulu, Hawaii, December 2010.
- Session co-chair for numerous technical sessions at Electrochemical Society, American Chemical Society, and other technical meetings.
- Manuscript reviewer for Journal of Physical Chemistry, Angewandte Chemie, Journal of the American Chemical Society, Macromolecules, Industrial & Engineering Chemistry Research, Journal of Polymer Science and Engineering, Electrochimica Acta, Science, Fuel Cells, Applied Physics Letters, Nature Publishing Group, Journal of Membrane Science, Electrochemical and Solid- State Letters, Journal of the Electrochemical Society, International Journal of Hydrogen Energy, Journal of Power Sources, Polymer, Polymer International, ASME Journal of Fuel Cell Science and Technology.
- Proposal reviewer for NRC Canada, DOE Basic Energy Sciences, DOE Energy Efficiency and Renewable Energy, American Chemical Society Petroleum Research Fund, NSF Engineering Directorate and Division of Materials Research, American Association for the Advancement of Science, Danish Innovation Fund, National Center for Science and Technology – Kazakhstan, CRDF Global – a US non-profit.

University and Department Service

- MSU CHEMS/ECE Semiconductor Search Committee 2023-2024.
- MSU College of Engineering College Review Committee 2023-2024.
- MSU CHEMS Faculty Advisory Committee 2023-2024.
- MSU College of Engineering, Engineering Research Counsel 2023-2024.
- PSU EMS Faculty Performance Evaluation Committee 2019-2022.
- PSU MATSE Department Diversity Committee 2020-2022.
- PSU MATSE Department Graduate Recruiting Committee 2019-present.
- PSU Department of Chemical Engineering/PSIEE faculty search committee – 2019.
- PSU MATSE Faculty Search Committee – 2019.
- PSU MATSE Department Mentoring Committee 2017-2022.
- PSU MATSE Department Facilities Committee 2017-present.
- PSU MATSE Department Awards Committee 2016-present.
- PSU EMS faculty senator, sabbatical replacement appointment – 2016-2017.

- PSU Department of Chemistry faculty search committee – 2016-2018.
- PSU Undergraduate class adviser for MATSE – 2013-2018.
- PSU Materials Research Institute and MATSE Department strategic planning committees – 2015.
- PSU MATSE Department Steidle Building renovation committee – 2013-2015.
- PSU MATSE Department safety committee faculty chair – 2009-2015.
- PSU MATSE Department faculty search committee – Fall 2012 and Fall 2015.
- PSU Earth and Mineral Sciences College Faculty Advisory Committee member – 2011-2013.
- PSU MATSE Department undergraduate curriculum committee member - Core I, recommendations submitted to department chair – 2011.
- PSU Chemical Engineering Department faculty search committee – Fall 2008.
- PSU Nuclear and Mechanical Engineering Department faculty search committee – Spring 2008.
- PSU MATSE Department recruiting committee – 2007-2010.
- PSU MATSE Department Energy strategic planning subgroup, report submitted to department chair – 2008.

Awards

2019	PMSE Cooperative Research Award from the Polymeric Materials Science and Engineering Division of the American Chemical Society – with NIST and DOW team members.
2017	CRDF Global Visiting Scholar Sabbatical Fellowship at KAUST.
2017	Faculty mentoring award, Penn State College of Earth and Mineral Sciences.
2016-2019	Corning Faculty Fellow, Department of Materials Science and Engineering, The Pennsylvania State University.
2013	Rustum and Della Roy Innovation in Materials Research Award, The Pennsylvania State University.
2010-2013	Virginia S. and Philip L. Walker, Jr. Faculty Fellow, College of Earth and Mineral Sciences, The Pennsylvania State University.
2009	Presidential Early Career Award for Scientists and Engineers (PECASE) from DoD/ONR
2009	3M Non-tenured Faculty Grant.
2008	Students' Choice Faculty of the Year Award in Materials Science and Engineering Department, The Pennsylvania State University.
2008	U.S. Office of Naval Research Young Investigator Award.
2008	U.S. Army Research Office Young Investigator Award.
2008	Ralph E. Powe Junior Faculty Enhancement Award from Oak Ridge Associated Universities.
2004	R&D 100 Award for Proton Exchange Membrane Development with VT/Battelle Group.
Fall 2001	Richard A. Glenn Award for Best Paper in the Division of Fuel Chemistry at the National ACS Meeting, Chicago, IL.
2001	Omnova Solutions Graduate Student Signature Award.
1999–2002	Cunningham Doctoral Fellowship, Virginia Tech.
1999	Bredenkamp Award for Outstanding Unit Operations Team, Michigan Tech.
1999	Department Scholar – Chemical Engineering, Michigan Tech.
1998	AIChE Donald A. Othmer and Mildred Topp Othmer National Scholarship.

Professional Affiliations

- American Chemical Society
- Materials Research Society
- The Electrochemical Society

Peer-Reviewed Journal Publications

More than 29,000 citations as of February 2024 (Google Scholar)

Hirsch index = 84

<https://scholar.google.com/citations?user=RJHRgYQAAAAJ&hl=en>

Web of Science – more than 21,900 citations, Hirsch index = 75, Average citations per item = 69.35

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217. Rafalko, C., B. J. Stovall, T. Zimudzi, M. A. Hickner, “Tunable Stereolithography Photopolymerization Resin for Molding Water-Soluble Cavities,” *ACS Applied Polymer Materials* **2023**, 5 (12), 10097-10104.

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214. Liu, W., R. R. Campbell, M. Periyasamy, M. A. Hickner, “Additive manufacturing of silicone-thermoplastic elastomeric composite architectures,” *Journal of Composite Materials* **2022**, 5, 29, ASAP.

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Sheikhi “Ion exchange biomaterials to capture daptomycin and prevent resistance evolution in off-target bacterial populations,” *ACS Applied Materials & Interfaces* **2022**, 14 (38), 42864-42875.

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of water microenvironments in polyelectrolyte multilayers at varying temperatures,” *Soft Matter* **2020**, 16 (9), 2291-2300.

200. Zhu, L., X. Yu, X. Peng, T. J. Zimudzi, N. Saikia, M. T. Kwasny, Shaofei Song, Douglas I Kushner, Zhisheng Fu, Gregory N Tew, William E Mustain, Michael A Yandrasits, Michael A Hickner Poly (olefin)-Based Anion Exchange Membranes Prepared Using Ziegler–Natta Polymerization,” *Macromolecules* **2019**, 52, 11, 4030-4041.

199. Wang, X., R. Rossi, Z. Yan, W. Yang, M. A. Hickner, T. E. Mallouk, B. E. Logan, “Balancing water dissociation and current densities to enable sustainable hydrogen production with bipolar membranes in microbial electrolysis cells,” *Environmental Science & Technology* **2019**, 53, 24, 14761-14768.

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195. Lang, C., J. A. LaNasa, N. Utomo, Y. Xu, M. J. Nelson, W. Song, M. A. Hickner, R. H. Colby, M. Kumar, R. J. Hickey, “Solvent-non-solvent rapid-injection for preparing nanostructured materials from micelles to hydrogels,” *Nature Communications* **2019**, 10 (1), 1-10.

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- **Over 100 citations**
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- Review article with over 150 citations

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10. Every, H. A., M. A. Hickner, J. E. McGrath, T. A. Zawodzinski, "An NMR study of methanol diffusion in polymer electrolyte fuel cell membranes," *J. Membr. Sci.* **2005**, 250(1-2), 183-188.
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- Review article with over 1400 citations
8. Kim, Y. S., M. A. Hickner, L. Dong, B. S. Pivovar, J. E. McGrath, "Sulfonated poly(arylene ether sulfone) copolymer proton exchange membranes: composition and morphology effects on the methanol permeability," *J. Membrane Sci.* **2004**, 243(102), 317-326.
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- Over 100 citations
4. Kim Y. S., L. Dong, M. Hickner, B.S. Pivovar, J. E. McGrath, "Processing induced morphological development in hydrated sulfonated poly(arylene ether sulfone) copolymer membranes," *Polymer* **2003**, 44(19), 5729-5736.
3. Wang, F., M. Hickner, Y. Kim, T. Zawodzinski, J. E. McGrath, "Direct polymerization of sulfonated poly(arylene ether sulfone) random (statistical) copolymers: candidates for new proton exchange membranes," *J. Membr. Sci.* **2002**, 197, 231-242.
- Over 700 citations
2. O'Donnell, B.R., M. Hickner, B.A. Barna, "Economic risk analysis using analytical and monte carlo techniques," *Chem. Eng. Education* **2002**, 36(2).
1. Wang, F., M. Hickner, Q. Ji, W. Harrison, J.B. Mecham, T. Zawodzinski, J.E. McGrath, "Synthesis of highly sulfonated poly(arylene ether sulfone) random (statistical) copolymers via direct polymerization," *Macromolecular Symposia* **2001**, 175, 387.
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List of non-peer reviewed proceedings and conference papers with American Chemical Society and Electrochemical Society available on request.

Book Chapters

4. Pawar, M. S., Y. Zha, M. L. Disabb-Miller, Z. D. Johnson, M. A. Hickner, G. Tew, "Metal-ligand based anion exchange membranes," in Polymer Composites for Energy Harvesting, Conversion, and Storage, ACS Symposium Series Volume 1161, 127-146, eds L. Li, W. Wong-Ng and J. Sharp, American Chemical Society: Washington, DC, DOI: 10.1021/bk-2014-1161.ch006, Published July 7, 2014.
3. J. E. McGrath, M. A. Hickner, R. Höfer, Polymers for a Sustainable Environment and Green Energy, Vol. 10 in: K. Matyjaszewski, M. Möller (eds.) Polymer Science: A Comprehensive Reference, Elsevier, Amsterdam, Oxford, Waltham 2012.
2. M. A. Hickner, "Proton Exchange Membrane Nanocomposites" in Functional Polymer Nanocomposites for Energy Storage and Conversion, ACS Symposium Series Volume 1034, 155-170, eds Q. Wang and L. Zhu, American Chemical Society: Washington, DC, DOI: 10.1021/bk-2010-1034, Published March 11, 2010.
1. D. S. Hussey and M. A. Hickner, "Neutron Radioscopy: Industrial and Scientific Applications" in Encyclopedia of Analytical Chemistry, Eds. R.A. Meyers, John Wiley: Chichester, DOI: 9780470027318. Published 15th March 2010.

Patents

12. Periyasamy, M. R. R. Campbell, E. Sassano, W. J. Hajduczek, M. A. Hickner, L. Peeke, "Method For Forming Layered Thermoset Silicone and Thermoplastic Articles Using Additive Manufacturing, Articles Formed Therefrom and Apparatus for Use Therein," U.S. Patent App. 20210299949 filed September **2021**.
11. Yandrasits, M. A., C. A. Laskowski, T. M. Gillard, M. Hickner, L. Zhu, "Anion exchange membranes based on polymerization of long chain alpha olefins," US Patent App. 20210032378 filed February **2021**.
10. Rahn, C., C. Bakis, Y. Zhang, M. Hickner "Sandwich panels with battery cores," U.S. and international patent application filed January **2014**, application #US 20160351939.
9. Shelnutt, J. A., W. Li, Y. Song, M. A. Hickner, "Dendritic metal nanostructures for fuel cells and other applications" U.S. 8,574,789 **2013**.
8. Li, W., T. Kawamura, T. Nagami, H. Takahashi, J. Muldoon, J. A. Shelnutt, Y. Song, J. E. Miller, M. A. Hickner, C. Medforth, "Photocatalytic methods for preparation of electrocatalyst materials," U.S. 8,541,146 **2013**.
7. McGrath, J. E., M. Hickner, F. Wang, Y.-S. Kim, "Ion-conducting sulfonated polymeric materials," U.S. 8,383,763 **2013**.
6. Hibbs, M., C. H. Fujimoto, K. Norman, M. A. Hickner, "Epoxy-crosslinked sulfonated poly(phenylene) Copolymer Proton Exchange Membranes," U.S. 7,816,482 **2010**.
5. McGrath, J. E., M. Hickner, F. Wang, Y.-S. Kim, "Ion-conducting sulfonated polymeric materials," U.S. 7,361,729 **2008** and 7,790,837 **2010**; European patent, EP 1 327 278 B1.

4. McGrath, J. E., M. Hickner, “Sulfonated polymer composition for forming fuel cell electrodes,” U.S. 7,790,314 **2010** and 7,544,764 **2009**.
3. Cornelius, C. J., C. H. Fujimoto, M. A. Hickner, “Sulfonated polyphenylene polymers useful for polymer electrolyte membranes and nanocomposites,” U.S. 7,301,002 **2007**.
2. McGrath, J. E., M. Hickner, F. Wang, Y.-S. Kim, “Ion-conducting sulfonated polymeric materials,” Japan 2002-528869.
1. McGrath, J. E., M. Hickner, “Sulfonated polymer composition for forming fuel cell electrodes,” U.S. 7,544,764 and 7,790,314, Canadian patent 2,481,343.

Lectures and Conference Activities *denotes invited talks

205. * “The Effects of Water Binding and Morphology on Proton Transport in Polymer Membranes,” Invited lecture at General Motors, Pontiac MI, April 27, 2023.
204. * “Advanced Batteries and Graduate School: Where to Chemical Engineers Fit?,” Invited talk at 2023 MSU AIChE chapter meeting, East Lansing, MI, March 12, 2023.
203. * “Synthesis of Ion Exchange Membranes for Large-Scale Energy Conversion and Storage,” Invited talk at 2022 AIChE Annual Meeting, Polymer Synthesis and Reaction Engineering session, Phoenix, AZ November 14, 2022.
205. * “3D Printed Membranes for Next-Generation Energy and Water Applications,” Invited talk at The ASTM International Conference on Additive Manufacturing (ICAM 2022), Orlando, FL November 1, 2022.
204. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at University of Illinois Chicago, Department of Chemical Engineering, Chicago, IL October 27, 2022.
203. * “Asymmetric Transport in Bipolar Membranes,” Invited talk at Polymers for Fuel Cells, Energy Storage, and Conversion, an ACS Polymer Chemistry Division workshop, Napa, CA, May 16th, 2022.
202. * “Novel Membranes and Ionomers,” Invited talk at DOE H2-AMP Workshop, Online, March 20, 2022.
201. * “Transport in Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited talk at American Physical Society March Meeting, Transport in Polymers, DPOLY Division, Chicago, IL March 14, 2022.
200. * “3D Printed Polymer Membranes,” Invited lecture at Penn State University, EMS 125th Anniversary Symposium, University Park, PA April 10, 2021.
199. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at Bucknell University, Department of Chemical Engineering, Lewisburg, PA February 12, 2021.
198. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture for Penn State Electrochemistry Club, University Park, PA December 14, 2020.

197. **“Polyolefin Anion Exchange Membranes,”* Invited talk at American Chemical Society Spring 2020 National Meeting & Expo, Designing Polymers for Electrochemical Energy Conversion & Storage, PMSE Division, Philadelphia, PA April 30, 2020.
196. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at Virginia Tech, Department of Chemistry, Blacksburg, VA February 27, 2020.
195. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at Michigan State University, Department of Chemical Engineering and Materials Science, East Lansing, MI February 21, 2020.
194. **“Polymers Containing Acidic or Basic Groups,”* Invited talk at Toyota Research Center, Ann Arbor, MI December 20, 2019.
193. **“Polymers Containing Acidic or Basic Groups,”* Invited talk at The University of Pennsylvania, Advanced Membrane Workshop, Philadelphia, PA December 17, 2019.
192. **“Ion-Conducting Membranes for Large-Scale Energy Storage,”* Invited talk at Materials Research Society Fall 2019 National Meeting, Session on Advanced Membranes for Energy-Efficient Molecular Separation and Ion Conduction, Boston, MA December 2, 2019.
191. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at University of Wyoming, Department of Mechanical Engineering, Laramie, WY October 31, 2019.
190. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Keynote lecture at 5th International Symposium on Energy Chemistry & Materials, Fudan University, Shanghai, China October 20th, 2019.
189. * *“Polyolefin Anion Exchange Membranes: Fundamentals, Membranes, and Devices,”* Invited lecture at Cornell University, Center for Alkaline-Based Electrochemical Systems, Ithaca, NY October 11, 2019.
188. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at Louisiana State University, Department of Chemical Engineering, Baton Rouge, LA September 13, 2019.
187. **“Using quantitative IR spectroscopy to probe thin polymer films,”* Invited talk at American Chemical Society Spring 2019 National Meeting & Expo, Young Industrial Polymer Scientist Award Symposium, POLY Division, San Diego, CA August 27, 2019.
186. **“Toughening Anion Exchange Membranes,”* Invited talk at American Chemical Society Spring 2019 National Meeting & Expo, Toughening of Networks & Gels through Molecular Design, PMSE Division, San Diego, CA August 27, 2019.
185. **“New Polymer Structures for Anion Exchange Membranes,”* Invited talk presented at the 235th Meeting of the Electrochemical Society, An Invited Symposium on Advances and Perspectives on Modern Polymer Electrolyte Fuel Cells, Dallas, TX, May 29th, 2019.
184. **“Membrane Design Principles and Characterization Methods,”* Roundtable on Ion Selective Membranes in CO₂ Electrolysis, CIFAR Symposium, Pittsburg PA May 15, 2019.
183. *“Using quantitative IR spectroscopy to probe thin polymer films,”* Invited talk at American Chemical Society Spring 2019 National Meeting & Expo, Cooperative Research Award Symposium, PMSE Division, Orlando, FL April 3, 2019.

182. **“New ion transport membranes for large-scale energy storage,”* Invited talk at American Chemical Society Spring 2019 National Meeting & Expo, Transport in Polymer Membranes, POLY Division, Orlando, FL April 2, 2019.
181. **“Ionic Materials - Applications and Future Prospects,”* Invited talk at American Chemical Society Spring 2019 National Meeting & Expo, ACS Award in Applied Polymer Science Symposium, PMSE Division, Orlando, FL April 1, 2019.
180. **“Polyolefin-based Anion Exchange Membranes,”* Invited talk at Polymers for Fuel Cells, Energy Storage, and Conversion, an ACS Polymer Chemistry Division workshop, Asilomar, CA, Feb. 25th, 2019.
179. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at New York University, Department of Chemical Engineering, New York, NY October 12th, 2018.
178. **“The Effects of Water Binding and Morphology on Proton Transport in Polymer Membranes,”* Invited talk presented at the AiMES 2018 Joint International meeting of ECS and SMEQ, Cancun, Mexico, October 3rd, 2018.
177. **“Designing Hydroxide-Conducting Polymer Membranes,”* Invited presentation at 19th Solid State Proton Conductors, Stowe, VT Sept 19, 2018.
176. **“Polymers Containing Acidic and Basic Groups,”* Invited lecture at Case Western Reserve University, Department of Macromolecular Science and Engineering, Cleveland, OH September 7, 2018.
175. * *“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at Case Western Reserve University, Department of Chemical Engineering, Cleveland, OH September 6, 2018.
174. **“Polyolefin-Based Anion Exchange Membranes,”* Invited presentation at 16th International Symposium on Polymer Electrolytes, Yokohama, Japan June 26, 2018.
173. **“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at Tokyo Institute of Technology, Department of Chemical Engineering, Yokohama, Japan June 22, 2018.
172. * *“Polymers Containing Acidic and Basic Groups,”* Invited lecture at UT Austin, Department of Chemical Engineering, Austin, Texas December 13, 2017.
171. * *“Toughening Anion Exchange Membranes,”* Invited talk at 4th US-Mexico Symposium on Advances in Polymer Science – MACROMEX 2017, Los Cabos, Mexico, December 5, 2017.
170. * *“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited lecture at Texas A&M University, Department of Chemical Engineering, College Station, Texas November 3, 2017.
169. * *“Membranes With Tethered Basic Groups,”* Invited lecture at King Abdullah University of Science and Technology (KAUST), Advanced Membranes and Porous Materials (AMPM) Center, Thuwal, Saudi Arabia, October 10, 2017.
168. * *“Micropatterned Membranes for Energy, Water, and Separation Applications,”* Invited lecture at SABIC Advanced Manufacturing Seminar, Plastic Applications Development Center (SPADC), Riyadh, Saudi Arabia, Oct 2, 2017.
167. * *“Polymer Membranes for Large-Scale Energy Conversion and Storage,”* Invited presentation at Arkema, King of Prussia, PA August 31, 2017.

166. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited presentation at 21st International Conference on Solid State Ionics, Padova, Italy June 15, 2017.
165. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at 3M Company, St. Paul, Minnesota June 12, 2017.
164. * “3D Printing of Micro-patterned Anion Exchange Membranes for Green Energy and Clean Water Applications,” Invited lecture at Polytechnic University of Milan, Department of Energy, Milan, Italy May 22, 2017.
163. * “Additive Manufacturing Technologies for Polymer Membranes,” Invited lecture at European Polymer Forum 8th Summer School on Transport Phenomena in Polymers and Hybrid Materials, Gragnano, Italy May 19, 2017.
162. * “3D Printing of Functional Micro-Patterned Membranes for Water and Energy Applications,” Introductory Speaker for the Taylor Lecture, Department of Materials Science and Engineering, University Park, PA, April 27, 2017.
161. * “Structured Anion Exchange Membranes,” Invited talk at CARISMA 2017 – European Coordination Fuel Cell Network Conference, Newcastle, UK, April 10th, 2017.
160. * “New Membranes for Aqueous Batteries,” Invited talk at International Battery Seminar, Flow Batteries – Deliver the Right Charge at the Right Time, Ft. Lauderdale, FL, March 23rd, 2017.
159. * “New Polymer Structures for Anion Exchange Membranes,” Invited talk at APS March Meeting, Ion Containing Polymers - The Role of Structure and Dynamics I, New Orleans, LA, March 13th, 2017.
158. * “3D Printing of Micro-patterned Anion Exchange Membranes for Green Energy and Clean Water Applications,” Invited lecture at Michigan State University, Department of Chemical Engineering, East Lansing, Michigan March 2, 2017.
157. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited talk at Advances in Polymers for Fuel Cells, Energy Storage, and Conversion, an ACS Polymer Chemistry Division workshop, Asilomar, CA, Feb. 26th, 2017.
156. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at Dalian University of Technology, Department of Chemical Engineering, Dalian, China December 12, 2016.
155. * “Designing Ion Exchange Membranes for New Energy and Clean Water Processes,” Invited lecture at Tsinghua University, Department of Environmental Science, Beijing, China December 9, 2016.
154. * “Crosslinked Anion Exchange Membranes,” Invited talk at Beijing Forum 2016 on Electrochemical Frontier, Wuhan University, Wuhan, China December 7, 2016.
153. * “New Designs for Anion Conducting Membranes,” Keynote talk 2016 AIChE Annual Meeting, Session on Membrane and Direct Methanol Fuel Cells, San Francisco, CA November 14, 2016.
152. * “Polymer Membranes for Large-Scale Green Energy and Clean Water Technologies,” DeNora N.A. Research Symposium, Cleveland, OH November 10, 2016.
151. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at Drexel University, Department of Materials Science and Engineering, Philadelphia, PA October 26, 2016.

150. * “Membranes and Water,” Invited lecture at The Millennium Cafe, Materials Research Institute, University Park, PA October 11, 2016.
149. * “3D Printing of Micro-patterned Anion Exchange Membranes,” Invited lecture at The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA September 14, 2016.
148. * “Ion-Conducting Polymers for Green Energy and Clean Water Applications,” Invited lecture at The Pennsylvania State University, Department of Materials Science and Engineering, University Park, PA September 15, 2016.
147. * “Composition and Alignment in Layer-by-layer Polyamide Thin Films,” Invited talk at 252nd American Chemical Society Fall 2016 National Meeting & Exposition, Polymer Science at the Interface of Industry, Government & Academics Session, Philadelphia, PA August 24, 2016.
146. “3D Printing of Micro-patterned Anion Exchange Membranes,” Invited talk at 252nd American Chemical Society Fall 2016 National Meeting & Exposition, Polymers Designed for 3D Printing Applications: Evaluation of the Fundamental & Applied Aspects of the Field Session, Philadelphia, PA August 22, 2016.
145. “Crosslinked Anion Exchange Membranes with Complex Structures,” International Symposium on Polymer Electrolytes, ISPE-15, Uppsala, Sweden August 15-19, 2016.
144. * “Nanostructured Anion Exchange Membranes,” Invited talk at MRS 2016 Spring Meeting & Exhibit, Phoenix, AZ March 28-April 1, 2016.
143. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at Arizona State University, School for Engineering of Matter, Transport and Energy, October 15th, 2015.
142. * “New Polymer Structures for Anion Exchange Membranes,” Invited talk presented at the 228th Meeting of the Electrochemical Society, Phoenix, AZ, October 14th, 2015.
141. * “Synthesis of Cationic Polymers for Membrane Applications,” Invited talk at Center for Nanophase Materials Sciences User Meeting, Oak Ridge, TN, Sept. 2nd, 2015.
140. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at Ohio University, Department of Chemical and Biomolecular Engineering, Athens, OH, Aug. 31st, 2015.
139. * “Ion Transport in Functionalized Polymers,” Invited talk at Center for Nanophase Materials Sciences, Oak Ridge, TN, May 14th, 2015.
138. * “Polymers in Additive Manufacturing - Materials and Processes,” Invited seminar at Center for Innovative Materials Processing by Direct Deposition (CIMP-3D), The Pennsylvania State University, Mar. 3rd, 2015.
137. * “Anion Exchange Membranes for Energy Applications,” Invited talk at Advances in Polymers for Fuel Cells and Energy Devices, an ACS Polymer Chemistry Division workshop, Asilomar, CA, Feb. 9th, 2015.
136. * “Anion Exchange Membranes for Energy Applications,” Invited talk at 3rd US-Mexico Symposium on Advances in Polymer Science – MACROMEX 2014, Nuevo Vallarta, Mexico, December 6, 2014.

135. * “Anion Exchange Membranes for Energy Applications,” Invited lecture at Yamanashi University, Fuel Cell Nanomaterials Center, Kofu, Japan, November 10, 2014.
134. * “Polymer Membranes for Large-Scale Energy Conversion and Storage,” Invited lecture at Boston University, Department of Materials Science and Engineering, Boston, MA, November 7, 2014.
133. * “Acidity and Morphology in Proton-Conducting Membranes,” Invited lecture at Carnegie Mellon University, Department of Chemical Engineering, Pittsburgh, PA, October 28, 2014.
132. * “Anion Exchange Membranes for Ammonium Bicarbonate-based Reverse Electrodialysis,” Invited lecture at Clemson University, Department of Chemical Engineering, Clemson, SC, October 9, 2014.
131. * “Anion Exchange Membranes for Ammonium Bicarbonate-based Reverse Electrodialysis,” Invited lecture at Hanyang University, Department of Energy Engineering, Seoul, South Korea, September 17, 2014.
130. * “Headgroup Acidity Effects in Proton Exchange Membrane Performance,” Keynote speech Solid State Protonic Conductors – 17 (SSPC-17), Korea Institute of Science and Technology (KIST), Seoul, South Korea, September 16, 2014.
129. “Acidic Polymers and Basic Polymers: Materials Synthesis and Mechanistic Analysis,” MATSE 590 seminar at Penn State University, Department of Materials Science and Engineering, University Park, PA, September 11, 2014.
128. * “Water Hydrogen Bonding in Functionalized Membranes,” Invited talk at 248th American Chemical Society Fall 2014 National Meeting & Exposition, Transport in Polymer Membranes Session, San Francisco, CA August 13, 2014.
127. * “Hydration, Conductivity, and Stability of Anion Exchange Membranes,” Invited lecture at the Gordon Research Conference on Fuel Cells, Smithfield, RI, August 6, 2014.
126. * “Membranes for Ammonium Bicarbonate-based Reverse Electrodialysis,” Keynote lecture at the International Conference on Membranes (ICOM) 2014, Suzhou, China, July 24, 2014.
125. * “Polycondensation for High Performance Fuel Cells,” Invited lecture at the American Chemical Society Polymer Chemistry Division Workshop - From Anionic Polymerization to Aerospace Materials to Membranes, Cetraro, Italy, June 30, 2014.
124. * “Designing Ion Exchange (Polymers and) Membranes for New Energy Processes,” Invited lecture at the North American regional meeting of the International Society for Electrochemistry and Microbiology (ISMET), The Pennsylvania State University, University Park, PA, May 15, 2014.
123. * “Ion-Containing Polymers for New Energy and Clean Water,” Keynote lecture at The 16th Israel Materials Engineering Conference (IMEC16), Technion – Israel Institute of Technology, Haifa, Israel, February 24-25, 2014.
122. * “Anion Exchange Membranes – Fundamental Polymer Properties and Performance in Pure Water Systems,” Invited lecture at Daihatsu Motor Company, Ryuo, Shiga Prefecture, Japan, December 18th, 2013.
121. * “Superacid Aromatic Membranes and Thin Ionomer Films,” Invited lecture at Nissan Motor Company Automotive Research Center, Yokosuka, Japan, December 16th, 2013.

120. * “Underlying Factors Governing Membrane Resistance and Permselectivity,” Invited lecture at Francqui Symposium: Recent Advances in Microbial and Enzymatic Electrocatalysis, Ghent University, Ghent, Belgium, Nov. 22, 2013.
119. * “Stability of Anion Exchange Membranes,” Invited lecture at 7th Santa Fe Workshop on Materials for Energy Conversion, Alkaline Membrane Fuel Cells, Bishop’s Lodge, NM, November 4-5, 2013.
118. * “Cationic Polymers for Anion Exchange Membranes,” Invited lecture at Rensselaer Polytechnic Institute, Department of Chemistry, Troy, NY, October 22nd, 2013.
117. * “Ion Exchange Membranes for New Energy and Clean Water,” Plenary Lecture, The Pennsylvania State University, Materials Day 2013 – Converging on Materials, October 16, 2013.
116. * “Water Binding Interactions in Superacid Proton Exchange Membranes,” Invited lecture at Norwegian University of Science and Technology (NTNU), PEM 2013 International Workshop, Trondheim, Norway, October 3-4, 2013.
115. * “Ion Mobility in Anion Exchange Membranes,” Invited lecture at University of Surrey, Anion-Exchange Membranes for Energy Generation Technologies Workshop, Guildford, England, July 25, 2013.
114. * “Ion-Containing Polymers in Energy and Water Applications,” Invited lecture at University of Massachusetts Amherst, Polymer Science and Engineering Department, Amherst, MA, May 23, 2013.
113. “Effects of Membrane Thickness on the Performance of Vanadium Redox Flow Batteries,” Contributed talk presented at the 223rd Meeting of the Electrochemical Society, Toronto, CA, May 14th, 2013.
112. “Anion Exchange Membranes for Vanadium Redox Flow Batteries,” Contributed talk presented at the 223rd Meeting of the Electrochemical Society, Toronto, CA, May 14th, 2013.
111. * “Designing New Ionic Polymers for Electrochemical Applications,” Invited lecture at Wuhan University, Department of Chemistry, Wuhan, China, May 23, 2013.
110. * “Anion Exchange Membranes for Energy Applications,” Invited lecture at Sun Yat-sen University, Department of Chemical Engineering, Guangzhou, China, March 19, 2013.
109. * “Using Infrared Spectroscopy to Learn about Water Treatment Membranes,” Invited talk at Advances in Materials and Processes for Polymeric Membrane Mediated Water Purification, an ACS POLY Division workshop, Pacific Grove, CA, Feb. 25, 2013.
108. * “Anion Exchange Membranes,” Advances in Materials for Proton Exchange Membrane Fuel Cell Systems, an ACS POLY Division workshop, Pacific Grove, CA, Feb. 20, 2013.
107. * “Cationic Polymers for Platinum-Free Fuel Cells,” Invited lecture at IPC 2012, The 9th SPSJ International Polymer Conference, Kobe, Japan, December 13, 2012.
106. * “Thin Ion-Containing Polymer Films,” Invited lecture at Texas A&M University, Materials Science and Engineering Program, College Station, TX, October 26, 2012.
105. * “Side Chain Functionalized Aromatic Polymers,” Invited talk at 244th American Chemical Society Fall 2012 National Meeting & Exposition, Journal of Polymer Science Award: Symposium in Honor of Christopher Bielawski, Philadelphia, PA August 20, 2012.

104. * “Tuning Polymer Nanophase Morphology for Higher Performance in Vanadium Redox Flow Batteries,” Invited talk at 244th American Chemical Society Fall 2012 National Meeting & Exposition, WCU International Symposium on Energy Storage and Conversion, Philadelphia, PA August 20, 2012.
103. * “Polymer membranes for new batteries and fuel cells,” Invited talk at 244th American Chemical Society Fall 2012 National Meeting & Exposition, Polymer Science of Everyday Things, Philadelphia, PA August 19, 2012.
102. * “New Polymers for Electrochemical Energy Conversion and Storage,” Invited lecture at Penn State-University of Freiburg Symposium on Energy Conversion, Freiburg University, Freiburg, Germany, July 13, 2012.
101. * “Using Lessons of Fuel Cell Membranes to Design Polymers for Energy Storage Applications,” Green Energy Conversion Science and Technology, University of Yamanashi, Kofu Japan, August 1, 2012.
100. * “Water-polymer interactions in cation and anion conducting membranes,” Invited lecture at Macro 2012 - IUPAC World Polymer Congress, Blacksburg, VA, June 25th, 2012.
99. * “Water Dynamics in Thin Polymer Films,” Invited lecture at Dow Water Solutions, Edina, MN, June 19, 2012.
98. * “Designing New Ionic Polymers for Electrochemical Applications,” Invited lecture at Technion – Israel Institute of Technology, Department of Materials Science and Engineering, Haifa, Israel, June 7, 2012.
97. * “New Polymer Membranes for Redox Flow Batteries and Fuel Cells,” Invited lecture at University of Rochester, Rochester Advanced Materials Program Nanomaterials 2012, Rochester, NY, May 21, 2012.
96. * “Ion and Water Motion in Self-Assembled Polymers,” Invited lecture at Carnegie Mellon University, Department of Chemistry, Pittsburgh, PA, April 20, 2012.
95. * “Electrostatically Assembled Mixed Charge Multilayers for Antifouling Applications,” Invited lecture at Dow Chemical Company for the Dow Discussion Group on Interfacial Science, Midland, MI, April 11, 2012.
94. * “Ion and Water Motion in Self-Assembled Polymers,” Introductory Speaker for the Taylor Lecture, Department of Materials Science and Engineering, University Park, PA, April 5, 2012.
93. * “Synthesis and Degradation of Anion Exchange Membranes,” Invited talk at 243rd American Chemical Society Spring 2012 National Meeting & Exposition, Materials and Catalysis in Fuel Cells, San Diego, CA March 27th, 2012.
92. * “Aromatic Ion-Conducting Membranes,” Invited lecture at WL Gore & Associates, Newark, DE, March 6, 2012.
91. * “Thin Ion-Containing Polymer Films,” Invited lecture at National Institute of Standards and Technology, Boulder, CO, Feb. 10, 2012.
90. * “New Polymers for Water Treatment and Energy Storage,” Invited lecture at King Abdulla University of Science and Technology (KAUST), Saudi Arabia, Jan. 22, 2012.

89. * “Polymer Assemblies for Ion Transport and Anti-fouling Surfaces,” Invited lecture at Penn State University, Department of Civil and Environmental Engineering, University Park, PA, Jan. 18, 2012.
88. * “Water in Ion-Containing Polymer Membranes,” Invited lecture at Penn State University, Department of Chemical Engineering, University Park, PA, Jan. 12, 2012.
87. * “Ion-Conducting Polymers for Electrochemical Applications,” Invited lecture at Queen’s University, Department of Chemical Engineering, Kingston, ON Canada, Nov. 17, 2011.
86. * “Water in Ion-Containing Polymers,” Invited lecture at University of Akron, Department of Polymer Engineering, Akron, OH, Oct. 21, 2011.
85. * “Block Copolymers for Fast Ion Transport,” Invited lecture at Michigan Technological University, Department of Chemistry, Houghton, MI, Oct. 14, 2011.
84. * “Block Copolymers for Fast Ion Transport,” Invited lecture at Case Western Reserve University, Department of Macromolecular Science and Engineering, Cleveland, OH, Sept. 30, 2011.
83. * “Surface charge and molecular adsorption on poly(ethylene oxide)-containing multilayer assemblies,” Invited talk at 242nd American Chemical Society Fall 2011 National Meeting & Exposition, Polyelectrolyte Complexes and Multilayers, Denver, CO Sept. 1st, 2011.
82. * “Structure property relationships of anion exchange membranes,” Invited talk at 242nd American Chemical Society Fall 2011 National Meeting & Exposition, Fuel Cells Chemistry and Operation, Denver, CO Aug. 29th, 2011.
81. * “Block Copolymers as Ion Transport Membranes,” Invited lecture at Clark University, Department of Chemistry, Worcester, MA, April 6, 2011.
80. * “Ionic nanopores as ion and water transport pathways in polymer membranes,” Invited talk at American Chemical Society Spring 2011 National Meeting & Exposition, Aerogels, Foams, and other Nanoporous Materials, Anaheim, CA, March 29th, 2011.
79. * “Designing selective membranes for energy storage applications,” Invited talk at American Chemical Society Spring 2011 National Meeting & Exposition, Polymers for Energy Storage and Delivery, Anaheim, CA, March 29th, 2011.
78. * “Surface Charge and Fouling of Ion-Containing Nanofiltration Membranes and Coatings,” Invited talk at Advances in Materials and Processes for Polymeric Membrane Mediated Water Purification, an ACS POLY Division workshop, Pacific Grove, CA, Feb. 28, 2011.
77. * “Block Copolymers as Ion Transport Membranes,” Invited lecture at Colorado School of Mines, Department of Chemistry, Golden, CO, Feb. 25, 2011.
76. * “Ion-Conducting Polymers for Electrochemical Applications,” Invited talk at Golden Gate Polymer Forum, Mountain View, CA, Feb. 23, 2011.
75. * “Block Copolymers for Ion-Conducting Membranes,” Advances in Materials for Proton Exchange Membrane Fuel Cell Systems, an ACS POLY Division workshop, Pacific Grove, CA, Feb. 22, 2011.
74. * “Hydration and Nanostructure in Ion-Containing Polymers,” Invited lecture at University of Nevada Las Vegas, Department of Chemistry, Las Vegas, NV, Oct 13th, 2010.

73. * “Mechanisms of Morphology and Water Motion in Proton Exchange Membranes,” Plenary lecture at 218th Meeting of the Electrochemical Society Meeting, Las Vegas, NV, Oct 11th, 2010.
72. * “Liquid-Like Conductivity in a Solid Polymer: Features of Fast Ion Conduction,” Invited lecture at Pennsylvania State University, Department of Chemistry – Analytical Division, State College, PA, September 29th, 2010.
71. “Ion and Water Motion in Anion Exchange Membranes,” Contributed talk presented at Progress MEA 2010 - CARISMA meeting, La Grande Motte, France, Sept. 13th, 2010.
70. * “Designing Polymers for Fast Ion Transport,” Invited lecture at University of Wisconsin Madison, Department of Materials Science and Engineering, Madison, WI, September 16th, 2010.
69. * “Poly(thiophene)/Carbon Nanotube Composites for Solar Cells,” Invited lecture at the Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Users Week, September 14th, 2010.
68. “Anion and Water Mobility in Poly(sulfone) Anion Exchange Membranes,” Contributed talk at the 12th International Symposium on Polymer Electrolytes, Padova, Italy, Aug. 31st, 2010.
67. * “Nanostructured Polymeric Membranes for Fuel Cell and Water Treatment Applications,” Invited lecture at ACS Fall National Meeting, WCU International Symposium on Energy Storage and Conversion, Boston, MA, August 22nd, 2010.
66. * “The Role of Water in Proton Exchange Membranes,” Invited lecture at 1st International Summer Seminar for Young Scientists, Lake Kawaguchiko, Japan, Aug. 19th, 2010.
65. * “Ion-Conducting Membranes for Electrochemical Applications,” Invited lecture at Pacific Northwest National Laboratory, Richland, WA, Aug. 16th, 2010.
64. * “Poly(thiophene)-Carbon Nanotube Composites for Solar Cells,” Invited lecture at Illinois Institute of Technology, Department of Chemical Engineering, Chicago, IL, April 21st, 2010.
63. * “Poly(thiophene)-Carbon Nanotube Composites for Solar Cells,” Invited talk at Polymer Nanocomposites 2010, Lehigh University, Bethlehem, PA, March 9th, 2010.
62. * “Polymer-Water Interactions and Transport Properties in Fuel Cell and Reverse Osmosis Membranes,” Invited lecture at Drexel University, Department of Chemical Engineering, Philadelphia, PA, Jan. 15th, 2010.
61. * “Polymers, Water, and Ions: Interesting Observations on Morphology, Diffusion, and Conductivity,” Invited talk at the National Institute of Standards and Technology, Gaithersburg, MD, Jan. 14th, 2010.
60. * “Interactions Between Ion-containing Polymers and Water - Applications Towards Water Treatment Membranes and Antifouling Surfaces,” Invited talk at the Naval Research Lab, Washington, DC, Jan. 12th, 2010.
59. * “Ion-Containing Polymers and Their Interactions with Water,” Invited lecture at Rochester Institute of Technology, Department of Chemistry, Rochester, NY, Jan. 5th, 2010.
58. “Morphology Control in Mid-block Sulfonated Triblock Copolymers,” Contributed talk at MRS Fall Meeting, Boston, Nov. 30th 2009.

57. * “Well-controlled Block Copolymer Architectures for Ion-conducting Membranes,” Invited talk at LANL-NEDO-AIST workshop, Palm Springs, CA, Nov. 19th, 2009.
56. * “Thiophene Polymerization and Polythiophene-Carbon Nanotube Composites for Solar Cells,” Invited talk at Waseda University, Department of Chemistry, Tokyo, Japan August 22nd, 2009.
55. * “Anion Exchange Membranes for Electrochemical Applications,” Invited talk at Polymer Batteries and Fuel Cells 2009, Yokohama, Japan, Aug. 6th, 2009.
54. * “Proton and Anion Exchange Membranes for Electrochemical Applications: Nanophase Structure and Ion-Transport,” Invited talk at Waseda University, Department of Chemistry, Tokyo, Japan August 5th, 2009.
53. * “Structured Poly(thiophene)/Carbon Nanotube Thin Films for Organic Photovoltaic Applications,” Invited lecture at Virginia Tech Polymer Alumni Symposium, Blacksburg, VA July 17th, 2009.
52. * “Morphology and Transport Properties of Anion and Cation Exchange Membranes,” Invited lecture at 3M Corporation Tech Forum for Polymers and Energy, St. Paul, MN, June 16th, 2009.
51. * “Ion-Containing Polymers and Their Application Towards Water Treatment,” Invited lecture at Dow Water Solutions, Edina, MN, June 15th, 2009.
50. * “Synthesis, Structure, and Properties of Ion-Containing Polymers,” Invited lecture at WL Gore & Associates, Newark, DE, May 13th, 2009.
49. * “Morphology and Transport Properties of Ion-Containing Polymers,” Invited lecture at the Army Research Lab, Aberdeen Proving Grounds, MD, April 21st, 2009.
48. * “Transport Properties of Proton Exchange Membrane Nanocomposites,” Invited talk at American Chemical Society Spring 2009 National Meeting & Exposition, Functional Polymer Nanocomposites for Energy Storage and Conversion, Salt Lake City, UT, March 23rd, 2009.
47. “Efficient Synthesis and Properties of Anion Exchange Membranes,” Contributed talk at American Chemical Society Spring 2009 National Meeting & Exposition, Ion-containing Polymers for New Technologies, Salt Lake City, UT, March 22nd, 2009.
46. * “Ion-Containing Polymers: Cutting-Edge Energy Applications Enabled by Insights into Chemistry, Morphology, and Transport Properties,” Invited talk at the joint meeting of the Polymers and Power/Energy panels of the Materials group of the Technical Cooperation Program (TTCP), Victoria, BC, March 10th, 2009.
45. * “Nanostructured Polymers: Using Chemistry and Morphology to Tune Transport Properties,” Invited lecture at Oak Ridge National Laboratory, Center for Nanophase Materials Sciences, Oak Ridge, TN, March 4th, 2009.
44. * “Cation and Anion Transport in Functionalized Polymers,” Invited lecture at University of Tennessee, Knoxville, Department of Chemical & Biomolecular Engineering, Knoxville, TN, March 3rd, 2009.
43. * “Flux and Rejection in Ion-containing and Surface-modified Polymer Membranes,” Invited talk at Advances in Materials and Processes for Polymeric Membrane Mediated Water Purification, an ACS Polymer Chemistry Division workshop, Asilomar, CA, Feb. 23rd, 2009.

42. * “Water Binding and Transport in Anionic and Cationic Membranes,” Invited talk at Advances in Materials for Proton Exchange Membrane Fuel Cell Systems, an ACS Polymer Chemistry Division workshop, Asilomar, CA, Feb. 16th, 2009.
41. * “Functional Materials for Fuel Cells,” Invited lecture for ASM Local Chapter, University Park, PA, Jan. 20th, 2009.
40. “Water uptake characteristics and backbone flexibility of novel polymers for proton exchange membranes,” Contributed talk presented at the Electrochemical Society Fall Meeting, Honolulu, HI, Oct. 15th, 2008.
39. “Water Uptake and Transport in Flexible Proton Exchange Membrane Networks,” Contributed talk presented at Progress MEA 2008 - CARISMA meeting, La Grande Motte, France, Sept. 22nd, 2008.
38. * “Functionalized Polymers for Fuel Cells,” Invited lecture at The Pennsylvania University, Department of Engineering Science and Mechanics, University Park, PA, Sept. 17th, 2008.
37. * “Cation and Anion Transport in Fuel Cell Membranes,” Invited lecture at University of Connecticut, Polymer Program, Storrs, CT, Sept. 12th, 2008.
36. “Bulk Heterojunction Morphology Control by Electro-deposition of Polythiophene,” Physical Chemistry of Interfaces and Nanomaterials VII, SPIE NanoScience + Engineering, San Diego, CA, Aug. 11th, 2008.
35. * “Cation and Anion Transport in Functionalized Polymers,” Invited lecture at University of Yamanashi, Clean Energy Research Center, Kofu, Japan, July 7th, 2008.
34. * “Polymers with Tethered Anionic and Cationic Groups as Membranes for Fuel Cells,” Invited lecture at Macro 2008, 42nd IUPAC World Polymer Congress, Taipei, Taiwan, July 1st, 2008.
33. * “Ion Transport Membranes,” Invited lecture at Virginia Tech, Macromolecules and Interfaces Institute, Blacksburg, VA, April 23rd, 2008.
32. * “Fuel Cells,” Materials Day Tutorial, The Pennsylvania State University, University Park, PA, April 14th, 2008.
31. * “Polymers for Fuel Cells,” American Chemical Society Spring 2008 National Meeting & Exposition, ACS Award in Polymer Chemistry: Symposium in Honor of James McGrath, New Orleans, LA, April 8th, 2008.
30. * “Membranes for Acidic and Basic Fuel Cells: Examples, Limits, and Directions,” NRC Institute for Fuel Cell Innovation, US-Canada Fuel Cell Workshop, Vancouver, BC, Canada, March 16th, 2008.
29. * “Morphology and Transport in Ion-containing Polymers,” Invited lecture at University of Illinois at Urbana-Champaign, NSF STC WaterCAMPWS, Champaign, IL, March 7th, 2008.
28. * “Cation and Anion Transport in Functionalized Polymers,” Invited lecture at Colorado School of Mines, Department of Chemical Engineering, Golden, CO, Jan. 18th, 2008.
27. * “Functional Polymers: Transport and Nanophase Morphology for Fuel Cell Applications,” Invited lecture for Materials Advantage, University Park, PA, Sept. 10th, 2007.
26. * “Neutron Imaging of Liquid Water in Fuel Cells,” Invited talk at the Gordon Research Conference – Fuel Cells, Smithfield, RI, July 22-27, 2007.

25. * “Neutron Imaging of Liquid Water Transport in Proton Exchange Membrane Fuel Cells: Heat Transfer and Fluid Dynamics,” Invited lecture at Michigan Technological University, Department of Mechanical Engineering, Houghton, MI, Nov. 30th, 2006.
24. * “Neutron Imaging Studies of Liquid Water Transport in PEM Fuel Cells,” Invited lecture presented to the San Francisco Local Section of the Electrochemical Society, Berkeley, CA, Nov. 20, 2006.
23. Hickner, M., N. Siegel, K. Chen, D. Hussey, D. Jacobson, M. Arif, “Neutron Imaging Studies of Water and Heat Transport in PEM Fuel Cells,” Contributed talk presented at the Fuel Cell Seminar & Exhibition, Honolulu, HI, Nov. 13–17, 2006.
22. Hickner, M., N. P. Siegel, K. Chen, D. Hussey, D. Jacobson, M. Arif, “Exploring Liquid Water Distribution and Local Heating Effects in an Operating PEM Fuel Cell,” Contributed talk at the World conference on neutron radiography, National Institute of Standards and Technology Gaithersburg, MD, Oct. 16-19, 2006.
21. * Hickner, M., C. J. Cornelius, M. R. Hibbs, C. H. Fujimoto¹, T. M. Alam, “Water Binding and Transport in Polymer Membranes with High Ion Content,” Invited talk presented at the 232nd ACS National Meeting, San Francisco, CA, Sept. 10-14 2006.
20. Hickner, M., K. Chen, N. Siegel, D. McBrayer, “Water and Heat Transport in PEM Fuel Cells,” Poster presented at The Gordon Research Conference - Fuel Cells, Smithfield, RI, July 23-28, 2006.
19. Hickner, M. C. J. Cornelius, M. R. Hibbs, C. H. Fujimoto, T. M. Alam, “The Nature of Water and Transport in Functionalized Poly(phenylene)s,” Contributed talk at the MRS 2006 Spring Meeting, San Francisco, CA, April 17 - 21, 2006.
18. * “Novel Polymeric Membranes for Fuel Cells,” Invited lecture at the University of Texas at Austin, Department of Chemical Engineering, Austin, TX, Oct. 27th, 2005.
17. * Hickner, M., K. Chen, “PEM Fuel Cell Water Management,” Invited lecture presented at the National Research Council of Canada's Institute for Fuel Cell Innovation, Vancouver, BC, Aug. 1st, 2005.
16. Hickner, M., K. Chen, N. Siegel, D. McBrayer, “Key Phenomena in PEM Fuel Cells Liquid Water Transport,” Poster presented at the Gordon Research Conference – Fuel Cells, Smithfield, RI, July 17-22, 2005.
15. Hickner, M., K. Chen, N. Siegel, D. McBrayer, “Key Phenomena in PEM Fuel Cells Liquid Water Transport,” Contributed talk presented at the 2nd International Conference on Polymer Batteries and Fuel Cells Las Vegas, NV, June 13-17, 2005.
14. * “Elucidating the Key Phenomena of Water Transport in Proton Exchange Membrane Fuel Cells,” Invited lecture at the New Mexico State University, Department of Chemical Engineering, Las Cruces, NM, Feb. 17th, 2005.
13. * “Polymer electrolytes for fuel cell applications,” Invited lecture at Highlands University, Department of Chemistry, Las Vegas, NM, Nov. 5th, 2004.
12. Hickner, M., K. Grossarth, K. S. Chen, D. R. Noble, “Liquid water droplet instability and removal at the GDL/Gas flow channel interface,” Poster presented at The Gordon Research Conference - Fuel Cells, Bristol, RI, July 25-30, 2004.

11. Hickner, M., J. E. McGrath, "The Role of Inorganic Additives in Determining Transport Properties of Organic-Inorganic Composite Proton Exchange Membranes," Contributed talk at the 203rd Meeting of The Electrochemical Society, Paris, France, April 27-May 2, 2003.
10. Hickner, M., B. Pivovar, F. Wang, T. Zawodzinski, J. E. McGrath, "Transport of methanol and protons in proton exchange membranes," Contributed talk at the 201st Meeting of The Electrochemical Society, Philadelphia, PA, May 12-17, 2002.
9. "Fuel cell research at Virginia Tech: A student's perspective," Contributed talk at the ACS 2002 Spring National Meeting, Orlando, FL, April 7-11, 2002.
8. Hickner, M., F. Wang, Y. S. Kim, B. Pivovar, T. Zawodzinski, J. E. McGrath, "Influencing the transport of water, methanol, and protons through a fuel cell ion exchange membrane," Contributed talk at the AIChE Spring National Meeting, New Orleans, LA, March 10-14, 2002.
7. Hickner, M., F. Wang, Y. Kim, B. Pivovar, T. Zawodzinski, J. E. McGrath, "Development of thin-film fuel cell electrodes containing novel polymers," Contributed talk at the 200th Meeting of The Electrochemical Society, San Francisco, CA, Sept. 2-7, 2001.
6. Hickner, M., F. Wang, Y. Kim, J. E. and McGrath, "Chemistry-morphology-property relationships of novel proton exchange membranes," Contributed talk at the 200th Meeting of The Electrochemical Society, San Francisco, CA, Sept. 2-7, 2001.
5. Hickner, M., F. Wang, Y. Kim, T. Zawodzinski, J.E. McGrath, "Chemistry-morphology-property relationships of novel proton exchange membranes for direct methanol fuel cells," Contributed talk at the ACS 2001 Fall National Meeting, Chicago, IL, Aug. 26-30, 2001.
4. Hickner, M., F. Wang, H. Shohba, N. Gunduz, J. Mecham, J. E. McGrath, T. Zawodzinski, "New proton exchange membranes via direct step or polycondensation," Contributed talk at the 199th Meeting of The Electrochemical Society, Washington D. C., March 25-30, 2001.
3. Hickner, M., F. Wang, H. Shobha, N. Gunduz, J. B. Mecham, J. E. McGrath, "Synthesis of proton exchange membranes via direct step or polycondensation," Contributed talk at the AIChE 2000 Fall National Meeting, Los Angeles, CA, Nov. 12-17, 2000.
2. Hickner, M. A., M. Sankarpandian, T. Zawodzinski, J. E. McGrath, "Adhesion issues within PEM membrane electrode assemblies," Contributed talk at the AIChE 2000 Fall National Meeting, Los Angeles, CA, Nov. 12-17, 2000.
1. Hickner, M. A., A. Banthia, J. E. McGrath, "Synthesis and characterization of phosphine oxide diol modified epoxy adhesives," Contributed talk at the ACS 2000 Fall National Meeting, Washington, D.C., Aug. 20-25, 2000.

Scientific Collaborators (Last Five Years)

C. Bae (RPI), C.J. Cornelius (UNebraska), C.H. Fujimoto (Sandia), E. Gomez (Penn State), Y.A. Elabd (TAMU), M.R. Hibbs (Sandia), D.S. Hussey (NIST), I. Ivanov (ORNL), D.A. Jacobson (NIST), M. Janik (Penn State), S. Kim (PNNL), Y.S. Kim (LANL), J. Liu (PNNL), B.E. Logan (Penn State), J.L. Lutkenhaus (TAMU), M.K. Mahanthappa (U. Wisconsin, Madison), D. Pickel (ORNL), S. Paddison (UT-Knoxville), B.S. Pivovar (NREL), R. Schaak (Penn State), G. Tew (UMass), C.-Y. Wang (Penn State), D. Wang (Penn State), Q. Wang (Penn State), A.Z. Weber (LBNL), Z. Yang (PNNL)

Graduate Advisor

James E. McGrath (Virginia Tech) (deceased)

Principal Postdoctoral Sponsor

Ken S. Chen (Sandia National Laboratories)

Synergistic ActivitiesTeaching

I developed a new course at Penn State entitled “Materials in Energy Research” which focuses on the uses of advanced materials for the conversion and utilization of energy. Research topics in important fields such as photovoltaics, fuel cells, solar thermal energy, and CO₂ conversion are stressed with an emphasis on energy transfer at the molecular/nanoscale and state-of-the-art materials research. The class is discussion-driven and covers fundamental materials science, energy transfer processes at the molecular scale, thermodynamics of energy conversion, and economic and political issues that influence energy choices. This class has been adapted for both first year and senior students depending on the need.

I have also developed “Polymer Materials II”. This is a lecture-based course, but covers modern research topics such as conducting polymers, ionic polymers, super-tough gels, and other relevant topics from the polymer science literature that the students will be exposed to in graduate school.

A new senate-approved course was developed in Fall 2016 – Polymers in 3D Printing as an elective in the Master’s Program in Additive Manufacturing. The purpose of the class is to educate students at the intersection of polymer science and additive manufacturing. Polymers-focused students will learn what is unique about 3D printing processes as they relate to polymer science, and additive manufacturing specialists will get a deeper look into the polymer science of 3D printing and the macromolecular nature of polymeric materials as applied in additive manufacturing.

Outreach

I have worked towards developing exciting hands-on units for two week-long residential camps for secondary educators and high school students (drawn from around the Northeast and the country) on Penn State’s University Park campus. These experimental activities focus on using the tools of chemistry and physical science to synthesize polymeric materials and explore their structure and function for water treatment and alternative energy applications. The student camp, which attracts 20-30 high school students annually, is sponsored by the ASM Materials Education Foundation and is designed to immerse students in exciting discovery-based learning and expose them to advanced scientific concepts. The teacher camp, sponsored by the Pennsylvania NASA Space Grant Consortium, gives approximately 20 high school teachers a chance to engage with college-level educators on new technical topics to both hone their own knowledge and develop new activities and modules to take back to their classrooms. The week is designed so that the teachers leave with information, materials, and demonstrations that can directly supplement their current courses.

Students and Researchers Currently SupervisedGraduate Students (8 current, 30 total)

Clara Cappirelli (Chem E)
 Nayan Sakia (Chem E)
 Raymond Lopez-Hallman (MATSE)
 Richard Wiencek (Chemistry)
 Preeya Kuray (MATSE)
 Megan Matta (Chemistry)
 Sarah Sheffield (Chemistry)
 Harrison Cassady (Chem E)

Undergraduate Researchers (5 current, 42 total)

Hannah Pohlmann (MATSE), Schreyer thesis
 Teague Williams (MATSE), Senior thesis
 Lachlan Peeke (MATSE)
 Kenneth Kimmons (MATSE)
 Natalie Mamrol (MATSE)

Post-Doctoral Researchers (2 current, 18 total)

Jing Pan (PhD Wuhan University)

Tawanda Zimudzi (Chemistry)

Visiting Researchers and Staff (4 current, 11 total)

Matthias Park (postgraduate researcher)

Carlos Rolando Fernandez Pulido (postgraduate researcher)

Hafis Graha (Tokyo Tech)

Saima Shabbir (Institute of Space Technology, Islamabad, Pakistan)

Hickner Group Alumni

Graduate Students

- Karan Doss (MS MATSE, August 2018), currently a PhD candidate in MATSE.
- Yifan Deng (MS MATSE, August 2018), currently a researcher in the Hickner Group.
- Tawanda Zimudzi (PhD Chemistry, August 2016), currently a staff researcher in MCL, Penn State.
- Liang Zhu (PhD MATSE, March 2016), currently a staff scientist at Dioxide Materials.
- Sean Nunez (PhD MATSE, August 2015), currently a staff scientist at Arkema.
- Douglass Kushner (PhD MATSE, August 2016), currently a postdoc at Lawrence Berkeley National Laboratory.
- Harrison Cassady (MS Chemical Engineering, March 2015), currently an entrepreneur in Portland, OR.
- Jiho Seo (MS MATSE, February 2016), currently a PhD candidate with Ralph Colby at PSU MATSE.
- Caroline Christensen (MS Chemistry, November 2015), currently a lab supervisor at University of Delaware.
- Clara Capparelli (MS MATSE, July 2015), currently in Argentina with the Fulbright Commission.
- Sarah Black (PhD Chemistry, July 2015), currently a staff member at the Center for Naval Analyses.
- Brian Chaloux (PhD MATSE, August 2014), currently a National Research Counsel Postdoc at the Naval Research Lab.
- Changwoo Nam. Currently a PhD candidate at Penn State.
- David Jones (MS MATSE, August 2014), currently resides in Knoxville, TN.
- Lizhu Wang (PhD MATSE, December 2013), postdoc at University of Nebraska Medical Center. Currently a research scientist at Missouri University of Science and Technology.
- Melanie Disabb-Miller (PhD MATSE, December 2013), currently resides in Baltimore, MD.
- Stephanie Petrina (MS MATSE, April 2010, PhD MATSE August 2013), currently employed with Georgia Pacific.
- Zhaoyan Ai (MS candidate), currently a PhD candidate in PSU Chemistry.
- Romesh Patel (PhD MATSE, December 2011), Postdoc in the PV group at AFRL in Dayton, OH. Currently at Nike.
- Alfonso Mendoza (PhD MATSE, December 2012), currently an entrepreneur in San Francisco, CA.
- Xie He (PhD MATSE, December 2012), postdoc at Penn State. Currently resides in Boston, MA.
- Matthew Gross (MS MATSE, Aug 2010), currently MGL Consulting, Boulder, CO.
- Hunter Moore (MS MATSE, April 2011), currently Virginia Western Community College, Roanoke, VA.

Post-Doctoral Researchers

- Liang Zhu March 2016-December 2017 (Ph.D. Penn State), currently at Dioxide Materials.
- Chris Lyon March 2017-November 2017 (Ph.D. UNH), current at Vantage Chemicals.
- Sean Nunez September 2015-February 2017 (Ph.D. Penn State), currently at Arkema.
- Brandon Calitree November 2012 – March 2015 (Ph.D. University of Buffalo), currently at University of Delaware.
- Geoff Geise, September 2012 – June 2014, (Ph.D. University of Texas) currently faculty in Chemical Engineering at University of Virginia.
- Praveen Meduri January 2013 – May 2014, (Ph.D. University of Kentucky) – PSIEE Postdoctoral Fellow. Currently a professor at IIT India.
- Ian Sines, January 2012 – August 2013, (Ph.D. The Pennsylvania State University, joint with Manish Kumar, PSU CHE). Currently a research scientist at St. Gobain.
- Nanwen Li, February 2012 – December 2013, currently a postdoc at Georgia Tech.

- Shudipto Dishari, October 2010 – August 2013, currently a postdoc at Penn State University.
- Dongyang Chen, August 2011 – August 2013, currently a postdoc at Northwestern University.
- Min Zhang, August 2012-March 2013, currently a postdoc at National University of Singapore.
- Guang Chen, August 2011-March 2013, currently a postdoc at National University of Singapore.
- Youngjin Cho, Feb. 2011-Jul. 2012, currently a staff scientist at DGIST, Korea.
- Timothy B. Tighe, Oct. 2009-Dec. 2011, currently a staff scientist at Penn State Materials Characterization Laboratory.
- Tomonori Saito, June 2008-July 2010, currently a staff member at Oak Ridge National Laboratory.
- Jingling Yan, Feb. 2008-Oct. 2010, currently a research associate at Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, China.

Visiting Researchers and Staff

- Hideaki Ono, March 2015-October 2015, Graduate Researcher, Yamanashi University.
- Juanjuan Han, August 2015-June 2016, Graduate Researcher, Wuhan University.
- Fang Chen, December 2012-December 2013, Professor, Department of Applied Chemistry, School of Natural and Applied Science, Northwestern Polytechnic University, Xi'an, China.
- Bencai Lin, October 2015-March 2016, Professor, School of Materials Science and Engineering, Changzhou University, China.
- Masaki Koike, January 2009-June 2009, visiting graduate researcher, Yamanashi University.
- Shinya Kawamura, January 2009-June 2009, visiting graduate researcher, Yamanashi University.

Undergraduate Research Students

- Xuedi Yu (MATSE), research student and visiting researcher – currently employed at Aleo BME, Inc.
- Franky Bernal (REU student), finishing degree at Cal State LA.
- Jessi Purawic (MATSE), undergraduate researcher – currently a senior in MATSE.
- Robert Kaminsky (MATSE), undergraduate researcher – currently employed at Arkema.
- Emma Vetland (MATSE), senior thesis – currently employed at NASA.
- Lindsay Erndwine (MATSE), senior thesis – currently a graduate student at University of Delaware.
- Kaitlyn Eckert (Chem E), undergraduate researcher.
- Christopher Malencia (Chem E), Schreyer Honors Thesis.
- Will Ferrell (MATSE), senior thesis – graduate student at UT Knoxville.
- Nichole Baer (MATSE), currently at First Quality Enterprises.
- Ziyi (Kent) Miao (MATSE), Schreyer Honors Thesis, currently a graduate student at Northwestern University.
- Emily Cimino (MATSE), senior thesis – currently employed at PPG.
- Sumant Kalidindi (MATSE), undergraduate research in PSU MATSE.
- Victoria Christensen (MATSE), undergraduate in PSU MATSE.
- John Nese (MATSE, senior thesis student), currently employed at AK Steel.
- Will Salem (BS PSU MATSE), currently employed at PPG.
- Rebecca Balaj (NSF Soft Materials REU), finishing degree at Columbia University.
- Christopher Rodriguez (NSF Soft Materials REU), finishing degree at Univ. Puerto Rico.
- Charles Michaelis (PSU CHE), currently at U. Virginia for graduate school.
- Kathleen Murzynski (PPG Fellow MATSE), finishing degree in PSU MATSE.
- Ying-Hsun “Mindy” Lin (MATSE), finishing degree in PSU MATSE.
- Jie “Jenny” Mou (MATSE), finishing degree in PSU MATSE.
- Andrew DeCarlo (PSU MATSE)
- Eric Fuemmeler (NSF Soft Materials REU, BS Chemistry Truman State University) currently graduate student at University of Illinois.
- Zach Johnson (NSF REU), finishing degree in PSU MATSE.
- Andrew Curtis (NSF Soft Materials REU, BS Chemistry Drake University).
- Rich Schatz (PSU Chemistry 2010).
- Kevin Dicker (BS PSU MATSE 2011, senior thesis student) currently a graduate student at UDEL MATSE.

- Julianne Carlson (BS PSU MATSE, senior thesis student).
- Colin Smith (BS PSU CHE) currently on coop with Medtronic.
- Tim Roberts (BS PSU CHE 2011) currently at Sunoco, Memphis TN.
- Matthew Menyo (BS PSU MATSE May 2009) currently a graduate student at UCSB, MATSE/BIO.
- Ernesto Martinez (NSF Soft Materials REU 2011) currently an undergraduate student at MIT.
- Rebecca Nolin (NSF Soft Materials REU, summer 2010) currently and undergraduate student at Virginia Tech.
- Kyle Bryson (BS PSU MATSE May 2010). PhD and NSF Graduate Fellowship recipient at UMASS-Amherst, PMSE. Currently employed at 3M Company.
- Chris Ewing (BS PSU CHE May 2010) currently graduate student at PITT, CHE.
- Patrick Mangiagli (BS PSU MATSE May 2010) currently a graduate student at Georgia Tech.
- Amy Beasten (NSF NNIN REU, summer 2008) CHE Tulane May 2009, currently a graduate student at North Carolina State University.
- Matthew Gross (BS PSU MATSE 2009, senior thesis student) currently at Ball Aerospace, Boulder CO.
- Kevin Donaher (NSF NNIN REU, summer 2009) currently an undergraduate student at Columbia University.
- Titi Shodiya (BS PSU MATSE May 2010). PhD Duke University. Currently a staff member at NIST.