US009385322B2

(12) **United States Patent**
Bulovic et al.

(10) **Patent No.: US 9,385,322 B2**
(45) **Date of Patent: Jul. 5, 2016**

(54) **METHOD AND APPARATUS FOR DEPOSITING LED ORGANIC FILM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 609 days.

(21) Appl. No.: **13/095,619**

(22) Filed: **Apr. 27, 2011**

(65) **Prior Publication Data**

US 2011/0262624 A1 Oct. 27, 2011

Related U.S. Application Data

(60) Division of application No. 11/282,472, filed on Nov. 21, 2005, now Pat. No. 8,128,753, and a continuation of application No. 13/050,907, filed on Mar. 17, 2011, now abandoned, and a continuation of application No. 13/088,323, filed on Apr. 15, 2011, now Pat. No. 8,986,780.

(51) **Int. Cl.**
C23C 16/00 (2006.01)
H01L 51/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01L 51/0011*** (2013.01); ***C23C 16/04*** (2013.01); ***C23C 16/042*** (2013.01); ***C23C 16/448*** (2013.01); ***C23C 16/4481*** (2013.01); ***C23C 16/4483*** (2013.01); ***C23C 16/4485*** (2013.01); ***C23C 16/45568*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC C23C 16/4481; C23C 16/45568; C23C 16/45585; C23C 16/04; C23C 16/4483; C23C 16/45565; C23C 16/448
USPC 427/255.6, 248.1
See application file for complete search history.

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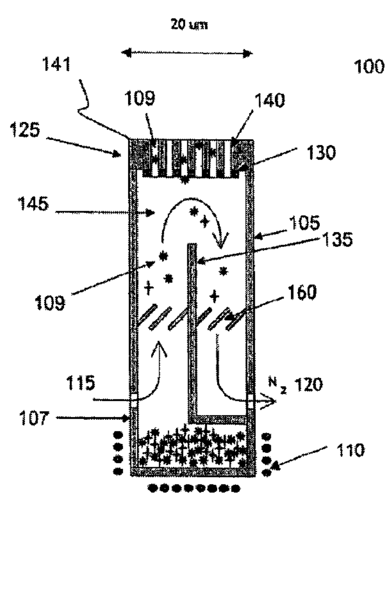
(57) **ABSTRACT**

In one embodiment the disclosure relates to an apparatus for depositing an organic material on a substrate, including a source heater for heating organic particles to form suspended organic particles; a transport stream for delivering the suspended organic particles to a discharge nozzle, the discharge nozzle having a plurality of micro-pores, the micro-pores providing a conduit for passage of the suspended organic particles; and a nozzle heater for pulsatingly heating the micro-pores nozzle to discharge the suspended organic particles from the discharge nozzle.

13 Claims, 5 Drawing Sheets



(51) **Int. Cl.**
C23C 16/448 (2006.01)
C23C 16/455 (2006.01)
C23C 16/04 (2006.01)
B05D 1/12 (2006.01)
H01L 51/56 (2006.01)

(52) **U.S. Cl.**
CPC *B05D1/12* (2013.01); *C23C 16/45565* (2013.01); *H01L 51/56* (2013.01)

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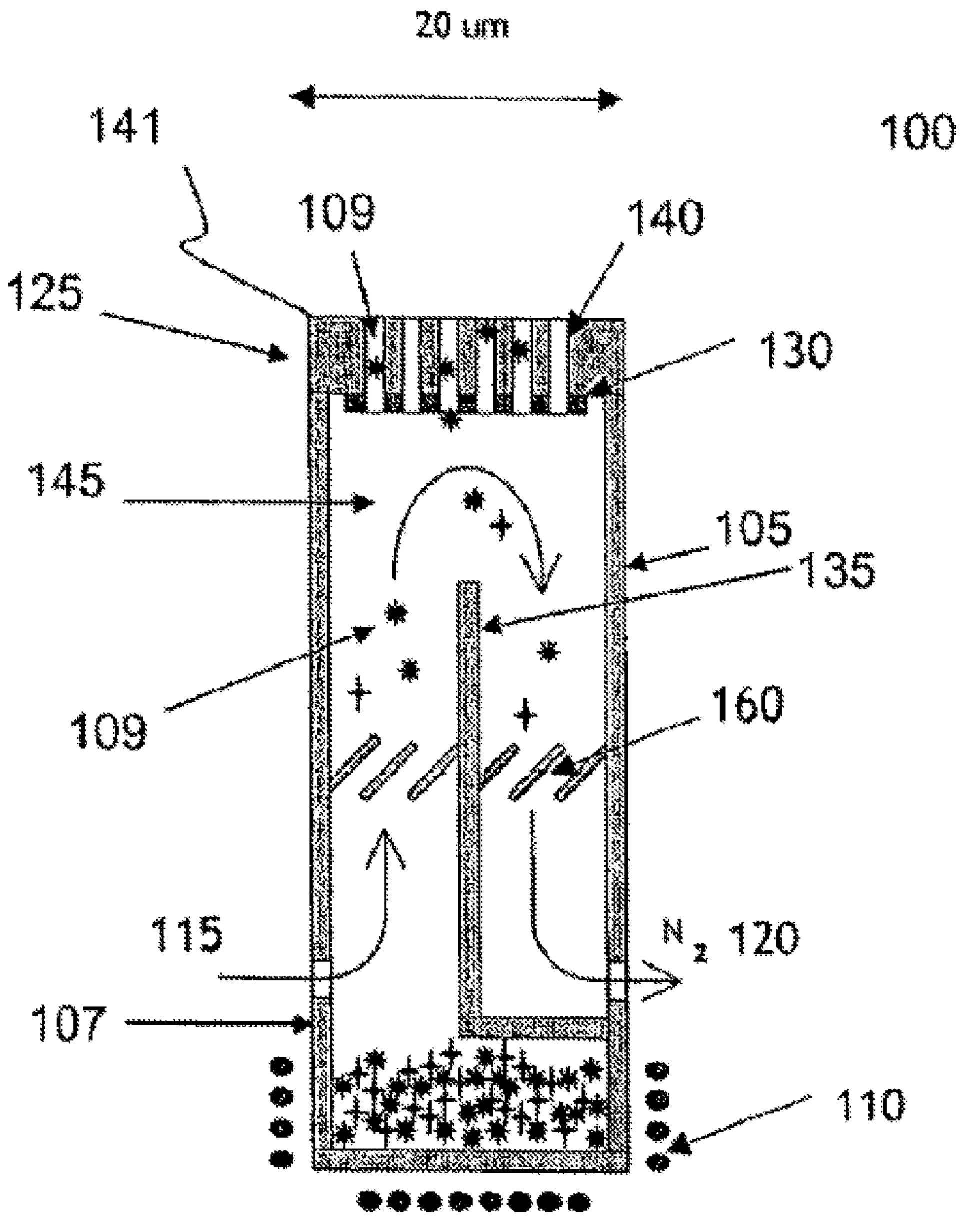
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Fig. 1

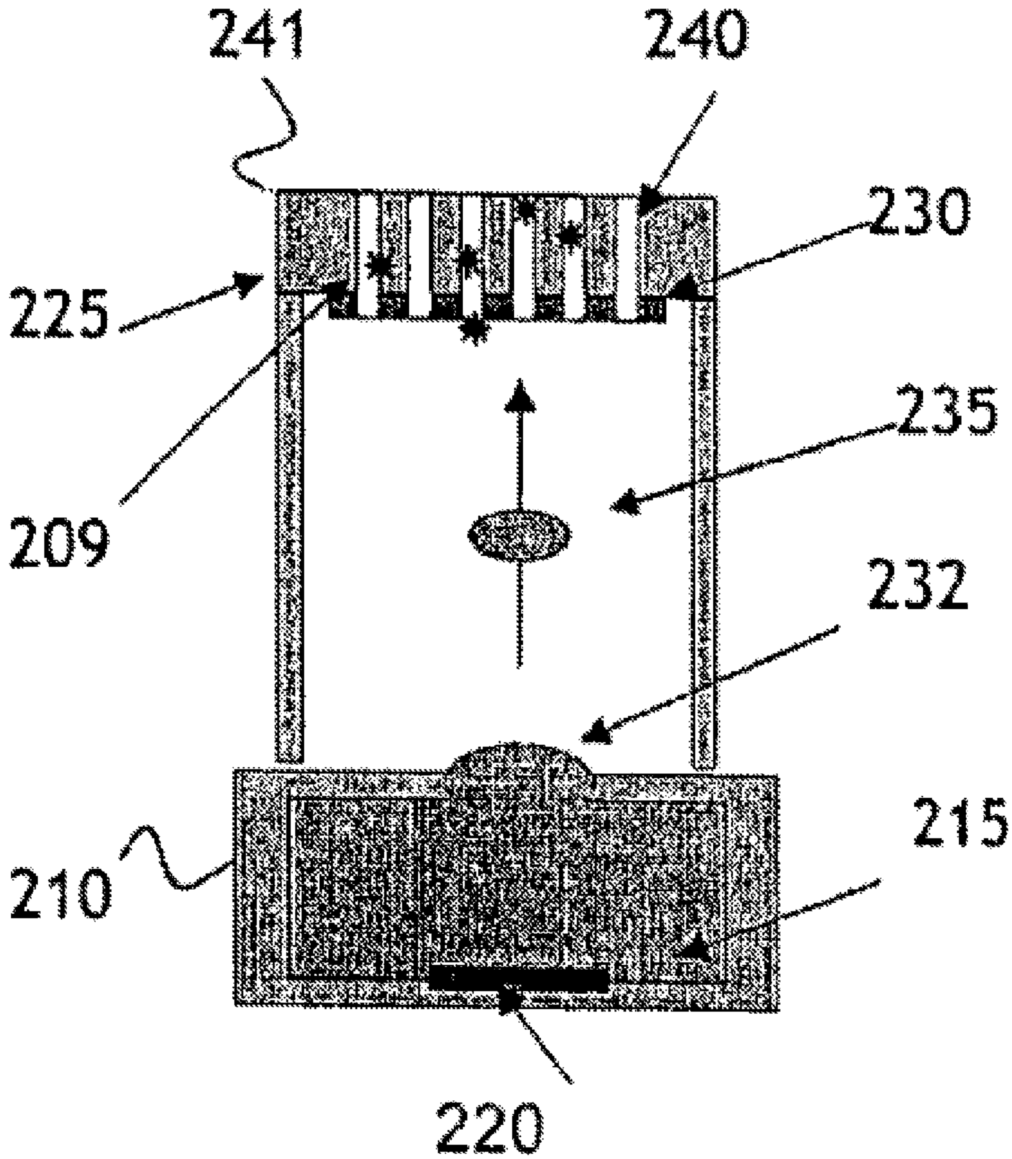


Fig. 2

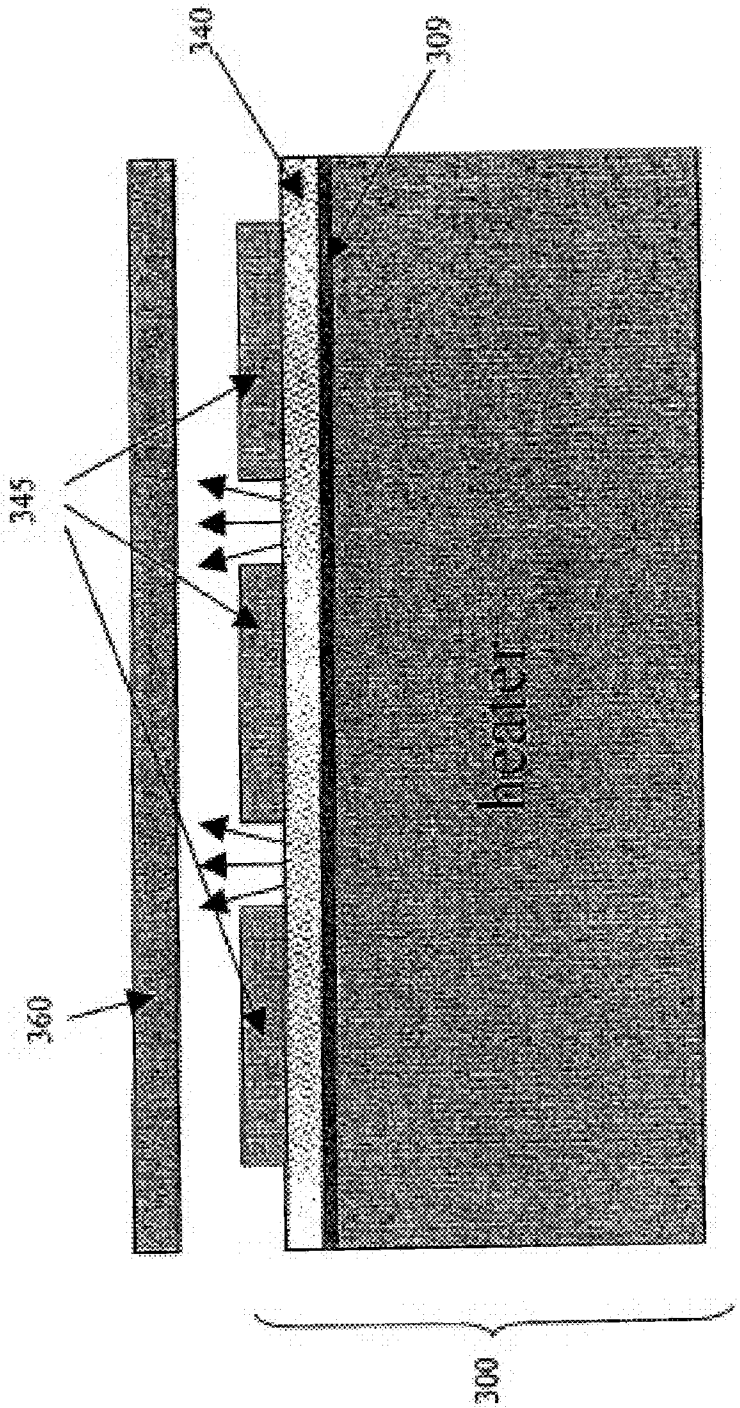
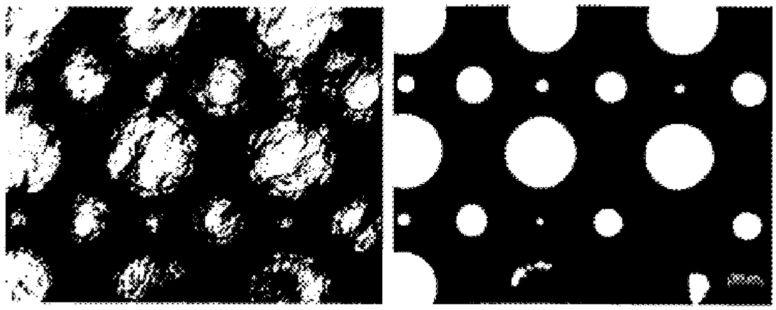


Fig. 3

Fig. 4



(a) (b)

Fig. 5

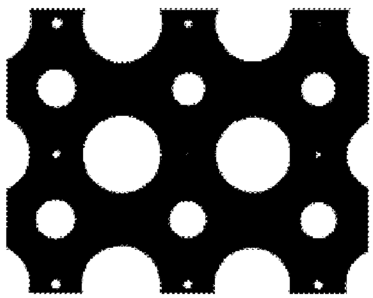
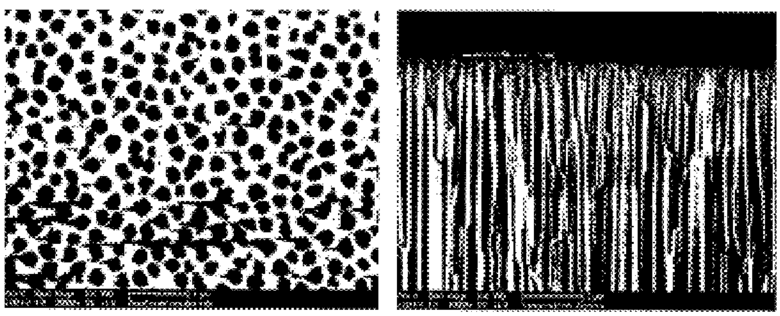


Fig. 6



(a) (b)

(a) cross-section and (b) top view

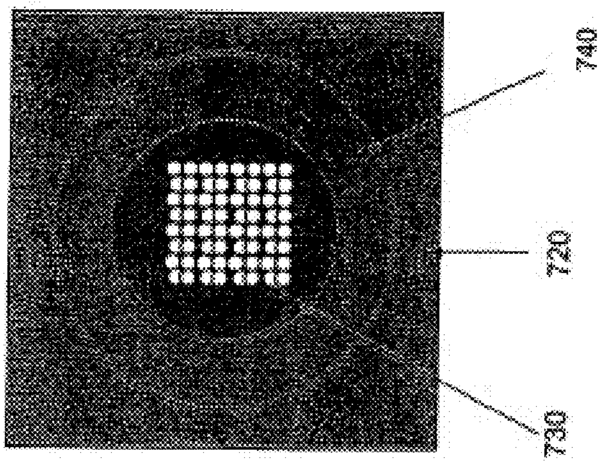


Fig. 7B

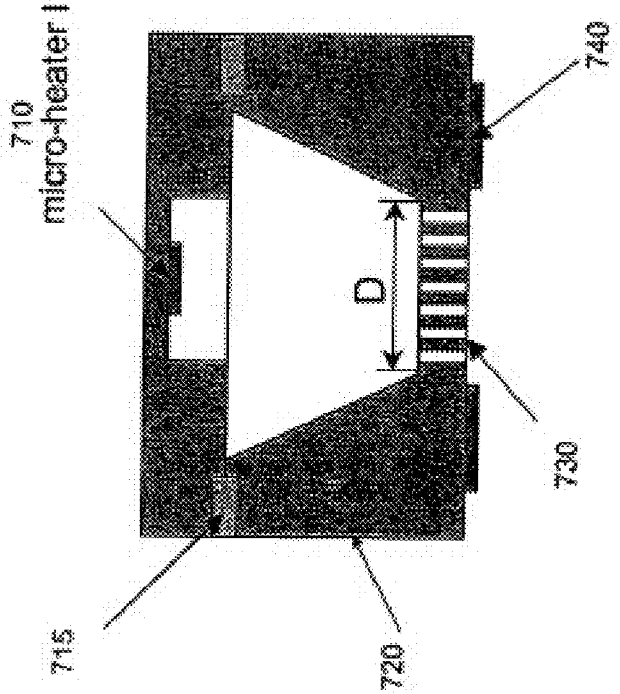


Fig. 7A

METHOD AND APPARATUS FOR DEPOSITING LED ORGANIC FILM

This instant application is a continuation of both U.S. Non-Provisional application Ser. No. 11/282,472 filed Nov. 21, 2005; U.S. Non-Provisional application Ser. No. 13/050,907 filed Mar. 17, 2011; U.S. Non-Provisional application Ser. No. 13/088,323 and claims the filing-date priority to U.S. Provisional Application No. 60/629,312, filed Nov. 19, 2004.

BACKGROUND

The disclosure relates to a method and apparatus for depositing an organic film on a substrate. Manufacturing light emitting diode (LED) cell requires depositing of two thin organic films on a substrate and coupling each of the thin films to an electrode. Conventionally, the deposition step is carried out by evaporating the desired organic film on the substrate. The film thickness is a prime consideration. The layer thickness is about 100 nm and each layer is optimally deposited to an accuracy of about .+−0.10 nm. As a result, conventional apparatus form multiple layers on a substrate with each layer having a thickness of about 10 nm. A combination of these layers will form the overall film. Because the organic constituents of the LED are often suspended in a solvent, removing the solvent prior to depositing each layer is crucial. A small amount of solvent in one layer of deposited organic thin film can cause contamination and destruction of the adjacent layers. Conventional techniques have failed to address this deficiency.

Another consideration in depositing organic thin films of an LED device is placing the films precisely at the desired location. Conventional technologies use shadow masking to form LED films of desired configuration. The shadow masking techniques require placing a well-defined mask over a region of the substrate followed by depositing the film over the entire substrate. Once deposition is complete, the shadow mask is removed to expose the protected portions of the substrate. Since every deposition step starts by forming a shadow mask and ends with removing and discarding the mask, a drawback of shadow masking technique is inefficiency.

SUMMARY OF THE DISCLOSURE

In one embodiment the disclosure relates to an apparatus for depositing an organic material on a substrate, the apparatus comprising: a source heater for heating organic particles to form suspended organic particles; a transport stream for delivering the suspended organic particles to a discharge nozzle, the discharge nozzle having a plurality of micro-pores, the micro-pores providing a conduit for passage of the suspended organic particles; and a nozzle heater for pulsatingly heating the nozzle to discharge the suspended organic particles from the discharge nozzle.

According to another embodiment, the disclosure relates to a method for depositing a layer of substantially solvent-free organic material on a substrate, comprising heating the organic material to form a plurality of suspended organic particles; delivering the suspended organic particles to a discharge nozzle, the discharge nozzle having a plurality of micro-pores for receiving the suspended organic particles; and energizing the discharge nozzle to pulsatingly eject the suspended organic particles from the discharge nozzle. Organic particle may include an organic molecule or a molecular aggregate.

According to another embodiment, the disclosure relates to a method for depositing a layer of organic material on a substrate. The organic material may be suspended in solvent to provide crystal growth or to convert an amorphous organic structure into a crystalline structure. The method can include heating the organic material to form a plurality of suspended organic particles; delivering the suspended organic particles to a discharge nozzle, the discharge nozzle having a plurality of micro-pores for receiving the suspended organic particles; and energizing the discharge nozzle to pulsatingly eject the suspended organic particles from the discharge nozzle. Organic particle may include an organic molecule or a molecular aggregate.

According to still another embodiment, the disclosure relates to an apparatus for depositing an organic compound on a substrate comprising a chamber having a reservoir for receiving the organic compound, the chamber having an inlet and an outlet for receiving a transport gas; a discharge nozzle having a plurality of micro-porous conduits for receiving the organic compound delivered by the transport gas; and an energy source coupled to the discharge nozzle to provide pulsating energy adapted to discharge at least a portion of the organic compound from one of the micro-porous conduits to a substrate.

In yet another embodiment, an apparatus for depositing an organic compound comprises a chamber having a reservoir for housing the organic material dissolved in a solvent, the reservoir separated from the chamber through an orifice; a discharge nozzle defined by a plurality of micro-porous conduits for receiving the organic compound communicated from the reservoir; and an energy source coupled to the discharge nozzle providing pulsating energy for discharging at least a portion of the organic compound from one of the micro-porous conduits to a substrate; and a delivery path connecting the chamber and the nozzle. The organic compound may be substantially free of solvent. Alternatively, the organic compound may include in solvent. In a solvent-based system, the solvent discharge from the nozzle provides the added benefit of cooling the nozzle upon discharge.

In still another embodiment, a micro-porous nozzle for depositing an organic composition on a substrate includes a thermal source communicating energy to organic material interposed between the heater and a porous medium, the porous medium having an integrated mask formed thereon to define a deposition pattern.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of a discharge apparatus for discharging organic compounds, or its mixture, according to one embodiment of the disclosure;

FIG. **2** is a schematic representation of a discharge apparatus for discharging organic compounds according to another embodiment of the disclosure;

FIG. **3** schematically illustrates a discharge nozzle according to one embodiment of the disclosure;

FIGS. **4**A and **4**B show an image printed according to one embodiment of the disclosure;

FIG. **5** is a photoluminescence image of a pattern printed by molecular jet printer system;

FIGS. **6**A and **6**B show the surface and the cross section, respectively, of a porous medium; and

FIGS. **7**A and **7**B illustrate a molecular jet printing apparatus according one embodiment of the disclosure in cross-sectional and top views, respectively.

DETAILED DESCRIPTION

In one embodiment, the disclosure relates to a method and apparatus for depositing a pure organic thin film, or a mixed organic film, or an organic thin film mixed with inorganic particles, or inorganic thin film on a substrate. Such films can be used, among others, in the design and construction of organic LED.

FIG. **1** is a schematic representation of a discharge apparatus for discharging organic compounds, or its mixture, according to one embodiment of the disclosure. Referring to FIG. **1**, exemplary apparatus for deposing an organic material on a substrate includes housing **105** having discharge nozzle **125** at one end and a reservoir **107** at another end. Reservoir **107** may contain organic constituents required for forming an LED film. The organic constituent may be liquid or solid. Heat source **110** is provided to heat reservoir **107** and the content thereof. Heat source **110** can provide heating of about 100-700.degree. C.

Housing **105** may optionally include inlet **115** and outlet **120**. The inlet and outlet can be defined by a flange adapted to receive a carrier gas (interchangeably, transport gas.) In one embodiment, the carrier gas is an inert gas such as nitrogen or argon. Delivery path **135** can be formed within housing **105** to guide the flow of the carrier gas. Thermal shields **160** may be positioned to deflect thermal radiation from heat source **110** to thereby protect discharge nozzle **125** and organic particles contained therein.

In the exemplary embodiment of FIG. **1**, the discharge section includes discharge nozzle **125** and nozzle heater **130**. Among others, the discharge nozzle can be formed from anodized porous aluminum oxide or porous silicon membranes or other solid membranes. Such material are capable of blocking organic material from escaping through the porous medium when the organic material is delivered onto the porous medium's surface. Discharge nozzle **125** includes rigid portions **141** separated by micro-pores **140**. Micro-pores **140** block organic material from escaping through the medium until the medium is appropriately activated. Depending on the desired application, micro-pores **140** can provide conduits (or passages) in the order of micro- or nano-pores. In one embodiment, the pore size is in the range of about 5 nm-100 microns. In another embodiment pores are about 100 nm to about 10 microns. Nozzle heater **130** is positioned proximal to the discharge nozzle **125**. When activated, nozzle heater **130** provides a pulse of energy, for example as heat, to discharge nozzle **125**. The activation energy of the pulse dislodges organic material **109** contained within micro-pores **140**.

In a method according to one embodiment of the disclosure, reservoir **107** is commissioned with organic material suitable for LED deposition. The organic material may be in liquid or solid form. Source heater **110** provides heat adequate to evaporate the organic material and form suspended particles **109**. By engaging a carrier gas inlet **115**, suspended particles **109** are transported through thermal shields **160** toward discharge nozzle **125**. The carrier gas is directed to gas outlet **120** through delivery path **135**. Particles **109** reaching discharge nozzle are lodged in micro-pores **130**. Activating nozzle heater **130** to provide energy to discharge nozzle **125** can cause ejection of organic particles **109** from the discharge nozzle. Nozzle heater **130** can provide energy in cyclical pulses. The intensity and the duration of each pulse can be defined by a controller (not shown.) The activating energy can be thermal energy. A substrate can be positioned immediately adjacent to discharge nozzle **125** to receive the ejected organic particles. Applicants have discovered that the exemplary embodiment shown in FIG. **1** can form a think organic film on a substrate with great accuracy. The embodiment of FIG. **1** is also advantageous in that it can substantially reduce substrate heating, minimizes local clogging and provide the most efficient use of organic material.

FIG. **2** is a schematic representation of a discharge apparatus for discharging organic compounds according to another embodiment of the disclosure. Referring to FIG. **2**, apparatus **200** is adapted for forming an organic film substantially free from solvent. Apparatus **200** includes reservoir **210** for receiving organic solution **215**. In one embodiment, organic solution **215** contains organic material dissolved in a solvent. Thermal resistor **220** is positioned proximal to reservoir **210** to heat organic solution **215**. Orifice **232** separates reservoir **210** from discharge nozzle **225**. Discharge nozzle **225** comprises micro-pores **240** separated by rigid sections **241**.

Because of the size of orifice **232**, surface tension of organic solution prevents discharge of organic solution **215** from the reservoir until appropriately activated. Once thermal resistor **220** is activated, energy in the form of heat causes evaporation of droplet **235** within a chamber of apparatus **200**. Solvents have a lower vapor pressure and evaporate rapidly. Once evaporates, organic compound within droplet **235** is transported to discharge nozzle **225**. Discharge nozzle **225** receives the organic material **209** within micro-pores **240**. The solvent can be recycled back to organic solution **215** or can be removed from the chamber (not shown). By activating nozzle heater **230**, micro-pores **240** dislodge organic particles **209**, thereby forming a film on an immediately adjacent substrate (not shown.) In one embodiment, nozzle heater **230** can be activated in a pulse-like manner to provide heat to discharge nozzle cyclically.

FIG. **3** schematically illustrates a discharge nozzle according to one embodiment of the disclosure. In FIG. **3**, discharge nozzle **300** comprises heater **330**, porous medium **340** and integrated mask **345**. Heater **330** is communicates pulse energy in the form of heat to organic material **309** causing dislodge thereof from porous medium **340**. Integrated mask **345** effectively masks portions of the porous medium from transmitting organic ink material **309**. Consequently, a film forming on substrate **360** will define a negative image of the integrated mask.

Thus, in one embodiment, the particles can be discharged from the porous medium by receiving thermal energy from a proximal resistive heater, or a thermal radiation heater, or by electrostatic force pull out of the micro-porous, or by mechanical vibration.

FIGS. **4**A and **4**B show an image printed according to one embodiment of the disclosure. Specifically, FIG. **4** shows the printing result using the exemplary apparatus shown in FIG. **3**. The ink material is Alq3 and was pre-coated on the backside of an anodized porous alumina disc. FIG. **4**A shows the LED organic printed pattern under halogen illumination. FIG. **4**B shows the photoluminescence image under UV illumination.

FIG. **5** is a photoluminescence image of a pattern printed by molecular jet printer system according to another embodiment of the disclosure. FIG. **5** was obtained by using the discharge nozzle shown in FIG. **3**. The ink material was Alq3. The ink material was drop cast on the backside of anodized porous alumina disc.

FIGS. **6**A and **6**B show the surface and the cross section, respectively, of a porous medium. The porous medium can be used according to the principles disclosed herein with a discharge nozzle or as a part of a nozzle having an integrated mask (see FIG. **3**.) FIG. **6**A shows the surface of the porous medium. FIG. **6**B shows a cross-section of the porous medium. FIG. **6**A shows a scale of 1 μm and FIG. **6**B has a scale of 2 μm.

FIGS. **7**A and **7**B illustrate a molecular jet printing apparatus according to an embodiment of the disclosure in cross-sectional and top views, respectively. Referring to FIG. **7**A, printing apparatus **700** includes micro-heater **710** which can be used as a liquid delivery system. Wafer bonding layer **715** connects the liquid delivery system to nozzle section **720**. Porous openings **730** are positioned at a discharge end of nozzle **720** and micro-heaters **740** are positioned adjacent to porous openings **730** to providing energy required to eject organic material or ink from nozzle **720**. FIG. **7**B shows a top view of the nozzle shown in FIG. **7**A including porous openings **730** and heaters **740**.

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 depositing a layer of substantially solvent-free organic material on a substrate, comprising:

heating the organic material to form a plurality of suspended organic particles;

delivering the suspended organic particles to a discharge nozzle, the discharge nozzle having a plurality of micro-pores for receiving the suspended organic particles;

processing the suspended organic particles through the plurality of micro-pores to substantially block a portion of the suspended organic particles; and

energizing the discharge nozzle to pulsatingly eject the suspended organic particles from the plurality of micro-pores onto the substrate.

2. The method of claim further comprising positioning the discharge nozzle proximal to the substrate.

3. The method of claim **1**, wherein the step of energizing the discharge nozzle further comprises heating the discharge nozzle.

4. The method of claim **1**, wherein the step of delivering the suspended organic particles further comprises transporting the suspended organic particles with a carrier gas.

5. The method of claim **4**, wherein the carrier gas is inert.

6. The method of claim **1**, wherein the step of energizing the discharge nozzle further comprises mechanically vibrating the discharge nozzle.

7. The method of claim **1**, wherein processing the suspended organic material further comprises processing the suspended organic material through micro-pores having a porous medium to separate a quantity of organic particles from a quantity of solvent.

8. The method of claim **1**, wherein processing the suspended organic material further comprises separating an organic material from a solvent.

9. The method of claim **1**, further comprising deflecting thermal radiation from the discharge nozzle.

10. A method for depositing substantially solvent-free organic film on a substrate, the method comprising:

transporting an OLED solution from a reservoir to a discharge nozzle, the OLED solution having OLED particles in a solvent;

receiving the OLED solution at a plurality of micro-pores of the discharge nozzle, each micro-pore containing a porous medium;

separating a quantity of OLED particles from the solvent at the porous medium of the micro-pores;

removing the solvent from the discharge nozzle; and

dislodging the quantity of organic particles from the discharge nozzle onto a substrate.

11. The method of claim **10**, wherein transporting an OLED solution from a reservoir to a discharge nozzle further comprises heating the OLED solution.

12. The method of claim **10**, wherein the OLED solution comprises a quantity of OLED particles dissolved in solvent.

13. The method of claim **10**, further comprising heating the discharge nozzle to dislodge the quantity of organic particles.

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