(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 November 2010 (04.11.2010)

PCT

(10) International Publication Number
WO 2010/127328 A2

(51) **International Patent Classification:**
HOlL 51/56 (2006.01)

(21) **International Application Number:**
PCT/US20 10/0333 15

(22) **International Filing Date:**
1 May 2010 (01 .05.2010)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
61/174,943 1 May 2009 (01 .05.2009) US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, **IT,** LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WO 2010/127328 A2

(54) **Title:** METHOD AND APPARATUS FOR ORGANIC VAPOR PRINTING

(57) **Abstract:** In one embodiment, the disclosure relates to providing a first gas stream carrying vaporized material and depositing the vaporized material onto a substrate by directing a plurality of gas streams containing the vaporized material to a substrate, forming an gas curtain around the streams to prevent its dissemination beyond a target print area, and allowing the vaporized material to condense on the target print area. In another embodiment, heat is used to regulate the flow of the material and the thickness of the deposited layer.

METHOD AND APPARATUS FOR ORGANIC VAPOR PRINTING

BACKGROUND

[0001] The instant application claims priority to provisional application number 61/174,943, which was filed on May 1, 2009, the disclosure of which is incorporated herein in its entirety.

Field of the Invention

[0002] The disclosure relates to a method and apparatus for printing substantially uniform organic films over target print areas and having profiled edges. More specifically, the disclosure relates to novel method and apparatus for printing an organic film (interchangeably, layer) by providing vaporized material, distributing the vaporized material over a target area and condensing the vaporized material to form a substantially uniform film on the target area.

Description of Related Art

[0003] The manufacture of organic light emitting devices (OLEDs) requires depositing one or more organic films on a substrate and coupling the top and bottom of the film stack to electrodes. The film thickness is a prime consideration. The total layer stack thickness is about 100 nm and each layer is optimally deposited uniformly with an accuracy of better than *+1-2%*. Film purity is also important. Conventional devices form the film stack using one of two methods: (1) thermal evaporation of organic material in a relative vacuum environment and subsequent condensation of the organic vapor on the substrate; or, (2) dissolution of organic material into a solvent, coating the substrate with the resulting solution, and subsequent removal of the solvent.

[0004] Another consideration in depositing the organic thin films of an OLED is placing the films precisely at the desired location. There are two conventional technologies for performing this task, depending on the method of film deposition. For thermal evaporation, shadow masking is used to form OLED films of a desired configuration. Shadow masking techniques require placing a well-defined physical mask over a region of the substrate followed by depositing the film over the entire substrate area. Once deposition is complete, the shadow mask is removed. The regions exposed through the mask define the pattern of material deposited on the substrate. This process is inefficient, as the entire substrate must be coated, even though only the regions exposed through the shadow mask require a film. Furthermore, the shadow mask becomes increasingly coated with each use, and must eventually be discarded or cleaned. Finally, the use of shadow masks over large areas is made difficult by the need to use very thin masks (to achieve small feature sizes) that make said masks structurally unstable. However, the vapor deposition technique yields OLED films with high uniformity and purity and adequate thickness control.

[0005] For solvent deposition, ink jet printing can be used to deposit patterns of OLED films. InkJet printing requires dissolving organic material into a solvent that yields a printable ink. Furthermore, ink jet printing is conventionally limited to the use of one or two layer OLED film stacks, which typically have lower performance as compared to four for five layer film stacks used in vapor deposited devices. The stack limitation arises because printing typically causes destructive dissolution of any underlying organic layers. Consequently, one must engineer each layer such that it is undamaged by the wet deposition of each subsequent layer, and this greatly constrains the material and stack options. Finally, unless the substrate is first prepared with defined regions that contain the ink within the areas where the films are to be deposited, a step that increases the cost and complexity of the process, ink jet printing has very poor thickness uniformity as compared to vapor deposited films. The material quality is also typically lower, due to structural changes in the material that occur during the drying process and due to material impurities present in the ink. However, the ink jet printing technique is capable of providing patterns of OLED films over very large areas with good material efficiency.

[0006] No conventional technique combines the large area patterning capabilities of ink jet printing with the high uniformity, purity, and thickness control achieved with vapor deposition for organic thin films. Because ink jet processed OLED devices continue to have inadequate quality for widespread commercialization, and thermal evaporation remains too expensive and impractical for scaling to large areas, it is a major technological challenge for the OLED industry to develop a technique that can offer both high film quality and cost-effective large area scalability.

[0007] Finally, manufacturing OLED displays may also require the patterned deposition of thin films of metals, inorganic semiconductors, and/or inorganic insulators. Conventionally, vapor deposition and/or sputtering have been used to deposit these layers. Patterning is accomplished using prior substrate preparation (e.g., patterned coating with an insulator), shadow masking as described above, and when a fresh substrate or protective layers are employed, conventional photolithography. Each of these approaches is inefficient as compared to the direct deposition of the desired pattern, either because it wastes material or requires additional processing steps. Thus, there is a need for these materials as well for a method and apparatus for depositing high-quality, cost effective, large area scalable films.

SUMMARY

[0008] An apparatus for printing a uniform-thickness film on a substrate according to one embodiment of the disclosure includes: a nozzle for communicating a mixture of vaporized organic material and a carrier gas stream; a plurality of micropores communicating the mixture from the nozzle, the plurality of micropores arranged to provide a plurality of overlapping sub-streams; and a substrate for receiving and condensing the plurality of overlapping sub-streams into a film. The plurality of micropores can be independent of each other. At least two of the plurality of micropores can be connected to another by a cavity.

[0009] In another embodiment, the disclosure provides a method for printing a film having a substantially uniform thickness. The method includes providing a first gas stream carrying vaporized material. The vaporized material can comprise an organic ink composition. "Ink" is generally defined as any mixture having a volume of fluid components (in either the liquid or gas phase); examples of such generalized "inks" include mixtures of gaseous materials, mixtures of liquid particles suspended in a carrier gas, and mixtures of solid particles suspended in a carrier gas. The first gas steam can have a first temperature. The first gas stream can be divided into a plurality of sub-streams with each sub-stream carrying vaporized material. The sub-streams can have a shortest cross-sectional dimension on the microscale (that is, generally between 1 μm and 200 μm. (The sub-stream cross section is generally defined as the area of flow through the plane perpendicular average flow vector. For example, if the sub-stream flows through a long tube having a rectangular cross section with 3 um short side and 15 um long side, the cross section of the sub-stream is the rectangular cross section of the tube itself, and the shortest dimension of that cross-section is about 3 um. The sub-streams are then directed to a substrate. Simultaneously, a second gas stream can be directed to the substrate. The second gas stream

forms a fluid curtain about the plurality of sub-streams to contain the vaporized material within a targeted region. The vaporized material condenses on the substrate, within the targeted region, to form a substantially solid film or layer. In a preferred embodiment, the substrate has a lower temperature than the vaporized material to expedite condensation. The fluid curtain can be positioned relative to the substrate and the sub-streams to allow formation of a printed layer having a substantially uniform film thickness. The fluid curtain can also be positioned relative to the substrate such that the film has a substantially profiled edges.

[0010] In another embodiment, the disclosure relates to a film deposition apparatus having a conduit for communicating a first gas stream carrying vaporized material. The first gas stream contains vaporized material of ink composition. A multipore nozzle can be placed in fluid communication with the conduit. The multipore nozzle divides the first gas stream into a plurality of micron-scale sub-streams with each sub-stream carrying the vaporized material. A secondary nozzle provides a gas curtain about the plurality of sub-streams. A substrate can be positioned relative to the multipore nozzle and the secondary nozzle to condensate the vaporized material of ink composition and thereby form a substantially solid film on a target print area. The plurality of sub-streams can also be positioned relative to each other and the fluid curtain to deposit a film having a substantially uniform film thickness with a profiled edge.

[0011] In still another embodiment, the disclosure relates to a method for printing a film of uniform thickness profile by: targeting a print area on a substrate; directing a first stream having a carrier gas and a quantity of organic material to the print area to deposit a layer of organic material on the substrate; addressing a second stream to the print area, the second stream targeting an edge of the print layer; wherein the first stream has a higher temperature than the substrate to thereby condense the organic material on the print area. In an exemplary implementation, the sub-streams overlap each other.

[0012] In yet another embodiment, the disclosure relates to an apparatus for forming a profiled edge on a print layer. The apparatus comprises: a first discharge nozzle for discharging a carrier gas containing a quantity of organic material in a plurality of sub-streams; a substrate for receiving and condensing the quantity of organic material onto a print layer having an edge, the substrate having a target print area; a second (auxiliary) discharge nozzle forming a fluid curtain over at least a portion of the target print area, the fluid curtain contacting an edge of the print layer to form a substantially profiled edge. The plurality of sub-streams can be positioned to deposit a film having a substantially uniform film thickness profile.

[0013] Another embodiment of the disclosure relates to a method for controlling organic material discharge from a nozzle. The method comprises the steps of : (a) supplying a carrier gas with an organic material to a discharge nozzle, the discharge nozzle having multiple pores; (b) forming a plurality of discharge streams at the discharge nozzle, each discharge stream having a quantity of organic material; (c) discharging the quantity of organic material from the discharge nozzle by heating the discharge nozzle; (d) condensing the organic material in the multiple pores of the discharge nozzle by removing heat from the discharge nozzle; (e) repeating steps (a) through (d) to control the deposition rate from the print nozzle.

[0014] An apparatus according to yet another embodiment of the disclosure comprises a discharge nozzle having a plurality of micropores; a conduit for communicating a carrier gas having a quantity of an organic material to a discharge nozzle; a heater for heating at least one of the micropores; and a controller for modulating the heater to communicate the quantity of organic material through the micropores or condense the quantity of organic material in the micropores.

[0015] In another embodiment, the disclosure relates to a method for printing a film having a profiled edge by delivering a carrier gas stream containing a vaporized organic material; distributing the gas stream and the vaporized material into a plurality of sub-streams, each sub-stream having a quantity of vaporized organic material; and directing the plurality of sub-streams to a substrate surface. The substrate surface condenses the quantity of vaporized material into a printed layer of organic material. The profiled edge can be defined as an edge connecting two substantially orthogonal edges of the deposited layer.

[0016] In still another embodiment, an array of multiple nozzles is formed for film deposition. The multi-nozzle array can include any number of nozzles. The number of nozzles can be determined by considerations such as the size of the targeted print area. Each nozzle may have a multipore discharge so as to provide overlapping or non-overlapping sub-streams.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] These and other embodiments of the disclosure will be discussed with reference to the following exemplary and non-limiting illustrations, in which like elements are numbered similarly, and where:

[0018] Fig. 1 schematically shows a conventional nozzle for depositing a film;

[0019] Fig. 2A illustrates printed profile of the nozzle of Fig. 1;

[0020] Fig. 2B illustrates the desired printed profile;

[0021] Fig. 3 shows lateral contamination caused by the conventional techniques;

[0022] Fig. 4 shows a multipore nozzle according to one embodiment of the disclosure;

[0023] Figs. 5A-5C show several exemplary pore patterns;

[0024] Figs. 6A-6C show complex pore patterns according to another embodiment of the disclosure;

[0025] Fig. 7 illustrates an exemplary array of multipore nozzles;

[0026] Fig. 8 shows an embodiment of the disclosure having auxiliary gas streams for a fluid curtain;

[0027] Fig. 9 illustrates a multipore assembly with a gas curtain according to one embodiment of the disclosure;

[0028] Fig. 10 is a cross-sectional view of the interface plate of Fig. 9;

[0029] Fig. 11 shows a multipore nozzle with a thermal shutter according to another embodiment of the disclosure;

[0030] Fig. 12 shows the multipore nozzle of Fig. 11 with the heater turned off;

[0031] Fig. 13 shows an exemplary nozzle having multiple orifices (or pores) for a fluid curtain;

[0032] Fig. 14 shows an exemplary nozzle with apertures for forming a fluid curtain;

[0033] Fig. 15 shows another exemplary discharge structure having multipore nozzles with two fluid ducts; and

[0034] Fig. 16 shows an exemplary embodiment in which the micropores provide overlapping deposits.

DETAILED DESCRIPTION

[0035] Patterning of organic thin film is useful in variety of applications, including fabrication of light emitting displays. This is critical for OLED displays in particular because such displays require fabricating a number of patterned layers on a substrate. Each layer defines one of the colors: red, green and blue in each full color pixel. The patterning is performed using shadow mask evaporation. The shadow mask process is expensive and labor intensive. It is also prone to error and believed to be applicable only to relatively small areas.

[0036] The disclosed embodiments overcome the deficiencies of the conventional techniques by providing a method and apparatus for depositing patterned organic thin films at low cost over large areas that further offer good uniformity over the target printed area and, where required, sharp edge profiles. While the disclosure is described in the context of using a carrier gas to communicate organic vapor material, it should be noted that the disclosed principles are not limited to organic vapor material and can apply to all printing methods in which a carrier medium is used to convey the deposition material to a destination substrate.

[0037] In one embodiment, the disclosure relates to a structure for depositing a film of substantially uniform thickness by receiving a carrier gas stream containing organic vapor material at a nozzle, distributing the carrier gas stream into a plurality of sub-streams at a microscale distributor (interchangeably, micron-scale showerhead) and directing the sub-streams through a plurality of micropores onto a substrate. The substrate having a lower temperature relative to the carrier gas stream causes condensation of the organic vapor material. The micropores can be organized to such that the vapor stream from each micropore simultaneously delivers an overlapping deposit of organic material on the substrate. The cross section of the deposit from a single microscale distributor can have a continuous, non-zero cross section that can be controlled through the proper engineering of the size, shape and pattern of the micropores.

Thus, in an inventive embodiment, multiple vapor streams (or sub-streams) are at least partially merged to form a uniform deposited film.

[0038] Fig. 1 schematically shows a conventional nozzle for depositing film. In conventional deposition techniques, a stream of heated carrier gas is used to convey vaporized organic material. In Fig. 1, stream 110 represents a carrier gas containing vaporized organic material. The vaporized organic material carried in stream 110 is deposited on the top surface of substrate 130 to form a layer of film 115. The conduit for conveying stream 110 to substrate 130 is schematically shown by walls 120. Thus, by using a stream of heated carrier gas, vaporized organic material can be transported through a tube and out of nozzle 125. In conventional applications, substrate 130 is moved relative to nozzle 125 in order to deposit a desired pattern. Typical deposited film thicknesses range from between 10 nm to 200 nm when applied to OLED applications; however, there are no fundamental limits on the range of deposited film thicknesses when utilizing this technique.

[0039] The single orifice nozzle 125 produces an approximately Gaussian shaped film profile as shown in Fig. 2A. The Gaussian shaped film profile typically does not have a uniform thickness over the target print region (unless the target print region is confined to a very narrow portion in the middle of the deposited area, which is usually impractical.) Multiple overlapping passes are needed with a very narrow print stream to approximate a flat region with sharp sidewalls (profiled edge) as shown in Fig. 2B. However, such overlapping techniques are slow, expensive and prone to error given the tight mechanical alignment and tolerance required. It is also difficult to create a print stream that is sufficiently narrow to get sharp edge profiles at the edge of the printed region.

[0040] In addition, due to the high temperature and flow rate of the carrier gas, not all the material deposits on the substrate directly. Instead, the material bounces off the substrate and flows laterally, eventually depositing on the substrate far from the desired region as illustrated in Fig. 3. This contamination of the substrate renders the conventional techniques unattractive for any production, much less a large scale production.

[0041] Fig. 4 shows a multipore nozzle according to one embodiment of the disclosure. In Fig. 4, gas stream 410 is a hot gas carrying organic vapor material to be deposited on substrate 430.

Gas steam 410 is transported through conduit 420 to multipore nozzle 425. Multipore nozzle 425 divides stream 410 to multiple sub-streams 412. Each sub-stream 412 includes the carrier gas and vapor organic material. Sub-streams 412 deposit film layer 415 on substrate 430. Film layer 415 has the desired profiled edges. Film 415 also has a substantially uniform thickness. Finally, multipore nozzle 425 prevents lateral contamination of organic vapor material across the substrate.

[0042] The multipore nozzle can be fabricated using conventional techniques. In one embodiment of the disclosure, the multipore nozzle was fabricated using MEMS fabrication techniques by forming very small pore (orifice) arrays and by depositing very small features. The pores and the features typically have a diameter of between 1-10 μm, though pore sizes of up to 100 μm are possible. The small, micron-scale size of the pores enable excellent film deposit uniformity and profiled edges (sharp sidewall).

[0043] Figs. 5A-5C show several exemplary pore patterns. In Fig. 5A, the circular pores are arranged in an array. The multipore nozzle of Fig. 5A includes surface 510, having fabricated therein pores 512. Pores 512 are circular in shape and are arranged symmetrically about the nozzle. In Fig. 5B, pores 514 are rectangular in shape and in Fig. 5C, rectangular pore 516 is supplemented by semi-circular pores 518 on each side. Figs. 5A-5C illustrates that the shape of the pores can be designed to accommodate a number of shapes and orientations to accommodate different engineered deposited patterns and related film cross sections. The nozzles of Figs. 5A-5C can be fabricated using conventional fabrication techniques such as MEMS.

[0044] In certain applications it may be advantageous to convert the micropore patterns into a single continuous orifice (or several orifices) by strategically forming thin openings between two or more micropores. This structure is shown in Figs. 6A-6C. Specifically, Figs. 6A-6C show more complex pore patterns of multipore nozzles. Specifically, Fig. 6 shows patterns of connected pores, having circular (Fig. 6A), rectangular (Fig. 6B) or complex (Fig. 6C) shapes. The shapes can be designed to provide different patterns and desired film cross sections.

[0045] Fig. 7 illustrates an exemplary array of multipore nozzles. In Fig. 7, substrate 730 is positioned across an array of multipore nozzles 725 which deposit discrete films 715 from stream 710. Stream 710 can have a hot carrier gas containing vaporized organic material. Each deposited film segment has a profiled edge and a substantially uniform thickness. Conduits 720 can be integrated with the multipore array or can be separate. In another implementation of the disclosure, conduits 720 may be eliminated entirely. In still another embodiment, the multipore nozzles are designed as interface plates and are removably coupled to a discharge conduit. Several multipore nozzles can be arranged to form an array of nozzles. The neighboring multi-nozzle pores in the array need not have identical shapes.

[0046] Fig. 8 shows an embodiment of the disclosure having auxiliary gas streams. In this embodiment, gas streams are positioned near the multipore nozzle in order to further rectify the shape of the vapor deposition. The auxiliary gas streams form an air curtain about the hot gas stream and further prevent lateral dissemination of organic vapor material. The auxiliary gas streams also help refining the profiled edge and the thickness of the deposited material. Referring to Fig. 8, first gas stream 810 defines a hot gas stream carrying vaporized organic material therein. The vaporized organic material can be ink composed for OLED application. Gas stream 810 can have a temperature in the range of about 150 ^{0}C to 450 ^{0}C, with 300 ^{0}C being typical.

[0047] Gas stream 810 is directed to nozzles 825. Nozzle 825 includes several micropores which divide gas stream 810 into a corresponding number of sub-streams. Each sub-stream carries a quantity of vaporized organic material. The sub-streams are then directed to substrate 830. Substrate 830 can have a temperature lower than that of the first gas stream, allowing the vaporized organic material to condense on the surface thereof

[0048] Simultaneous with the deposition process, auxiliary gas stream 850 is directed through corresponding micropores of nozzle 825 to form auxiliary sub-streams 855. The auxiliary sub-streams can have a lower temperature than gas stream 810 and may contain no vapor organic material. The auxiliary gas stream can be, for example, a noble gas. Depending on the location of the micropores, auxiliary gas streams 855 can form a fluid (or gas) curtain about the target deposition area. The fluid curtain can form a profiled edge and a substantially uniform thickness for the condensed organic vapor material 815. The cool gas curtain also prevents lateral spreading of the organic vapor material.

[0049] Fig. 9 illustrates a multipore nozzle with a gas curtain according to one embodiment of the disclosure. The embodiment of Fig. 9 is substantially similar to that of Fig. 8, except for the addition of interface plate 970 above conduit 920.

[0050] Fig, 10 is a cross-sectional view of the interface plate of Fig. 9. As shown in Fig. 10, auxiliary gas inlet 1072 which forms the fluid curtain is offset from hot carrier gas inlet 1074. The hot carrier gas inlet contains organic vapor material and can have a substantially higher temperature than the auxiliary gas. Inlets 1072 and 1074 can be fabricated easily on surface 1070 using techniques such as mechanical milling or chemical etching. The inlets 1072 and 1074 on interface plate 1070 can be replicated or reconfigured to produce multipore discharge nozzles or arrays thereof. Using interface 1070, gas delivery system can be reduced to a simple supply line (or conduit) having two inlets. A first inlet delivers cool auxiliary gas for the fluid curtain and the second inlet delivers hot carrier gas containing organic vapor material. The interface plate provides a cost-efficient means for integrating the first and second inlet streams with a multi-nozzle discharge device.

[0051] Fig. 11 shows a multipore nozzle with a thermal shutter according to another embodiment of the disclosure. Here, element heating units 1160 are added to multipore nozzle 1125. When the heaters are turned on, the pores are heated and hot gas 1110 is transmitted through the nozzle as shown by arrows 1155. On the other hand, when heaters are in the off state, the organic vapor material condenses on the interior surfaces of the pores and the flow is obstructed. This condition is shown in Fig. 12 where pores of nozzle 1225 are obstructed after the hot organic vapor condenses inside the cool pores. Because of the small size of nozzle 1225, an elemental heater can be effective for rapidly heating and cooling the system. Additional means, such as heat sink (not shown) can be added to the system to provide for faster cooling. The heating means can provide one or more of convection, conduction and/or radiation heating.

[0052] To control the rapidly changing temperature of the pores, a controller can be used. The controller can have one or more microprocessor circuits connected to one or more memory circuits. In addition, a flow regulator can be incorporated in the system to communicate with the controller. The flow regulator can optionally increase or decrease the hot gas flow rate (1110 in Fig. 11) according to whether heaters 1160 are on or off. The memory circuit can contain instructions for running the processor circuit and for starting and stopping the heater and/or the regulator.

[0053] By integrating a heating element and then modulating the heat applied to the multipore nozzle (or directly to the pores), the flow of organic vapor material through the nozzles can be modulated. When the heater is on, the material flows through the micropores without condensing on the micropore walls. When the heater is off (with optional support from a heat sink), the micropores are cool enough that the material condenses on the walls instead of passing through.

[0054] The disclosed embodiments can be combined to further control the film thickness, uniformity and the profiled edge. For example, a nozzle heater and the fluid curtain can be used conjunctively to further control deposition thickness and profile. Alternatively, the fluid curtain can be activated only when the heater is on to further enhance deposition profile. Both the nozzle heater and the fluid curtain can be combined with a multipore nozzle to provide even more accuracy and control over film deposition profile.

[0055] Fig. 13 shows an exemplary nozzle having multiple orifices for a fluid curtain. Specifically, Fig. 13 A shows structure 1310 having circular nozzle 1320 at the center thereof and pores 1330 distributed around the nozzle. Here, nozzle 1320 has one outlet port and pores 1330 provide a fluid curtain to the organic vapor film deposited through structure 1310. A heater may optionally be added to structure 13 10. It is noted that nozzle 1320 can be replaced with a multipore nozzle according to the instant disclosure. At least two micropores 1330 can be connected by a cavity to provide a different fluid curtain profile as shown with reference to Fig. 6.

[0056] Fig. 14 shows another exemplary nozzle 1410 with apertures for forming a fluid curtain. In Fig. 14, circular nozzle 1420 is positioned between fluid ducts 1430. The organic vapor material which is conveyed through nozzle 1420 is surrounded by a fluid curtain provided by ducts 1430. The exemplary structure shown in Fig. 14 can be replicated to form a large array containing multiple nozzles 1420 surrounded by ducts 1430.

[0057] Fig. 15 shows exemplary discharge structure 1510 having multipore nozzles 1520 and ducts 1530. Ducts 1530 form a fluid curtain which delimits vapor organic material dispersion beyond a targeted print region. As with the previous embodiments, discharge structure 1510 can be formed in an array to provide for large area deposition. A heating apparatus may further be added to the embodiment of Fig. 15. Finally, it is noted that pores 1520 need not be circular and can assume any shape or form to accommodate the printing requirements.

[0058] Fig. 16 shows an exemplary embodiment in which the micropores provide overlapping deposits. In Fig. 16, hot carrier gas stream 1605 is directed through nozzle 1610 to microscale distributor 1620. Nozzle 1610 and distributer 1620 can be integrated into one unit. Alternatively, they can be built separately so that different distributors can be assembled to different nozzles. Microscale distributor 1620 distributes stream 1605 into a plurality of sub-streams through a plurality of micropores 1630. Micropores 1630 can be organized such that the vapor stream from each micropore 1630 simultaneously delivers an overlapping deposit 1640 to substrate 1650. In one embodiment, the cross section of the deposit from a single microscale distributor has a continuous, non-zero cross section 1635 that can be controlled through the design of the size, shape and pattern of micropores 1630. The organic vapor streams form film 1640 which has substantially uniform thickness. The embodiment of Fig. 16 overcomes many of the deficiencies of the conventional methods by replacing a single continuous orifice nozzle by a plurality of microscale orifices (which may not necessarily be circular). Positioning a fluid curtain at the nozzle can further refine the edges of deposit layer 1640 according to the embodiments disclosed above.

[0059] While the principles of the disclosure have been illustrated in relation to the exemplary embodiments shown herein, the principles of the disclosure are not limited thereto and include any modification, variation or permutation thereof.

What is claimed is:

1. A method for printing a film of substantially uniform thickness over the target printed area, comprising:

providing a first gas stream carrying vaporized material, the vaporized material defining an ink composition and the gas steam having a first temperature;

directing the first gas stream through a nozzle comprising a plurality of micropores to form multiple micron-scale sub-streams, each sub-stream carrying the vaporized material;

directing the sub-streams onto a substrate; and

condensing the vaporized material on the substrate to form a substantially solid film;

wherein the plurality of micron-scale sub-streams are positioned relative to each other to deposit a film having a substantially uniform film thickness profile over the target printed area.

2. The method of claim 1, wherein the vaporized material further comprises an organic ink.

3. The method of claim 1, further comprising directing a second gas stream onto the substrate, the second gas stream forming a fluid curtain about the plurality of sub-streams and the fluid curtain positioned relative to the micron-scale sub-streams.

4. The method of claim 3, wherein the fluid curtain has a temperature lower than the first temperature.

5. The method of claim 1, further comprising directing the first gas stream through a plurality of micropore nozzles, each nozzle serving to form an associated plurality of micron-scale sub-streams.

6. The method of claim 3, wherein at least two of the plurality of sub-streams are overlapping.

7. The method of claim 1, wherein the substrate has a temperature lower than the first temperature.

8. The method of claim 1, wherein the plurality of sub-streams are independent of each other.

9. The method of claim 1, wherein the plurality of sub-streams are delivered to the substrate substantially continuously.

10. The method of claim 1, wherein the plurality of sub-streams are delivered to the substrate in pulses.

11. The method of claim 1, wherein the vaporized material is substantially insoluble in the first gas stream or the second gas stream.

12. A film deposition apparatus, comprising:

a conduit for communicating a first gas stream carrying vaporized material, the first gas stream having vaporized material of ink composition;

a nozzle having a plurality of micropores in fluid communication with the conduit, the nozzle dividing the first gas stream into a plurality of micron-scale sub-streams, each sub-stream carrying the vaporized material; and

a substrate positioned relative to the multipore nozzle to condense the vaporized material of ink composition thereby forming a substantially solid film on a target print area;

wherein the plurality of sub-streams are positioned relative to each other to deposit a film having a substantially uniform film thickness profile.

13. The apparatus of claim 12, wherein the conduit is integrated with the multipore nozzle.

14. The apparatus of claim 12, further comprising a secondary nozzle providing a gas curtain around the plurality of sub-streams.

15. The apparatus of claim 14, wherein the gas curtain prevents the first gas stream from extending beyond the target print area.

16. The apparatus of claim 14, wherein the secondary nozzle further comprises a single-pore nozzle affecting an edge of the target printing area.

17. The apparatus of claim 14, wherein the multipore nozzle directs the plurality of sub-streams onto the target print area to thereby form a print layer of substantially uniform thickness.

18. The apparatus of claim 14, wherein the multipore nozzle further comprises a plurality of independent orifices in which at least two orifices are connected through an opening.

19. The apparatus of claim 14, wherein the conduit and the multi-nozzle pore are integrated into one structure.

20. The apparatus of claim 14, further comprising a plurality of nozzles arranged to form a nozzle array, the nozzle array being surrounded by at least one secondary nozzle providing a fluid curtain to the boundary of the target print area.

21. The apparatus of claim 14, wherein the sub-streams are independent of each other.

22. The apparatus of claim 21, wherein the nozzles are positioned relative to each others such that at least two of the pluralities of sub-streams are overlapping.

23. A method for printing a film of uniform thickness profile, comprising:

targeting a print area on a substrate;

directing a first stream having a carrier gas and a quantity of organic material to the print area to deposit a layer of organic material on the substrate;

dividing the first stream into a plurality of micron-scale sub-streams, each sub-stream containing a quantity of the organic vapor material and the carrier gas; and

directing a second stream at the print area, the second stream targeting an edge of the print layer;

wherein the first stream has a higher temperature than the substrate to thereby condense the organic material on the print area.

24. The method of claim 23, wherein the second stream is parallel to the first stream.

25. The method of claim 23, wherein the second stream is at an angle with respect to the second stream.

26. The method of claim 23, wherein the second stream is cooler than the first stream.

27. The method of claim 23, wherein the second stream has an inert composition.

28. The method of claim 23, wherein the target print area moves relative to the first stream.

29. The method of claim 23, wherein the organic material is substantially insoluble in the first stream or the second stream.

30. The method of claim 23, further comprising directing the second stream and the first stream simultaneously to a target print area such that the second stream limits deposit of organic material to the target print area.

31. The method of claim 23, further comprising directing the second stream to the target area at an angle to deposit a substantially uniform layer of organic material.

32. An apparatus for forming a profiled edge on a print layer, the apparatus comprising:

a first discharge nozzle for discharging a carrier gas containing a quantity of organic material in a plurality of micron-scale sub-streams;

a substrate for receiving and condensing the quantity of organic material onto a print layer having an edge, the substrate having a target print area;

a second discharge nozzle forming a fluid curtain over at least a portion of the target print area, the fluid curtain contacting an edge of the print layer to form a substantially profiled edge;

wherein the plurality of sub-streams are positioned relative to each other and the fluid curtain to deposit a film having a substantially uniform film thickness profile.

33. The apparatus of claim 32, wherein the discharge nozzle is a multipore nozzle for dividing a gas stream into multiple parallel gas streams.

34 The apparatus of claim 32, wherein the discharge nozzle comprises multiple sub-nozzles, each sub-nozzle comprising a multipore nozzle for dividing a gas stream into multiple parallel gas streams.

35. The apparatus of claim 32, further comprising a conduit for communicating the carrier gas to the first discharge nozzle.

36. The apparatus of claim 32, wherein the first discharge nozzle further comprises a plurality of micropores where adjacent micropores are separated by a partition.

37. The apparatus of claim 32, wherein the first discharge nozzle further comprises a plurality of micropores and wherein the second discharge nozzle forms a fluid curtain about the target print area such that the print layer formed on the target print area defines a substantially flat surface.

38. The apparatus of claim 32, wherein the first discharge nozzle further comprises a plurality of micropores and wherein the second discharge nozzle forms a fluid curtain about the target print area such that the print layer formed on the target print area defines a substantially profiled edges.

39. The apparatus of claim 32, wherein the fluid curtain is defined by a second gas flow having a flow rate higher than the carrier gas flow rate.

40. The apparatus of claim 32, wherein the profiled edge further comprises a profile width which is between 1 μm and 100 μm, with an expected range of about 5 to 30 um.

41. A method for controlling organic material discharge from a nozzle, comprising:

(a) supplying a carrier gas with an organic material to a discharge nozzle, the discharge nozzle having multiple pores;

(b) forming a plurality of discharge streams at the discharge nozzle, each discharge stream having a quantity of organic material;

(c) discharging the quantity of organic material from the discharge nozzle by heating the discharge nozzle;

(d) condensing the organic material in the multiple pores of the discharge nozzle by removing heat from the discharge nozzle;

(e) repeating steps (a) through (d) to control the deposition rate from the print nozzle.

42. The method of claim 41, wherein step (c) further comprises intermittently heating the discharge nozzle.

43. The method of claim 41, wherein step (c) further comprising forming a printed organic layer by condensing the quantity of organic material on a substrate.

44. The method of claim 43, further comprising shaping the profile of the printed organic layer by forming a fluid curtain about an edge of the print layer.

45. The method of claim 43, further comprising forming a profiled edge by targeting a second gas steam at an edge of the print layer.

46. An apparatus for controlling the profile of a printed layer, comprising:

a discharge nozzle having a plurality of micropores;

a conduit for communicating a carrier gas having a quantity of an organic material to a discharge nozzle;

a heater for heating at least one of the micropores; and

a controller for modulating the heater to communicate the quantity of organic material through the micropores or condense the quantity of organic material in the micropores.

47. The apparatus of claim 46, further comprising a heat sink for removing heat from the discharge nozzle.

48. The apparatus of claim 46, further comprising means for removing heat from the discharge nozzle.

49. The apparatus of claim 46, wherein the heater defines one of a conduction, convection or radiation heater.

50. The apparatus of claim 46, further comprising an auxiliary nozzle for providing a fluid stream shielding a portion of the discharged organic material.

51. The apparatus of claim 46, wherein the controller further comprises a processor circuit in communication with a memory circuit, the memory circuit providing instructions to the processor circuit to intermittently heat or cool the discharge nozzle.

52. The apparatus of claim 46, wherein the controller further comprises a processor circuit in communication with a memory circuit, the memory circuit providing instructions to the processor circuit to intermittently heat the discharge nozzle, cool the discharge nozzle and/or provide a fluid curtain to guide the discharged quantity of material

53. A method of printing films, comprising:

delivering a carrier gas stream having containing a vaporized organic material therein;

distributing the gas stream and the vaporized material into a plurality of micron-scale sub-streams each sub-stream having a quantity of vaporized organic material;

directing the plurality of sub-streams to a substrate surface; and

condensing the quantity of vaporized material into a printed layer of organic material on the substrate surface;

wherein the plurality of sub-streams overlap to condense a continuous film on the substrate.

54 The method of claim 53, further comprising heating the carrier gas and the organic material.

55. The method of claim 53, wherein the vaporized material comprises organic material.

56. The method of claim 53, wherein the vaporized material comprises organic light emitting diode.

57. The method of claim 53, further comprising providing an auxiliary gas curtain define a target print area on the substrate.

58. The method of claim 53, further comprising moving the substrate relative to the plurality of sub-streams.

59. An apparatus for printing a film on a substrate, comprising:

a nozzle for communicating an mixture of vaporized organic material and a carrier gas stream;

a plurality of micropores communicating the mixture from the nozzle, the plurality of micropores arranged to provide a plurality of overlapping sub-streams; and

a substrate for receiving and condensing the plurality of overlapping sub-streams into a film;

wherein the plurality of micropores are independent of each other.

60. The apparatus of claim 59, wherein at least two of micropores are connected to each other by a cavity.

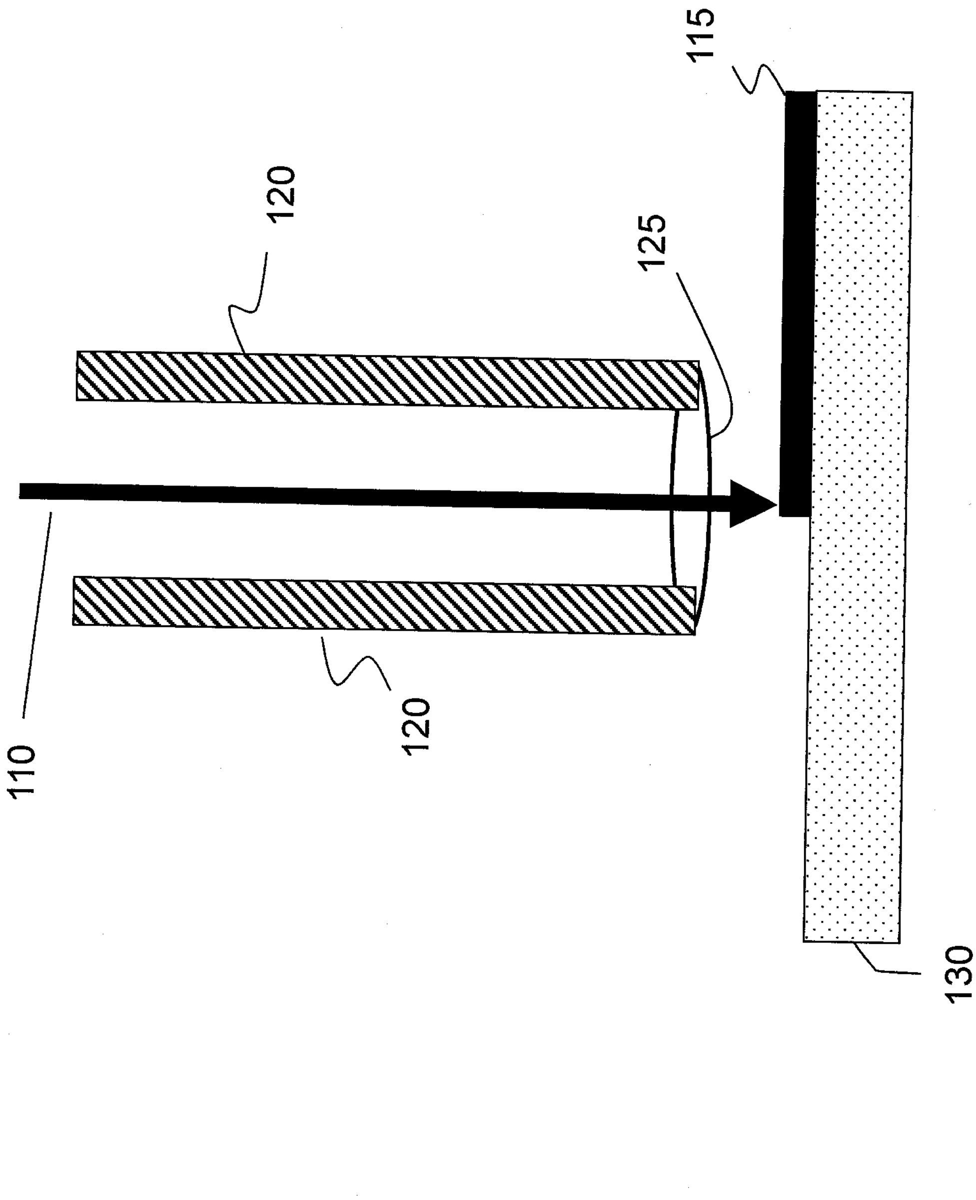
61. The apparatus of claim 59, further comprising a heater for heating at least one of the nozzle or the plurality of micropores.

62. The apparatus of claim 59, further comprising an auxiliary micropore for forming a fluid curtain about at least one micropore.

63. The apparatus of claim 59, further comprising a plurality of auxiliary micropores for forming a fluid curtain surrounding the nozzle.

64. The apparatus of claim 59, wherein the vaporized organic material defines an organic ink.

65. The apparatus of claim 59, wherein the mixture of vaporized organic material and the carrier gas are at an elevated temperature with respect to the substrate.



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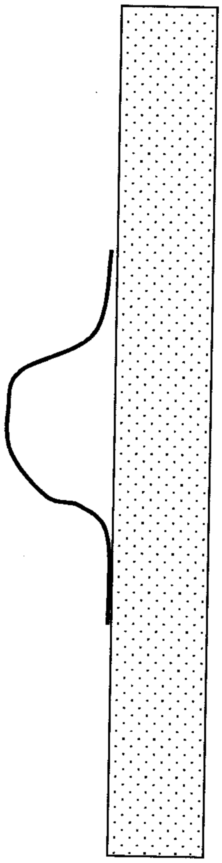


Figure 2A

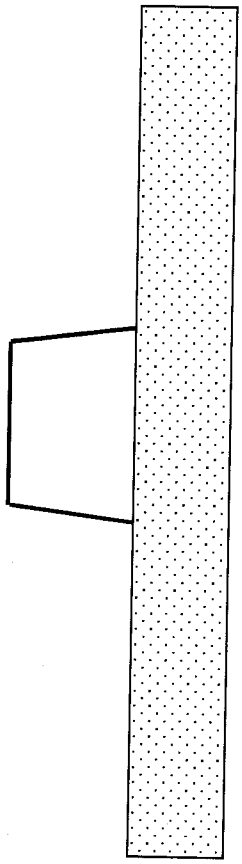
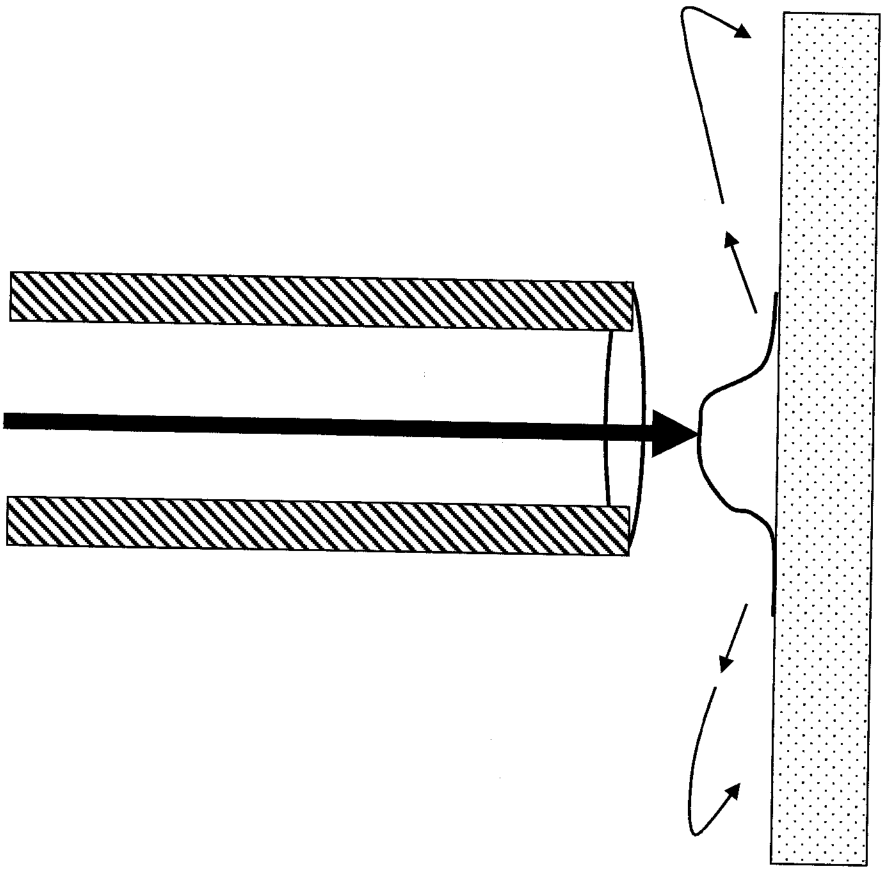


Figure 2B



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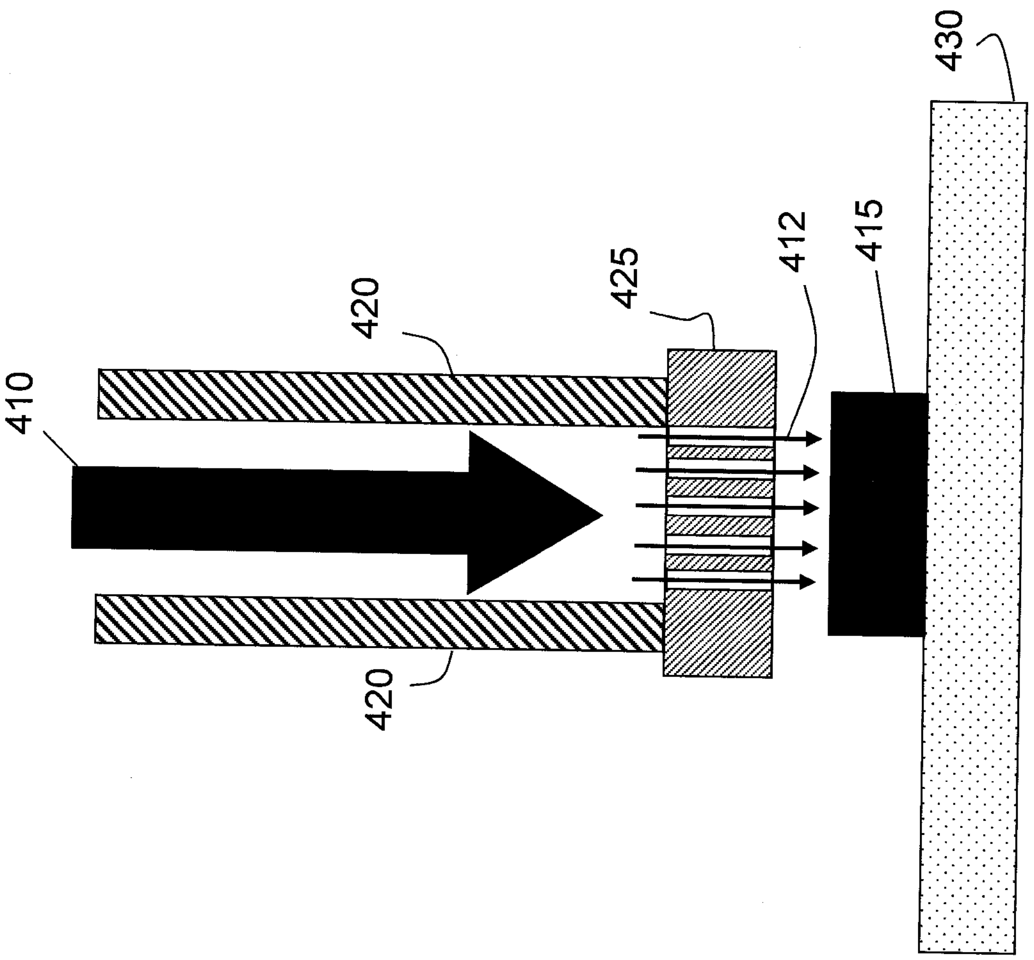

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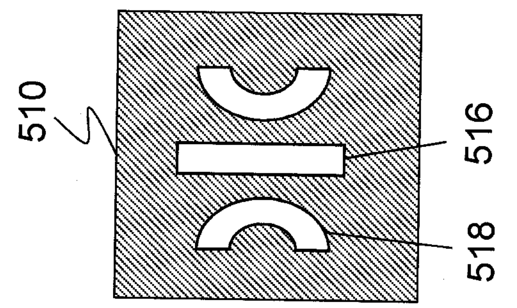


Figure 5C

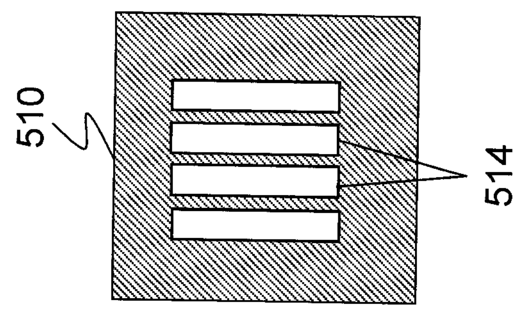


Figure 5B

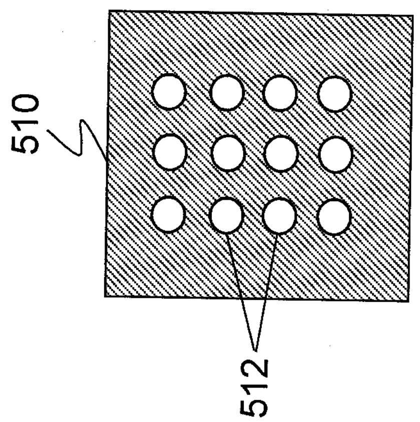
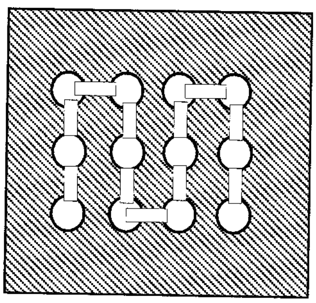


Figure 5A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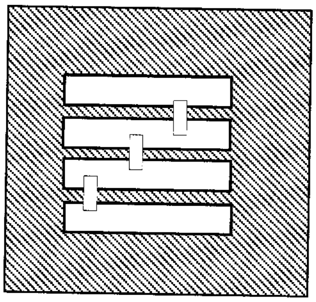
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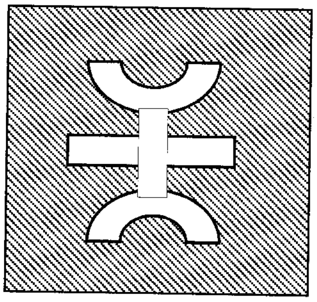
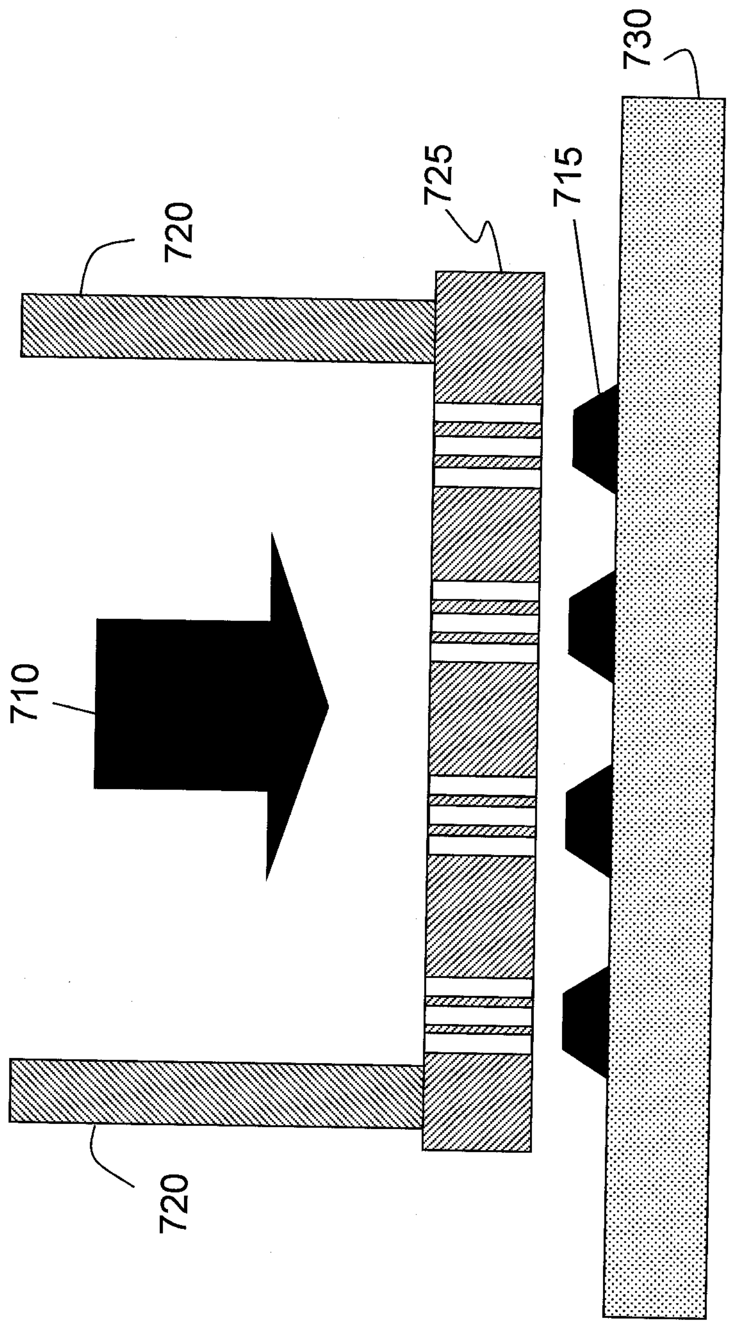


Figure 6C



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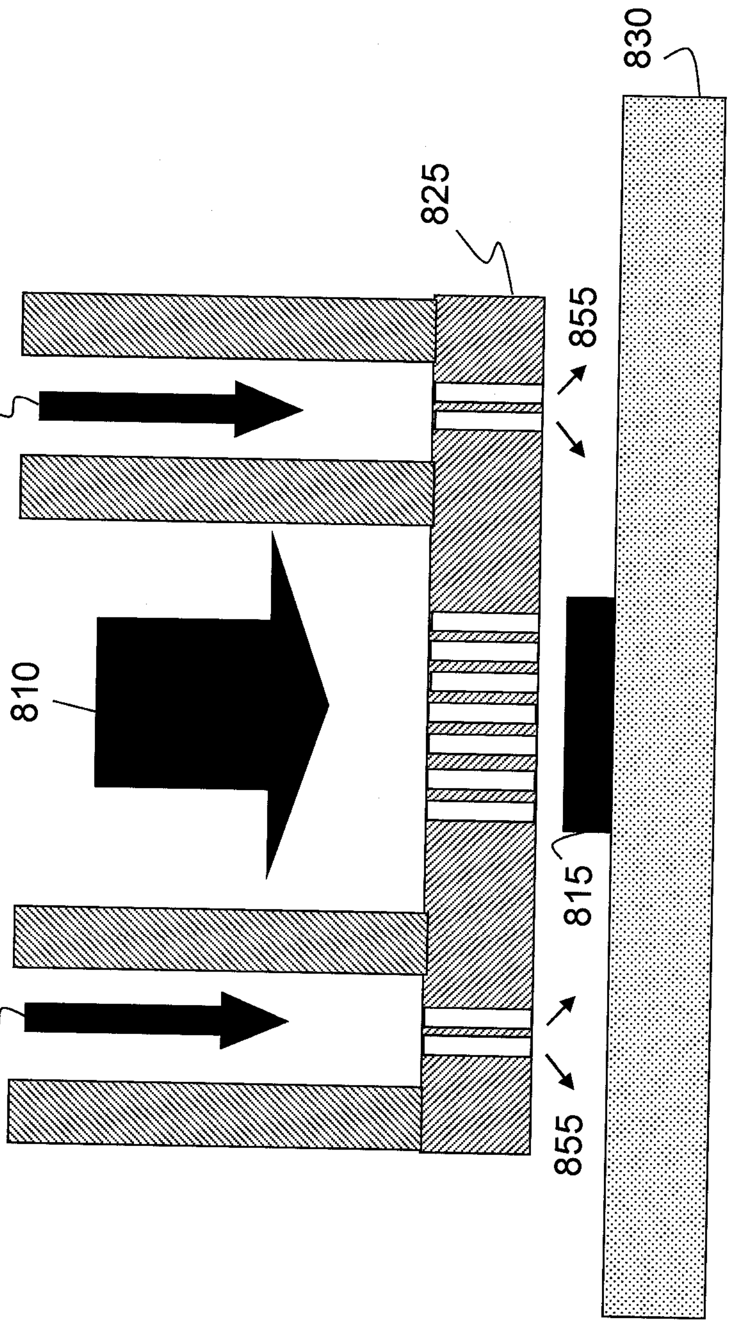
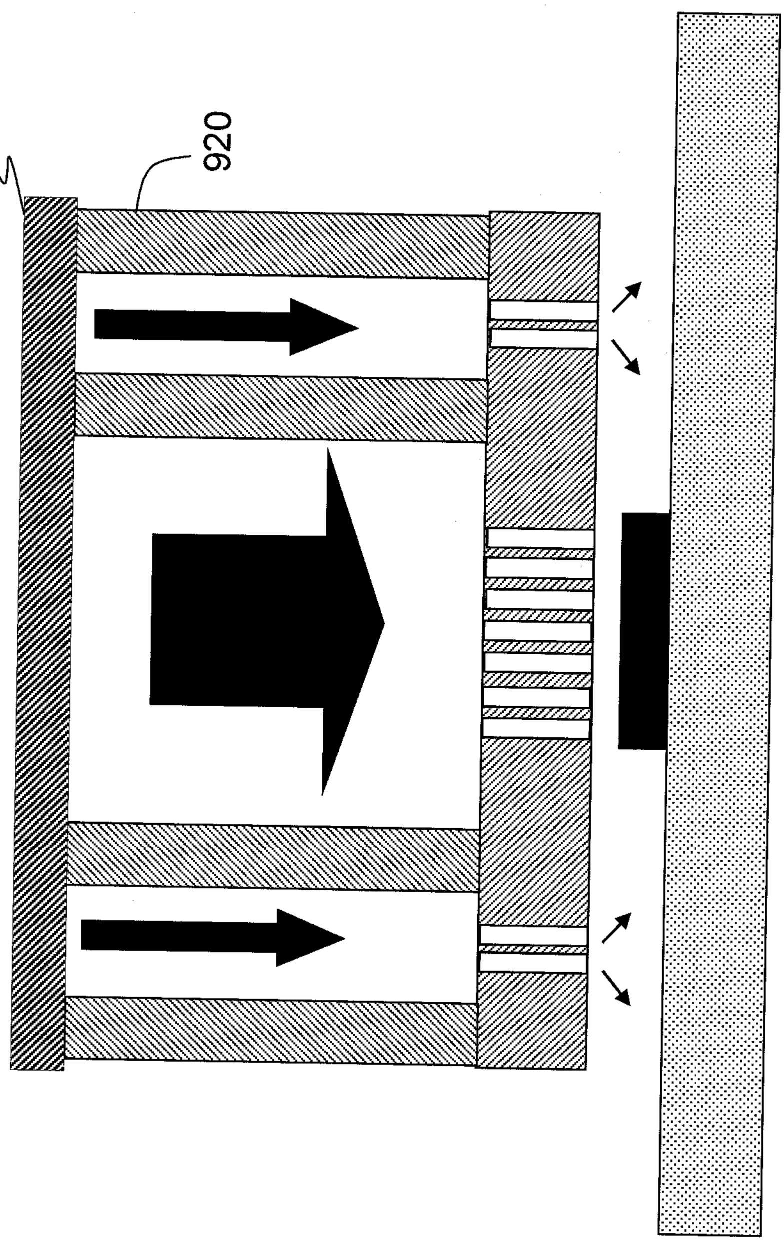


Figure 8



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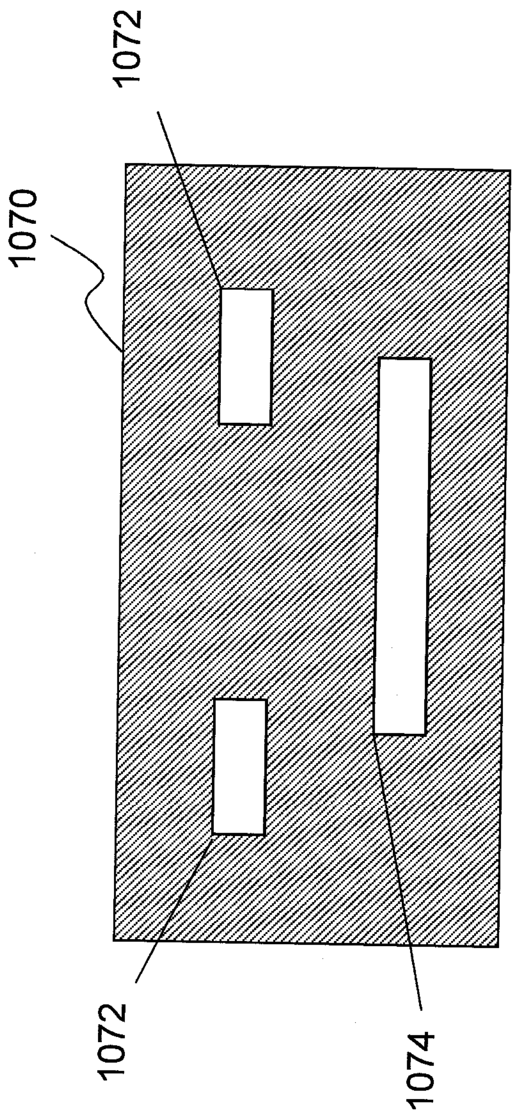


Figure 10

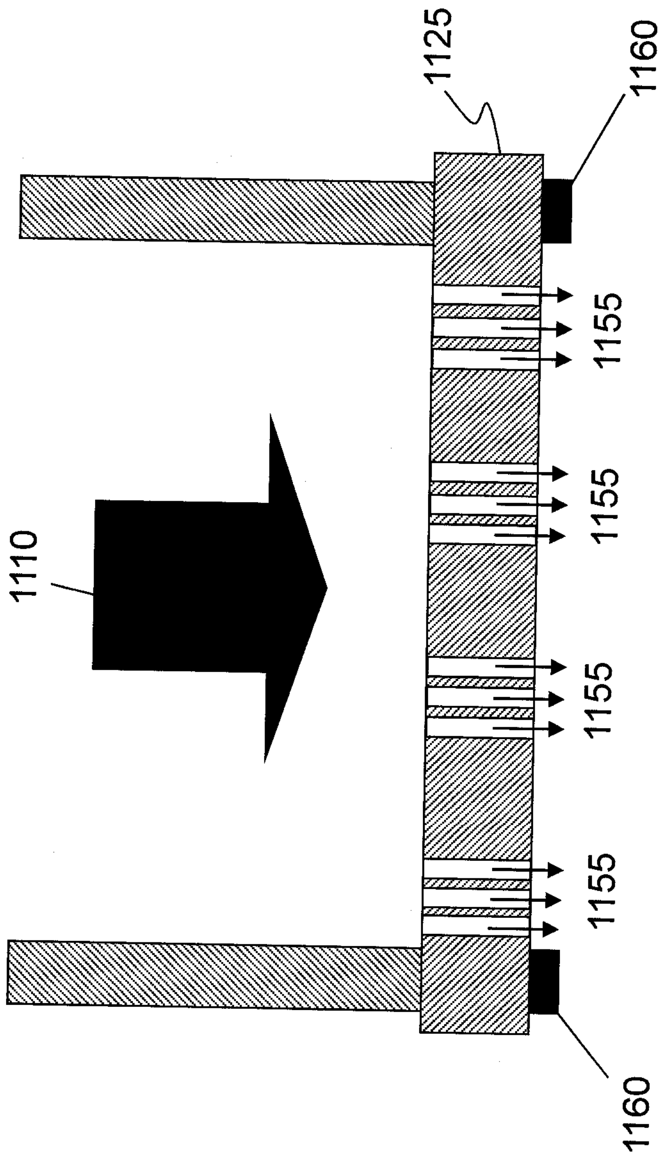
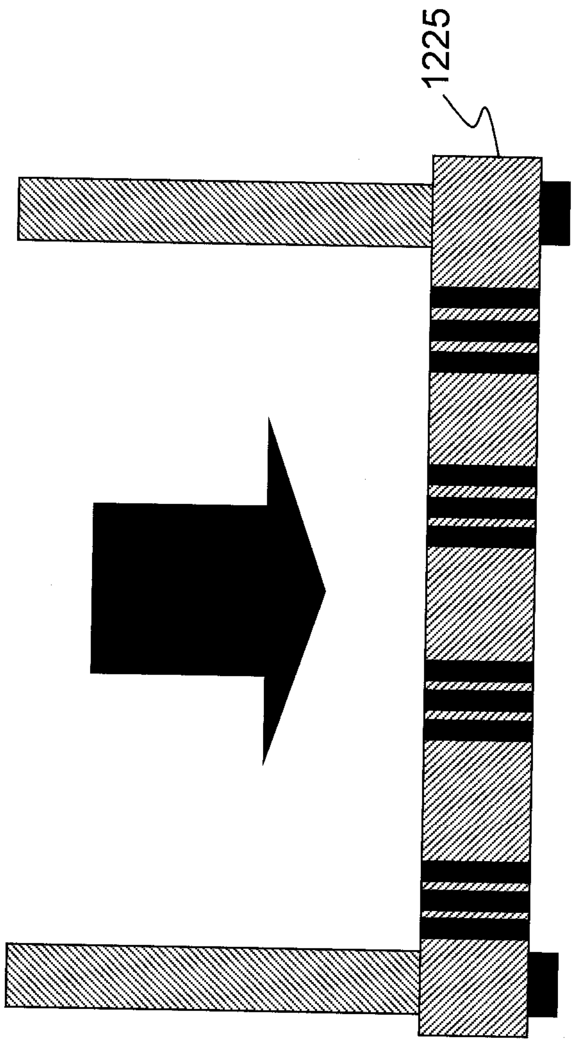


Figure 11



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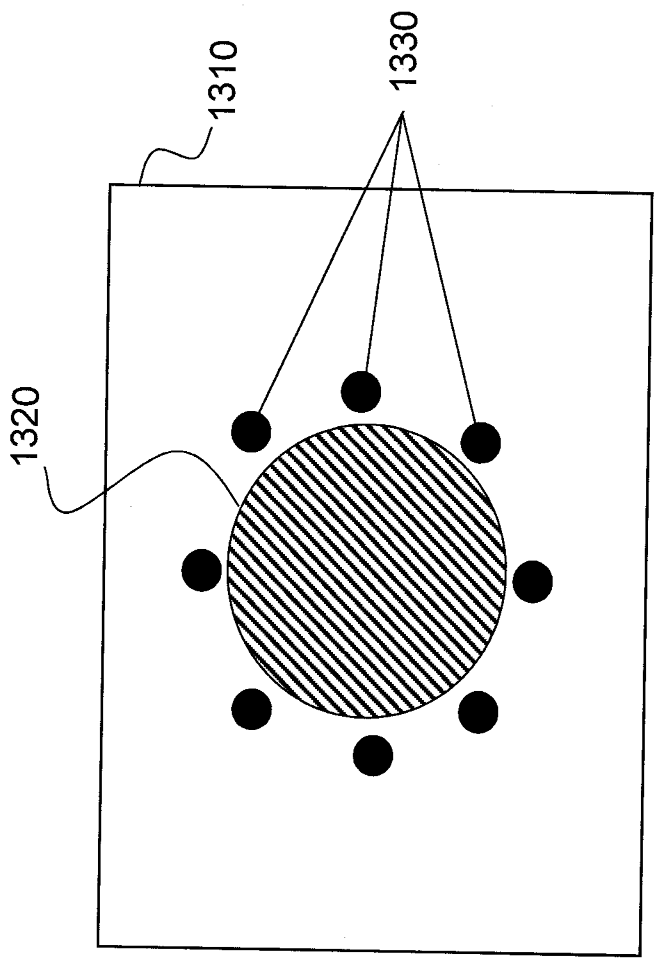

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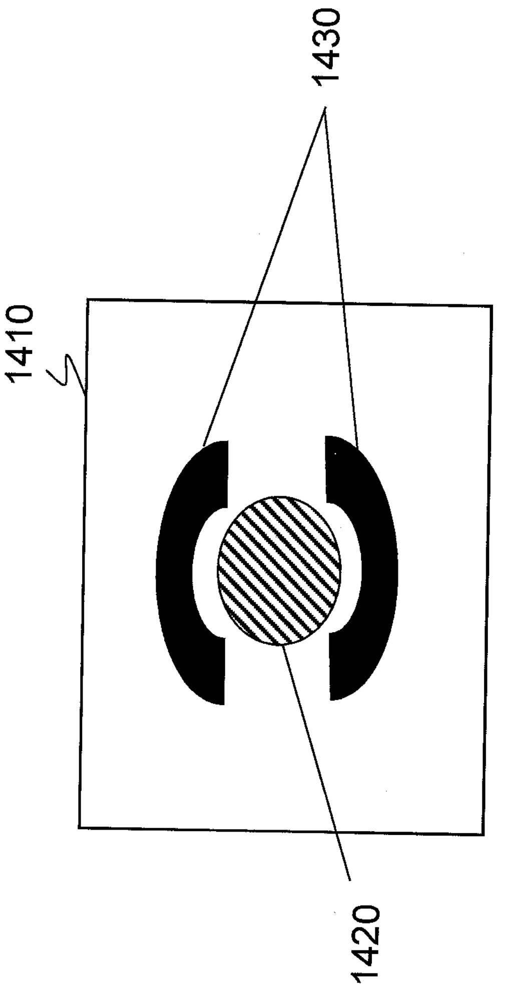

Figure 14

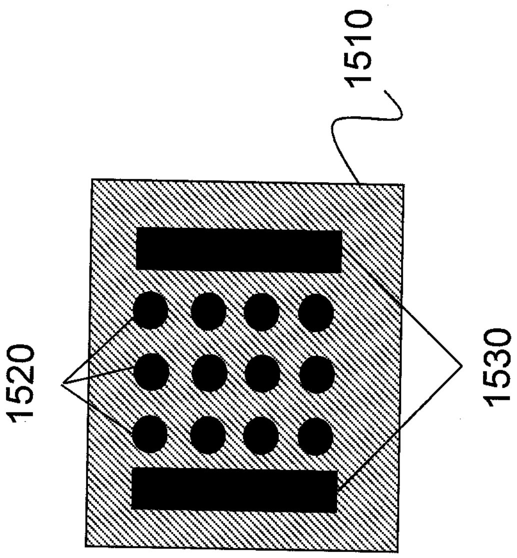

Figure 15

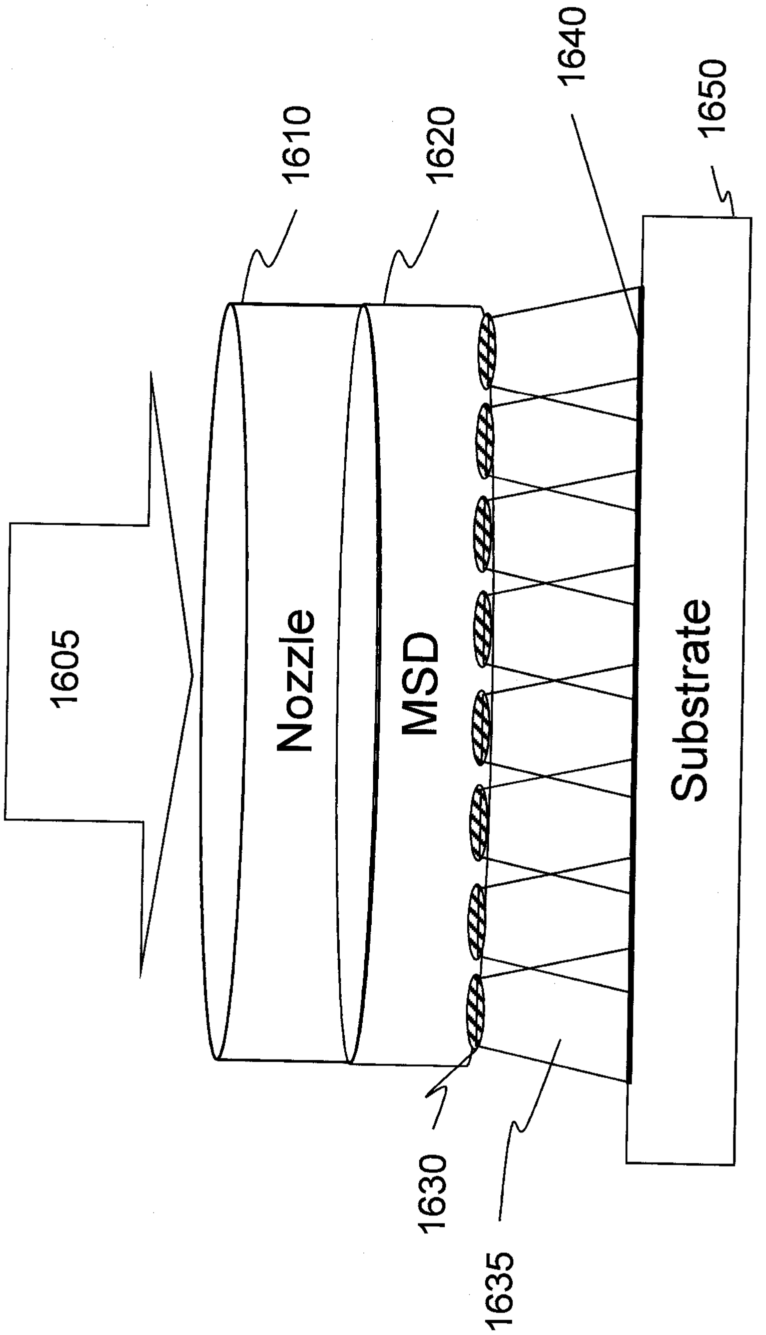

Figure 16