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Fellowship

Optomec Manual

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Introduction

Optomec is a new powerful tool for additive manufacturing. It is changing the way materials are printed or adhered to substrates and/or features. The Optomec is an aerosol jet printer and will be my main focus on this project. It has the unique capabilities including a small minimum feature size (10 um) and it can apply a wide range of inks or materials with varying viscosities, for example from 1 cP to 1000 cP. This manual is a documentation that will accompany the user-friendly tutorial videos. These are guidelines that will explain how to use the Optomec effectively and suggest some of the novel things that one can achieve with them for projects in robotics, medical devices, etc. It can support research on a wide range of applications including device with resistors and transistors on flexible electronics. It can even support biological applications, where it can deposit live cells on a wide variety of substrates. It will be widely useful to future researchers in robotics, medical devices, bio-hybrid machines, etc. As an example application depositing PEdot on flexible PDMS substrates for electrostatic adhesion and sensing systems in robotics.

Tutorial set up videos are ideal to help new users and non frequent users get up to speed on the tool. Please view all the videos and review this document before attending training. These videos show the step by step process on how to assemble, disassemble the machine, convert CAD models, and design layouts into the software which commands the machine to print. These online videos are available at all times so the user can review as many times as needed and has some prior knowledge before coming to the first training session. This manual will live next to the Optomec and will be used when the user is operating the machine.

Video Tutorials:

- Introduction to the Optomec - <https://youtu.be/2DnvTfhusZ0>
- Virtual Impactor - <https://youtu.be/mzuX0bs4qNU>
- Fine Feature Nozzle - https://youtu.be/fEx_XbdmbhE
- Wide Nozzle - <https://youtu.be/uPdCfDcnj4g>
- VM Tools Software - <https://youtu.be/pj4lFR-dEcE>
- Pneumatic Atomizer - <https://youtu.be/IFBBkoEolWc>
- Ultrasonic Atomizer - <https://youtu.be/IFBBkoEolWc>

Standard Operating Procedure for Pneumatic Atomizer Mode

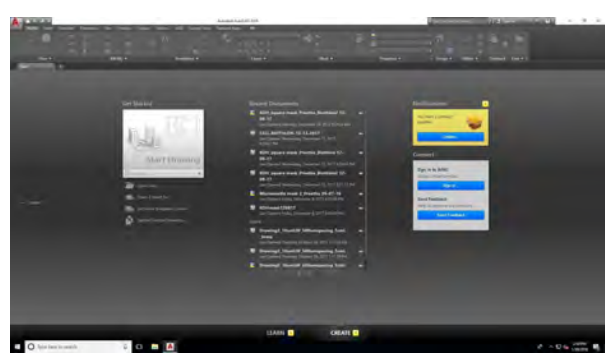
This section covers topics related to Optomec standard operating procedure under the pneumatic atomizer mode with a fine feature printhead, including generation of Optomec-compatible print pattern files, Optomec system assembly and initialization, troubleshooting of common hardware and software issues, disassembly, and the minimum cleaning protocol.

1. Generating Print Pattern Files Using VMTools (30 mins)

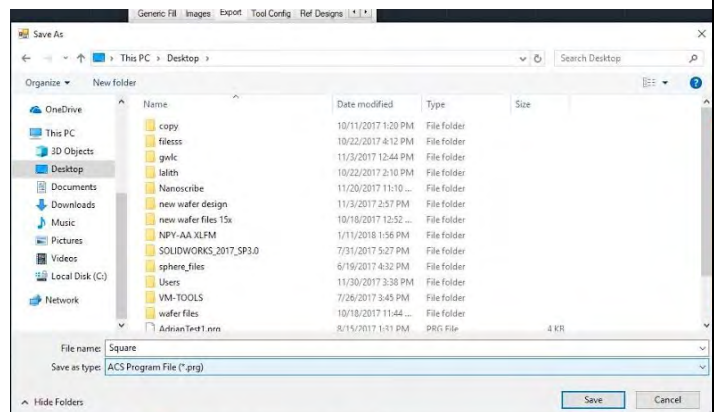
SNF offers computers with VMTools-installed AutoCAD software, and this section intends to provide an overview on how to generate Optomec-compatible print pattern files. A user may refer to VMTools Manual and AutoCAD Manual for details on specific software functions.

VM Tools Software Video - <https://youtu.be/pj4IFR-dEcE>

1. Create print patterns using AutoCAD or other CAD software and **save it as a drawing file in .DXF** which is the only format supported by VMTools. Since Optomec interprets the CAD data in millimeters, it is recommended to set the AutoCAD dimensions in millimeters when designing the print patterns.

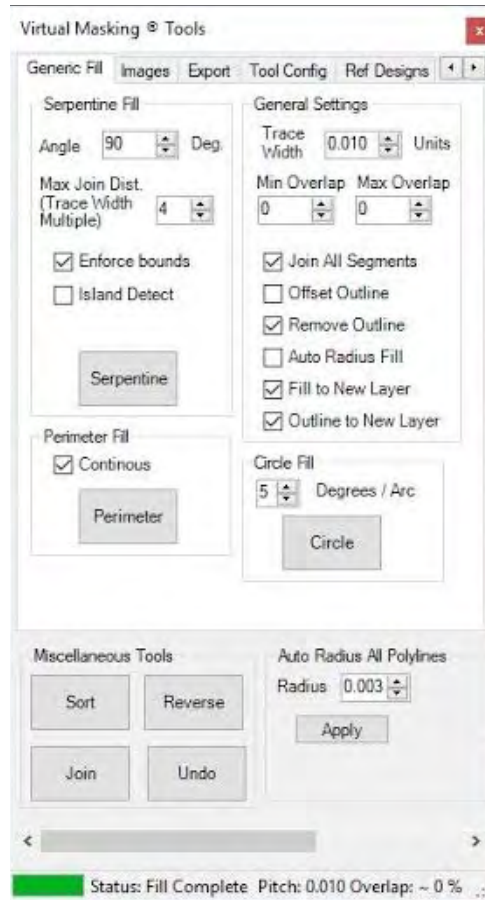


2. Make sure to **save** any changes to the print pattern .DXF file if your imported it from another CAD software before importing to VMTools. Click on the VMTools icon on the AutoCAD Draw menu to start VMTools. This will open a VMTools utility window with several tabs, including Import, Generic Fill, Images, Export, Tool Config, etc.



3. In the “Import” tab of VMTools utility window, **click the “Import Dxf”** button to import the currently open .DXF file in AutoCAD.

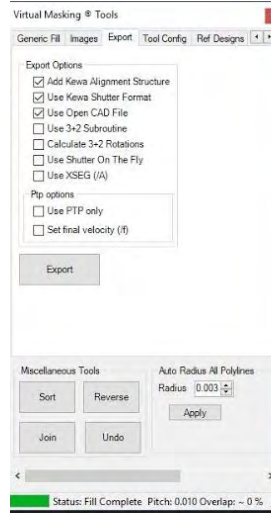
4. **Click the “Generic fill” tab.** In the “Generic Fill” tab, the user can specify the filling method (serpentine, perimeter, circle) for various closed shapes. Before proceeding to specifying the filling method, first adjust the items under “General Setting” box which is also presented in the Generic Fill tab. The item **“Trace Width” specifies how wide the line of deposited ink will be.** The default value is 0.1 mm but it can be adjusted to any value in the range of 0.005 ~ 5 mm. The input trace width value is what VMTools and Optomec believe the printed line width will be, and therefore it is not necessarily representative of the actual printed line width. Therefore, this parameter should be adjusted after measurement of printed lines for a specific ink, substrate, and set of printing conditions. If the ink, substrate or printing conditions are changed, the user must print and measure again to determine the actual input trace width.



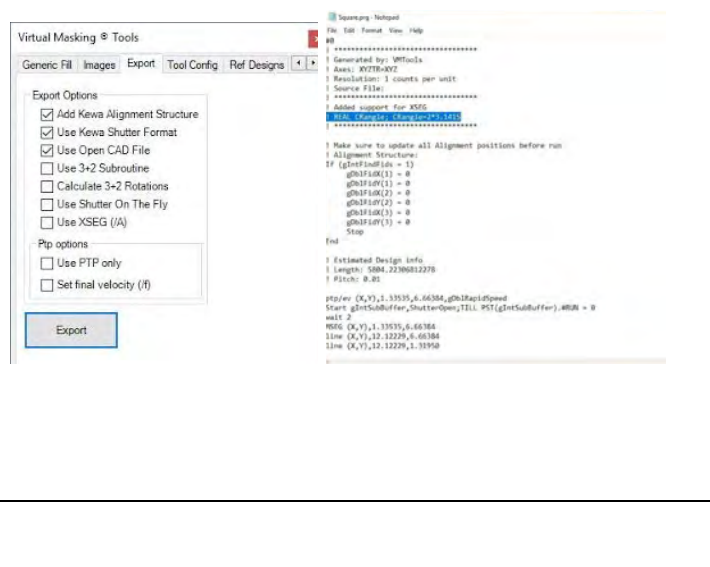
5. **Click the filling method button of choice,** and then select the shape entities to be filled in AutoCAD.



6. Click the “Export” tab. In the “Export” tab, the user may define the shutter delay time (msec). By clicking “Export” button, the user can create the toolpath file in **.prg format** which contains motion and shutter commands for Optomec to print the designed patterns.



7. Open the exported **.prg file** with notepad. We observed that the exported **.prg file** presents a syntax error - there is a line comment that is missing its corresponding comment character maker ('!'). To solve this issue, **add “!” in front of the line that starts with “REAL CRangle;...”** to comment the line and fix the syntax error. Other command lines can also be suppressed by adding “!” in front. 8. If the user is familiar with programming, such as MATLAB, the user may create a custom toolpath generation/optimization code, as there can be unexpected errors with VMTools (e.g. random creation of extra command lines).



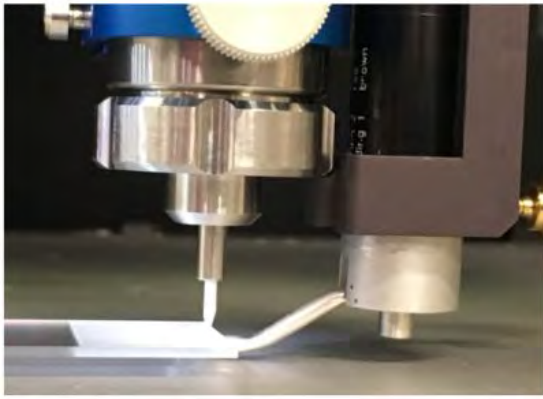
8. **Save** your new **.prg** onto your USB stick.

You are now ready to start setting up the machine!

2. Tool setup (30 mins)

1. **Design the print patterns using AutoCAD and VMTools** as described in the above [Section 1](#). While print patterns can be edited manually at the printer for simple paths, we recommend using VMTools for most cases.
2. **Assemble and install** the nozzle and atomizing assembly, as described in Section 4-6.

3. **Calibrate the height of the nozzle tip** and shutter with respect to the printing substrate.



4. Ensure that the **settings on the machine** (bottom right cabinet under the Optomec) are as desired.
 - a. For fine-feature nozzle printing, the switch must be set to “0.5X head”. For wide nozzle printing, the switch must be set to “wide nozzle”.
5. For cleaning after, make sure that there is more than 1.5 bottles of isopropyl alcohol and 1/4 of a bottle of Branson cleaning solution underneath the hood in room 155. Depending on the printing specifics, more or less cleaning may be required – this is a general guideline for how much cleaning supplies are needed.

3. Turning on the machine (5 mins)

At this point the machine can be **enabled in SNF Badger**.

1. **Enable** the machine (nSIL>patterning>Optomec-printer).
2. If the computer is locked, the password is Optomec1.
3. On the computer desktop, **double click the KEWA gadget shortcut** to open the KEWA gadget interface.
4. **Press “start all”** to initialize all KEWA applications. For correct monitoring of the tool status and operation, we suggest arranging the following KEWA applications in the PC monitor in such a way they are constantly visible:
 - (a) KEWA Process Control
 - (b) KEWA Motion Manager
 - (c) KEWA Vision Manager
5. In KEWA Process Control, select the device controls tab for the atomizer type you will be using. We will walk through the pneumatic case but it is the same for the ultrasonic. Select the **‘Pneumatic’ tab**. Before successful atomization, the processes described in the following sections must be completed.
6. Hit the **green power on button** on the control panel
7. At any time you need to **emergency stop** the machine press the **EMO button**.





Control panel

After you hit the EMO button to disengage the button rotate it clockwise and press the blue reset button. After 10 seconds the motion controller will automatically re-enable the axes.

4. Assembly (Pneumatic Atomizer Mode, Fine Feature Printhead) (20 mins)

The Optomec setup begins with assembling the machine. This is an overview of the three important components that will be necessary to run the tool. The atomizer will take your material and atomize it and it will go through the virtual impactor and out the printhead. The exploded views of the three main subassemblies illustrate how individual parts fit together with the O-rings: (1) pneumatic atomizer Figure 1, (2) virtual impactor Figure 2, and (3) printhead Figure 3.

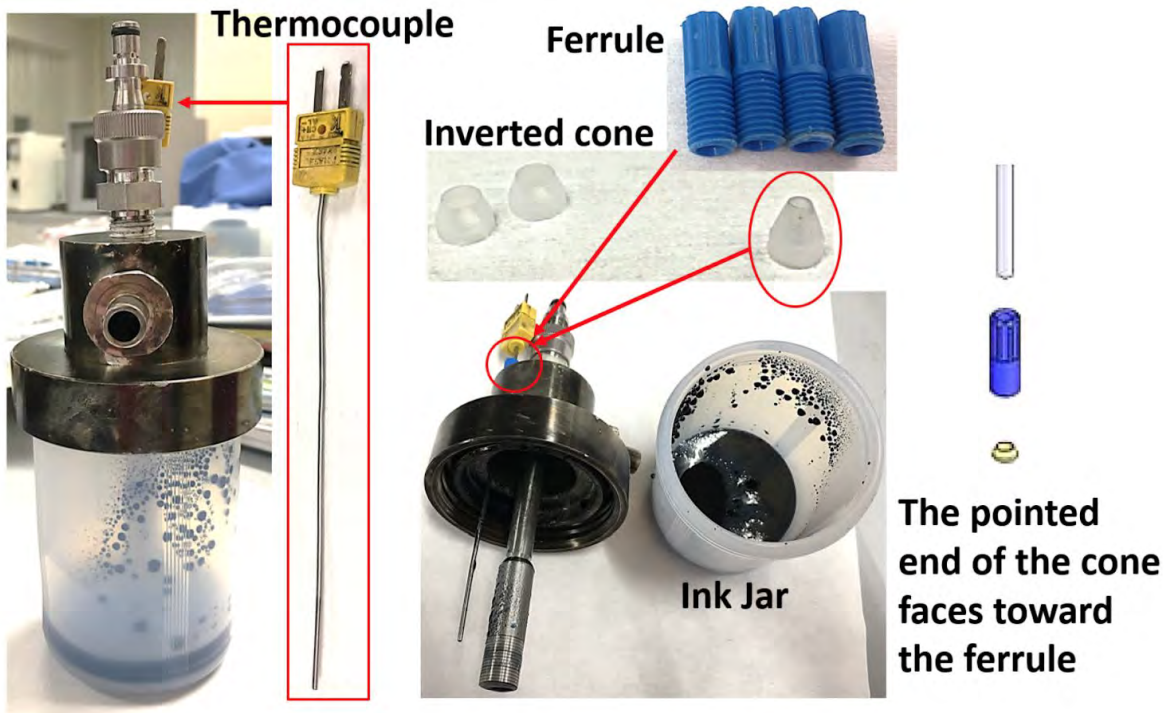


Figure 1: Pneumatic atomizer assembly

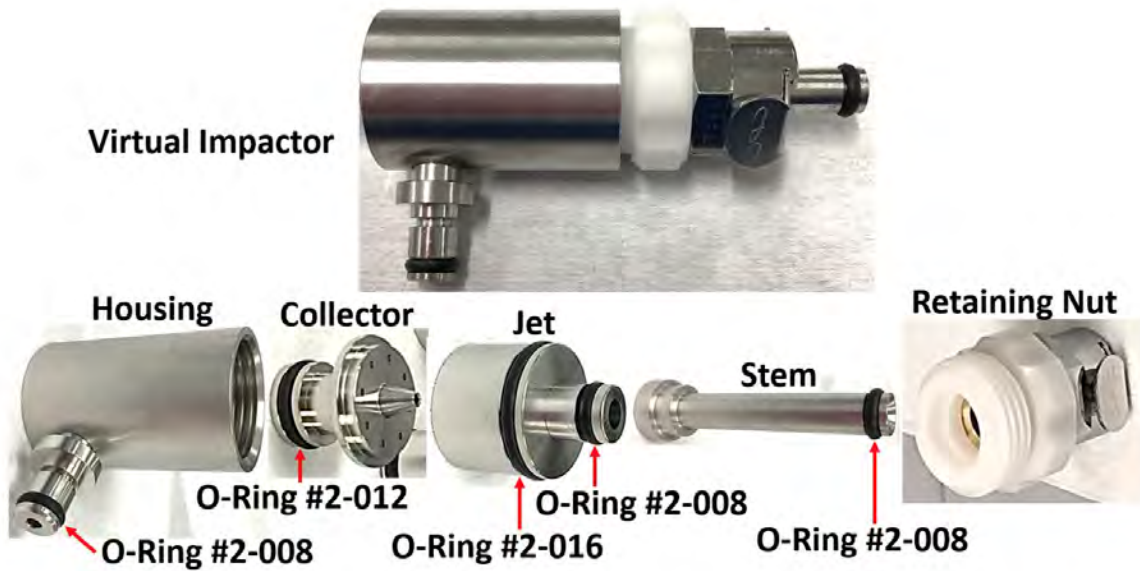


Figure 2: Fully assembled Virtual impactor (Top). The O-ring numbering and exploded view (bottom).

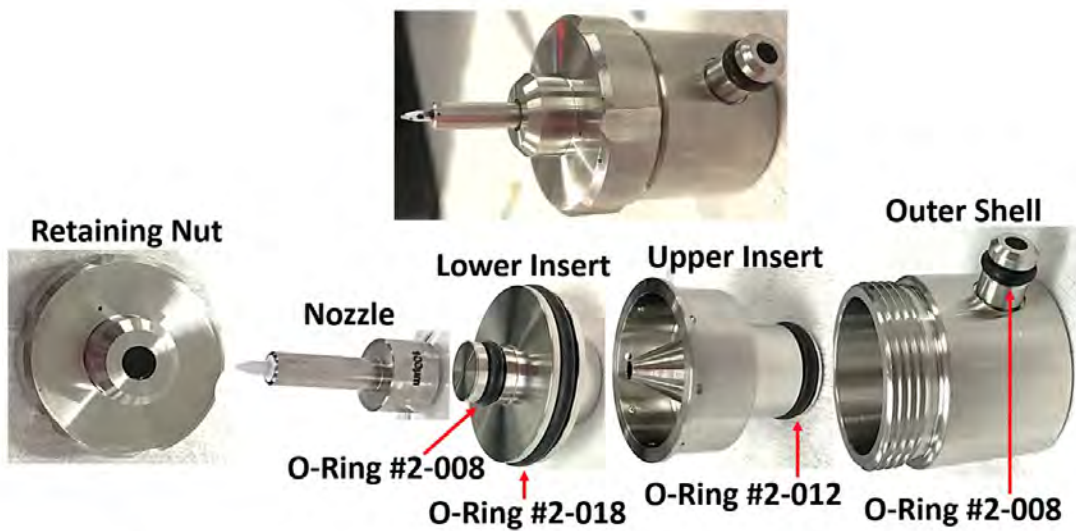


Figure 3: Fully assembled Fine feature nozzle (Top). The O-ring numbering and exploded view (bottom).

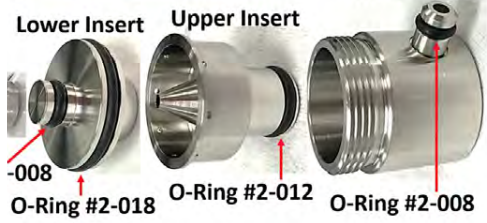


4.1 Assembly preparation

The following section is about assembly preparation. You will need to do the following steps before setting up the machine.

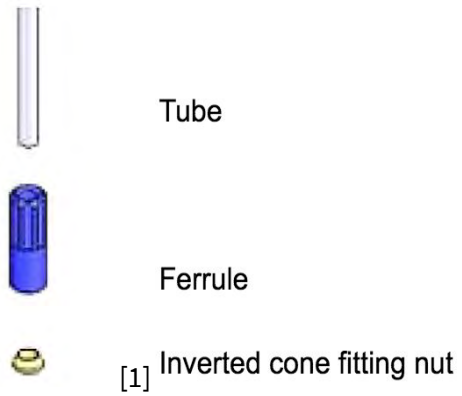
Virtual Impactor - <https://youtu.be/mzuX0bs4qNU>

Fine Feature Nozzle - https://youtu.be/fEx_XbdmbhE

Wide Nozzle - <https://youtu.be/uPdCfDcnj4g>

<p>1. Visually inspect the O-rings for imperatives or any defective (e.g. cracks, deep scratches, improper fit). Replace with new O-rings as needed if you see cracks, tears or excessive wear. Review video as well for replacing O-rings</p>	 <p>Lower Insert Upper Insert</p> <p>O-Ring #2-018 O-Ring #2-012 O-Ring #2-008</p>
<p>2. Apply sufficient lubricant (Apiezon L Grease) to the O-rings using cotton swabs. Refer to the user video for how to grease the O-rings.</p> <p>Virtual Impactor - https://youtu.be/mzuX0bs4qNU</p>	
<p>3. Using the tube cutter, cut a section of 1/8-in PFA tubing (Swagelok, P/N: PFA-T2-030-100, OD 0.125", Wall 0.030") into a length sufficient for connecting the printhead with the virtual impactor. Make sure that there is extra length to accommodate the movement of the printhead, but not enough to result in slacking or coiling of the tube, which can cause agglomeration of the ink aerosols inside the tube. It is important that the cut end of the tube is flat and pristine (no angled edge, no cut debris) to avoid gas leakage. (In troubleshooting for leaks, look for tubing that is cut at an angle)</p>	

4. Insert first the inverted cone and then the ferrule (Omni-lock inverted cone fitting nut) to the tube such that the pointed end of the cone points toward the ferrule.



5. **Assemble the atomizer cap** (Figure 4), then pour the ink into the jar (30 mL of ink is the recommended volume, any less volume may adversely affect the aerosolization process), and ensure the tight closure of the jar with the cap.

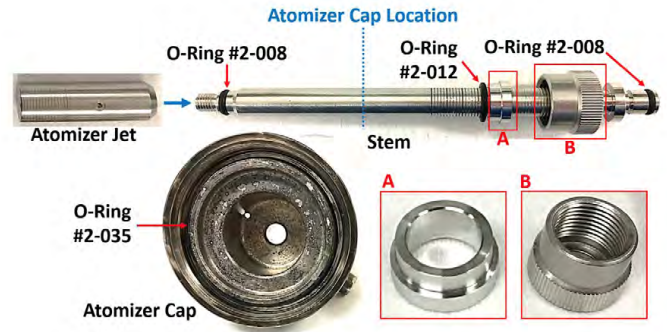
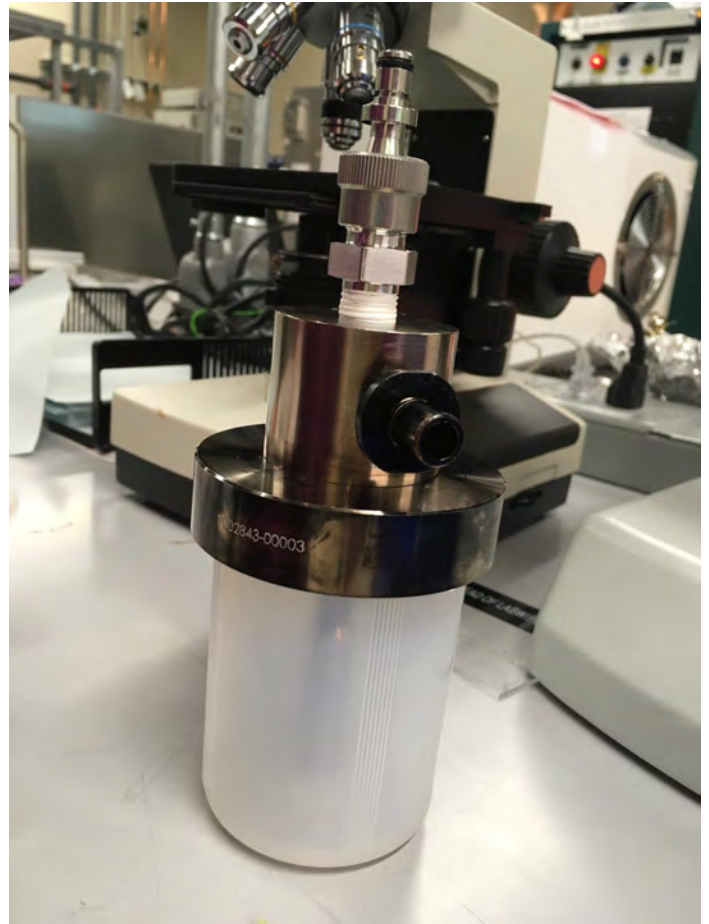
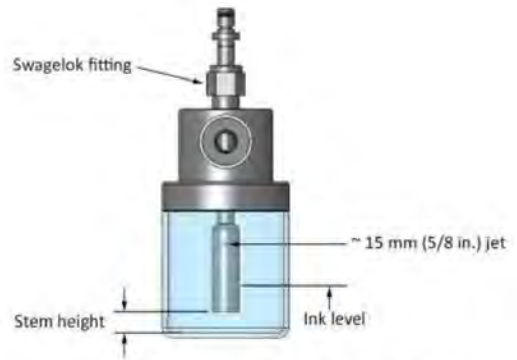


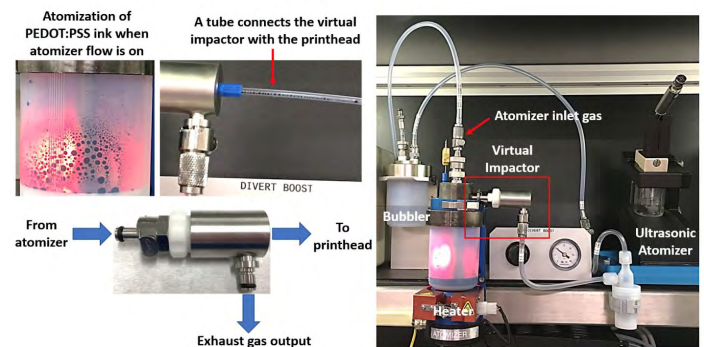
Figure 4: The exploded view of the pneumatic atomizer stem (Top). The O-ring numbering, atomizer cap(Bottom).



6. **Adjust the position of the atomizer stem** by loosening the Swagelok fitting around the stem such that the bottom of the atomizer jet is close to the bottom of the jar without touching it. The exact position is not critical. *However, it is important to ensure that the atomizer jet hole is approximately 15 mm (= 5/8 in.) above the surface of the ink because any deeper immersion of the atomizer jet hole into the ink may result in the interference between the ink surface and the atomizer jet operation.*



7. Once the pneumatic atomizer, virtual impactor, and printhead are assembled, install them in the Optomec and connect the parts as illustrated in Figure 5.



This section shows you what the pneumatic aerosol virtual impactor connections look like. The pneumatic atomizer bubbler and the ultrasonic atomizer are shown for reference.

1. Atomization of PEDOT:PSS ink when atomizer flow is on



2. The tube connects the virtual impactor with the printhead.



3. Diagram of where the atomizer, printhead and exhaust gas output leads into the Virtual impactor



4. Pneumatic aerosol virtual impactor connections. The pneumatic atomizer bubbler and the ultrasonic atomizer are shown for reference.

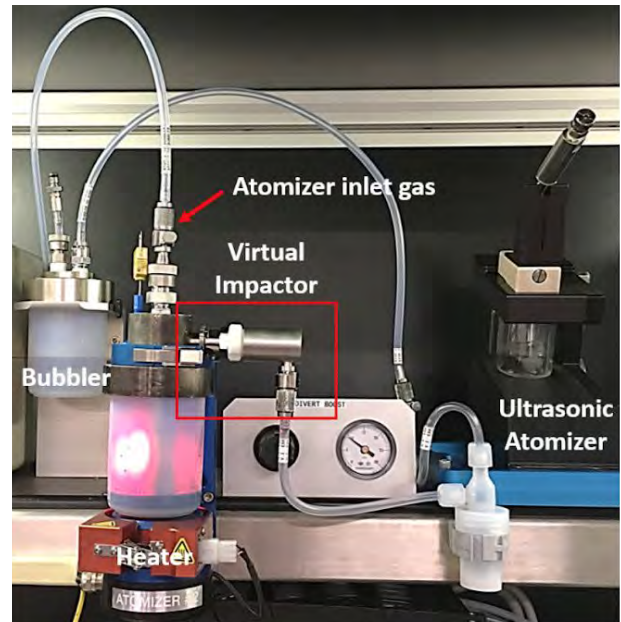
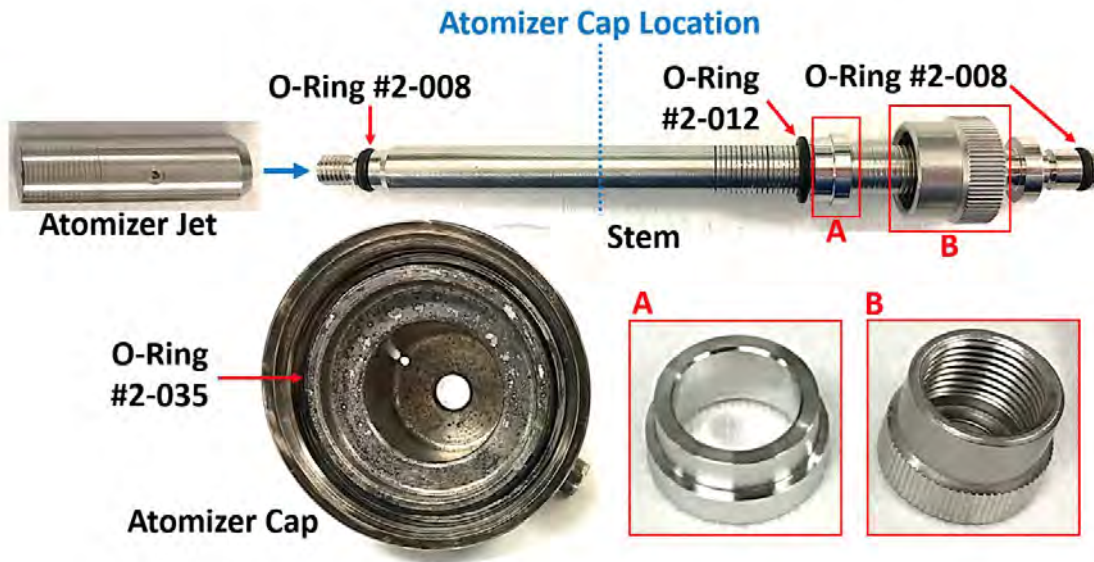


Figure 6: Pneumatic aerosol virtual impactor connections. The pneumatic atomizer bubbler and the ultrasonic atomizer are shown for reference.

4.2 Atomizer Cap Assembly

We will be going into detail the assembly of the atomizer cap. Here is an exploded view and the O-ring sizes.



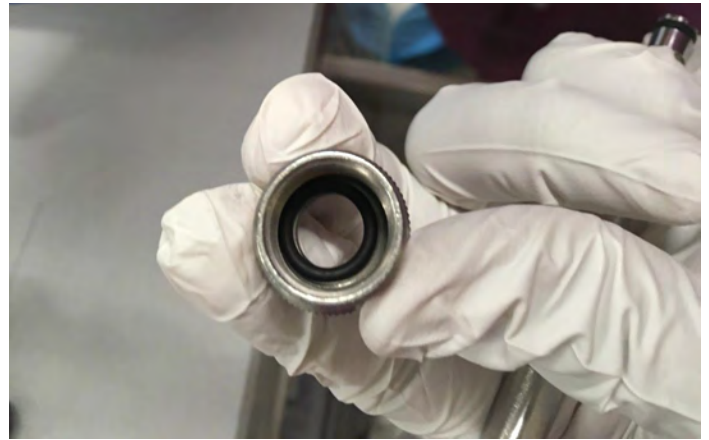
Pneumatic Atomizer Video - <https://youtu.be/IFBBkoEolWc>

Ultrasonic Atomizer Video - <https://youtu.be/IFBBkoEolWc>

1. Take the Atomizer cap



2. Check the O-ring for cracks and grease it before assembling the cap.

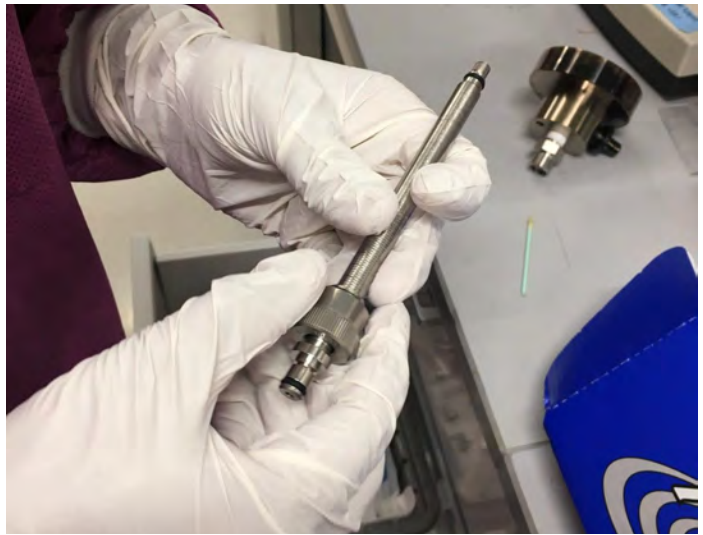


3. Put the O-ring #2-012 on the stem.

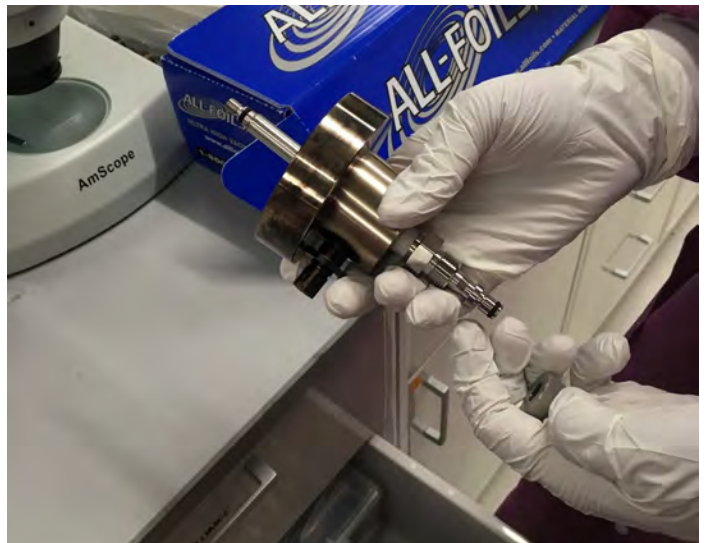




4.Screw on the nut.



5. Insert stem into atomizer cap. Be sure to carefully hold onto the stem and cap while inserting stem.



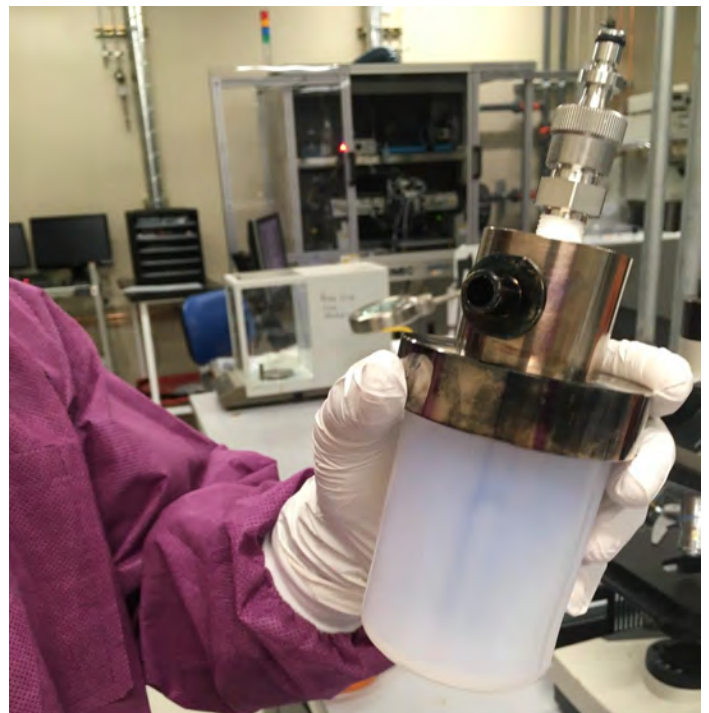
6. Take out the atomizer jet.



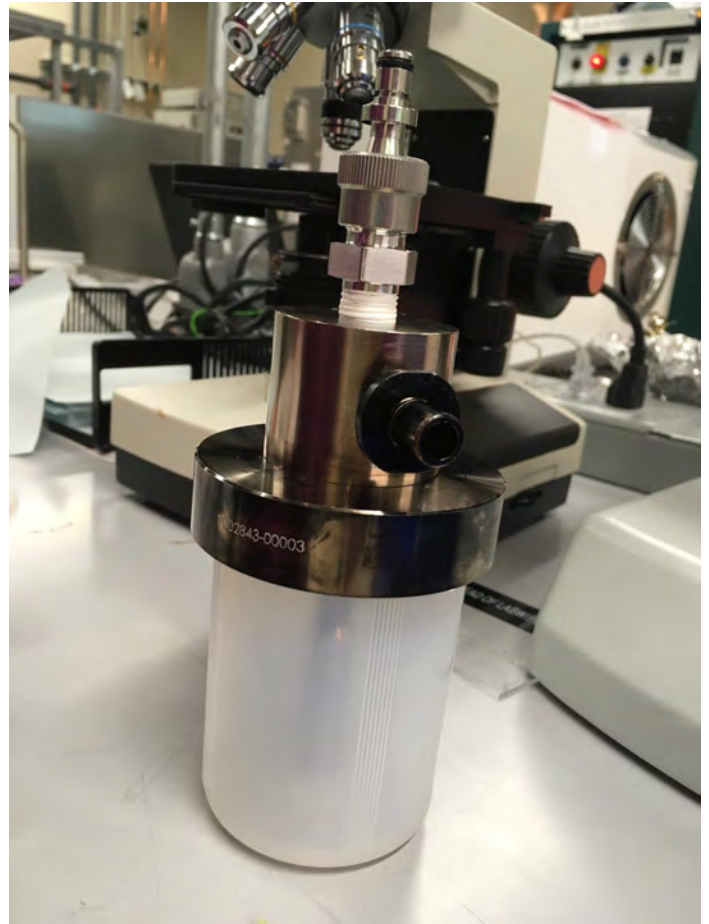
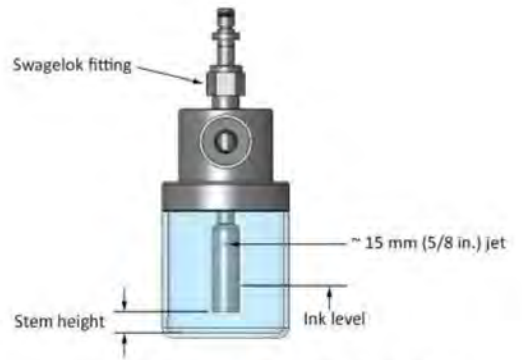
7. Screw on the atomizer jet.



8. Lastly screw the jar after you fill it with your desired liquid.



9. Make sure the ink level is 15mm below the small hole on the side of the jet. If the jet is immersed any deeper into the ink, the surface of the ink might interfere with the jet's operations.



10. Connect the tubing and insert the atomizer into the machine.

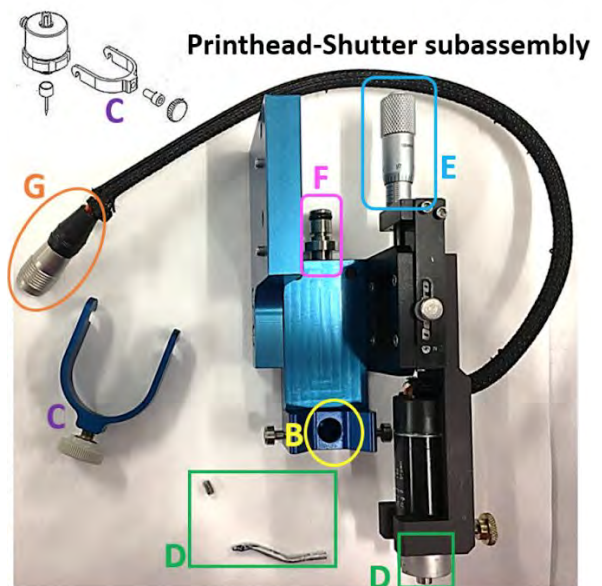


4.3 Printhead Shutter Subassembly

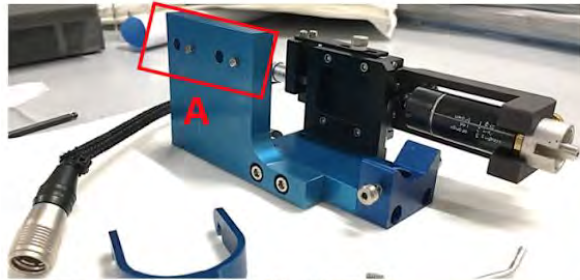
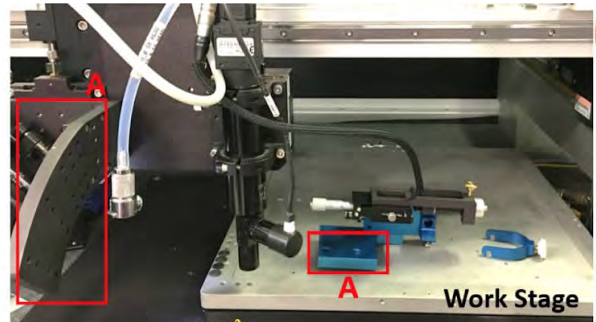
The following section shows how to connect the printhead shutter subassembly.

1. The printhead-shutter subassembly is done by (1) making the B-B connection which is then fixed by part C (mounting the printhead) and (2) making the D-D connection (mounting the shutter using a tiny hex screw).

Wide Nozzle Assembly Video -
<https://youtu.be/uPdCfDcnj4g>

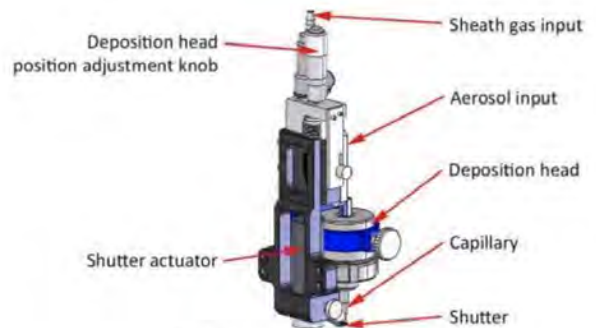
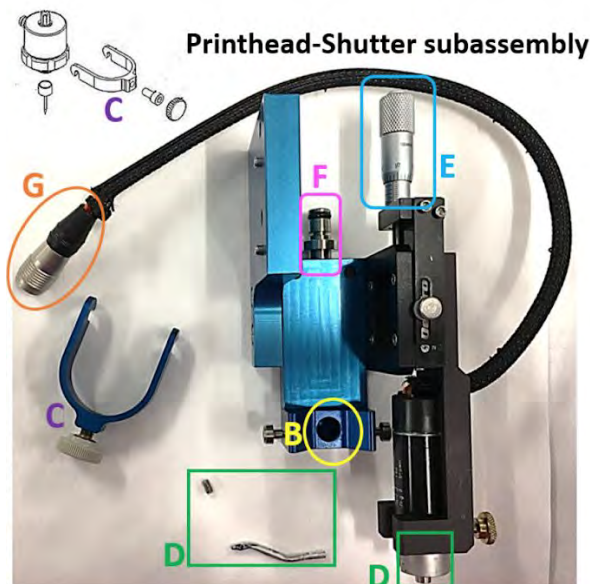


2. The printhead-shutter subassembly is then physically mounted to the Optomec system by making the A-A connection which can be done at various angles (i.e. the direction of the nozzle tip with respect to the work stage can be perpendicular or at some angle).



Close up image of nozzle holder

3. Connect part G of the printhead-shutter subassembly to the Optomec system to make electrical connection. The knob E allows the z-axis height adjustment of the shutter with respect to the substrate. While the printhead is connected to the virtual impactor by cutting tubing as described above in the [assembly preparation](#) section, a separate tube from the Optomec setup connects to the inlet F of the printhead-shutter subassembly as the sheath gas input.



Fine feature printhead exploded view and assembled with labels view

As shown in Figure 4, Optomec offers the alignment camera, which allows the user to view the substrate, as well as the process camera, which allows the user to observe the aerosol stream during printing. They are set up around the work stage on which the substrate is placed. Camera focusing and adjustments can be performed after enabling the tool in Badger, as is described below.

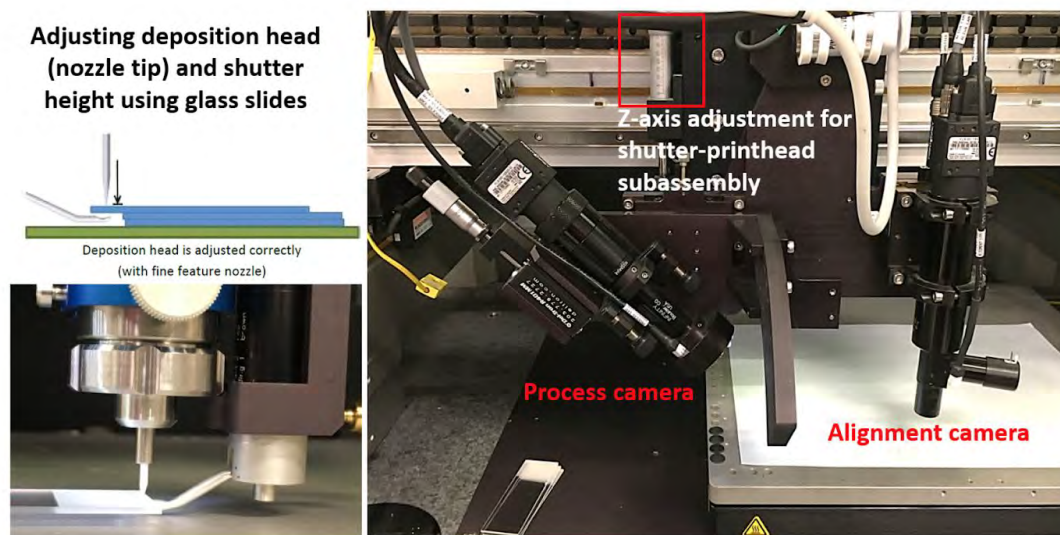
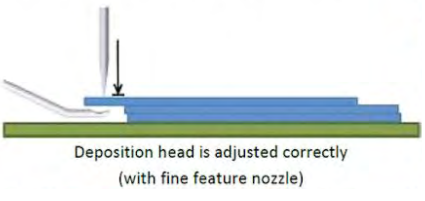
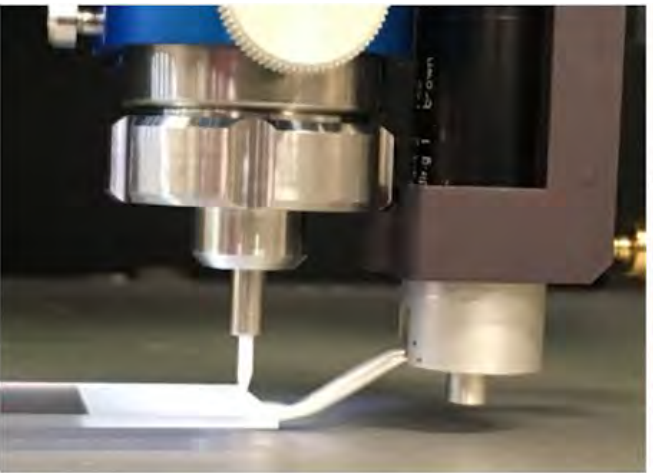
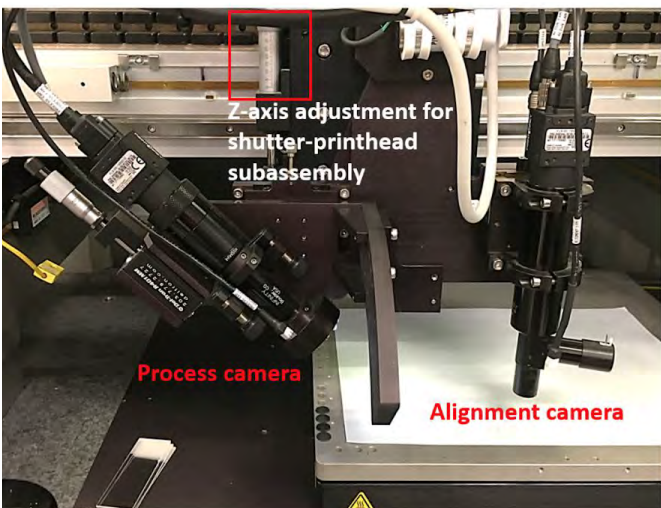


Figure 4: The nozzle tip and shutter height in the z-axis is calibrated with respect to the substrate using three 1 mm thick microscope glass slides. (left) The alignment camera and process camera setup (right).

Below will walk through how to adjust the nozzle tip height. This is Optomec's recommended settings, but the distance between the nozzle tip and substrate can be modified as a printing variable. The range of allowed distances is nominally 3 ~ 5 mm.

<p>1. Place three glass slides on the work space. Have the top one extend out 3 mm.</p>	<p>Adjusting deposition head (nozzle tip) and shutter height using glass slides</p>  <p>Deposition head is adjusted correctly (with fine feature nozzle) [1]</p>
<p>2. Real view of three microscope slides. Each slide is 1 mm thick.</p>	
<p>3. Z-axis adjustment for shutter-printhead, process camera and alignment camera should all be on. The z-axis knob moves the entire printhead-shutter assembly.</p>	 <p>Z-axis adjustment for shutter-printhead subassembly</p> <p>Process camera</p> <p>Alignment camera</p>

This is Optomec's recommended settings, but the distance between the nozzle tip and substrate can be modified as a printing variable. The range of allowed distances is nominally 3 ~ 5 mm.

Please refer to the user videos for a tutorial in hands on assembly procedure as well.

5. Assembly (Ultrasonic Atomizer Mode, Wide Feature Printhead) (20 mins)

The Optomec setup begins with assembling the machine. The exploded views of the three main subassemblies illustrate how individual parts fit together with the O-rings for the wide nozzle printhead.

1. Assemble the wide feature nozzle following same O-ring greasing and checking procedure as described in [Section 4](#).



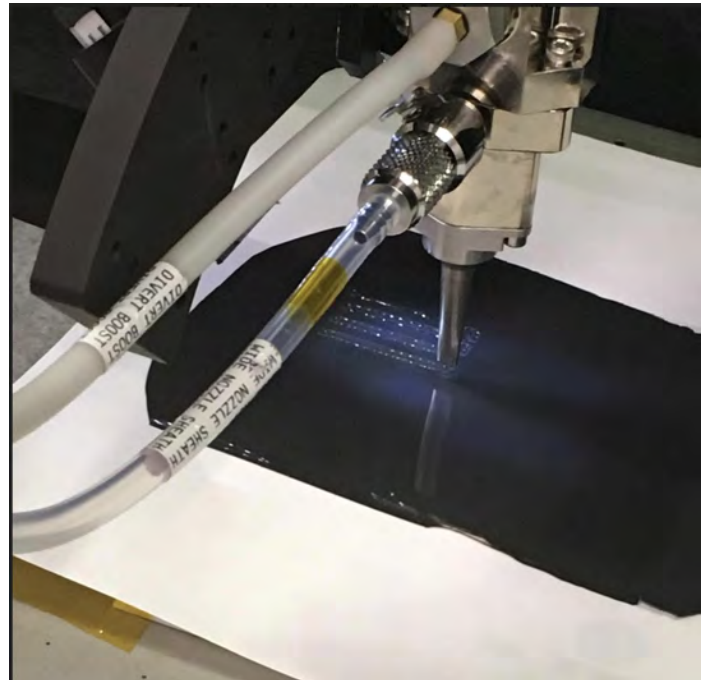
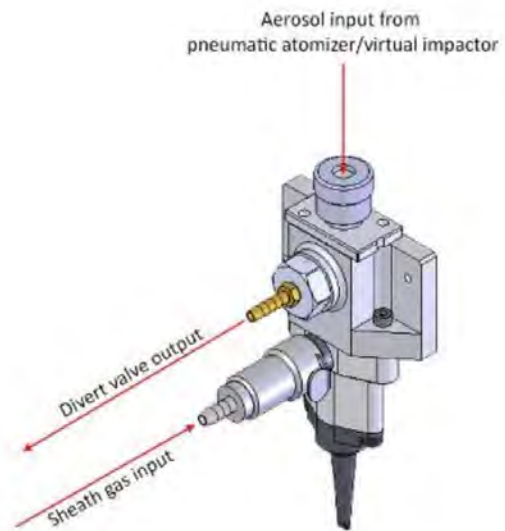
Exploded view of wide nozzle

2. Mount the wide nozzle into the machine as you did with the fine feature nozzle.



Wide nozzle print head mounting

3. Add appropriate tubing for the wide nozzle, divert valve output, sheath gas input, and the aerosol input from the atomizer.



Wide nozzle print head connections

4. Turn on and focus your process camera light



Process camera light controller

5. Turn on and adjust your alignment camera light



Alignment camera light controller

5.2 UA Max Ultrasonic Atomizer Setup

The following instructions are for the setup of the UA Max ultrasonic atomizer.

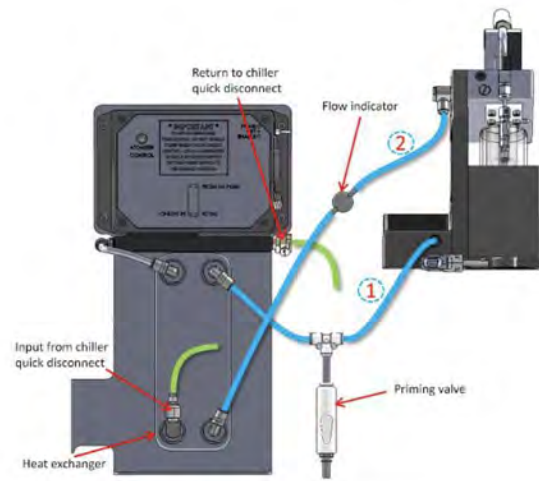
Ultrasonic Atomizer Video - <https://youtu.be/IFBBkoEolWc>

1. Make sure all the connections are made and the ultrasonic is fully mounted and set up.



UA Max heat exchanger electrical connections

2. Turn the power on for the machine but do not enable the atomizer power yet. This is to avoid damage until the bath is filled, pump power on, and bath flow has been established.
3. Fill the bath with water and prime the pump.



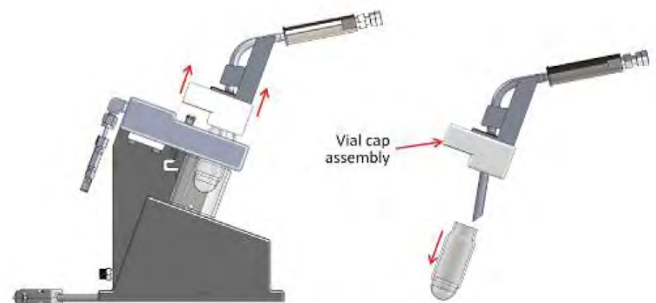
UA Max exchanger fluid connections

4. Check the bath level and add water if necessary.
5. Start the water flow.
6. Turn on the chiller unit and set temperature.



UA Max ultrasonic atomizer

7. Carefully slide the vial cap assembly with attached vial out of the atomizer assembly.



UA Max vial cap assembly

8. Unscrew the vial from vial cap assembly.
9. Fill vial with 0.5 to 2.5 mL of atomized material.
10. Replace the vial on the cap assembly top block.



Vial cap assembly

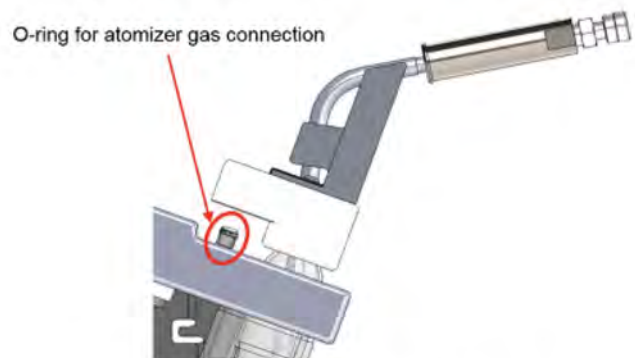
11. Slide the vial cap assembly back onto the atomizer assembly. Check to make sure the gasket for the atomizer gas makes a good seal. Grease the O-ring if necessary.



Figure 52. UA Max atomizer connections

UA Max atomizer connections

12. Loosen the knurled nut on the mist tube adapter Swagelok fitting and slide the mist delivery line all the way into the fitting until it bottoms out. Tighten the knurled nut.



Reinserting UA Max vial assembly

13. Make sure the mist tube adapter is mated against the must tube collar.



Attaching the UA Maz mist delivery line

6. Focus the process and alignment cameras (5 mins)

Once the tool has been enabled on Badger, it is possible to focus the process and alignment cameras.

To focus both cameras, on the operator panel.

1. Turn on the alignment and process camera lights.
2. Go to KEWA Vision Manager application and select the tab corresponding to the desired camera to focus. *A live video image of the selected camera will be shown in the application.*
3. Adjust the desired camera. *Both cameras have a micromanipulator knob to adjust the position of the camera with respect to the substrate.*
4. Use the camera knob to gently adjust the focus until you see a better resolved image in the KEWA Vision Manager application.

7. Check for gas leaks or a clogged nozzle tip (5-30 mins)

For optimum performance, all system leaks or clogging must be eliminated before atomization of the ink. This step is of utmost importance – **the user should not proceed with atomization if there are any leaks or clogging present in the system**, as this could damage components of the tool and/or lead to chemical contamination of tool parts and the user's samples.

1. Monitoring of the sheath gas flow will indicate if there are any leaks or clogging present in the system.
2. Visit Table 1 for the recommended sheath gas flow for optimum performance of the Optomec will depend on the nozzle tip size utilized.
3. Under the pneumatic tab in KEWA Process Control, enter the correct sheath flow value in the Sheath_MFC box.
4. Press enter.
5. The pressure reading will be displayed in the graph in the KEWA Process Control application, as well as next to the Sheath_MFC box.
6. Wait until the pressure stabilizes.
7. A reading below the values displayed in Table 1 indicates that there is a leak in the system. *A reading above these values indicates that there is a clog in the system. For troubleshooting of leaks and clogging, go to Sections 8.2 and Section 8.3, respectively.*

Nozzle tip size (μm)	Sheath gas flow (sccm)	Expected pressure (psi)
100	50	1.69 to 2.06
150	150	2.46 to 3.00
200	150	0.88 to 1.07
250	150	0.67 to 0.82
300	200	0.39 to 0.47

Table 1: Use this table to compare and determine if there are any leaks or clogging in the system. This is the sea altitude table in the Optomec User Manual. The left column gives nozzle tip size and you will be applying the appropriate sheath gas flow (middle column). To make sure you don't have a leak or clog check the stable pressure against the expected pressure (right column). [1]

8. Troubleshooting

This section describes common hardware and software issues that we experienced while using the Optomec, as well as strategies for overcoming them.

8.1 Optomec Operating Software (KEWA) Issues

Common software issues users have experienced include:

1. Software not starting fully or freezing during operation.
2. Software loading print pattern file but not executing printing procedure.
3. Software not measuring applied sheath, atomizer, or exhaust flow values.

Software complications are generally fixed by re-initializing the software or performing a hard reboot of the system. Propose the following procedure:

1. Software permitting, set to zero all the gas flows in the following order: atomizer → wait 10 s → exhaust → wait 60 s → sheath.
2. Close all applications of KEWA software and re-initialize all KEWA software instances.
3. If (2) fails, then turn off the PC, disable the tool using Badger, re-enable the tool, and re-start the KEWA gadget interface.
4. After re-initialization, turn on the sheath flow, exhaust flow and atomizer flow following the procedure stated in [Section 7](#).
5. Run again the homing routine and perform a test print to ensure that the printer is working properly.

8.2 Troubleshooting a Leak During Initialization

A reduced sheath flow during tool startup indicates that there is one or multiple components leaking in the system. Leaks can come from various elements, and thorough inspection of assembled components in the tool (as described in [Section 4](#)) and connecting elements is imperative.

Start by looking for leaks in the most common locations. Leaks most commonly occur at the locations where the tubes connect to the hardware and at the O-rings in the print head, virtual impactor, and atomizer.

1. While troubleshooting leaks, the user should ensure that the sheath gas flow is set to zero before carefully inspecting one item at a time and making any repairs the user deems necessary.
2. Check the connection tubes
3. Check O-rings, check if they are cracked or not greased well.
4. Check the PFA tubing, despite using freshly cut PFA tubing.

Given that some elements of the tool are more prone to produce leaks in the system, we suggest inspection of the tool items in the following order.

After performing any repairs in the system, the user should evaluate if the repair eliminated the leak source by applying the recommended sheath gas flow pressure and reading the pressure in the system. Only after the expected pressure is in the range displayed in Table 1 the user can confirm that all leak sources have been eliminated.

1. **Connection of the PFA tube to the printhead:** Remove the tube from the printhead and inspect the quality of the cut at the tube's end. If the cut is not flat, use the tube cutter to refine the cut, since any misalignment can produce an improper connection of the tube with the printhead. Attach the tube back to the printhead by pushing the tube all the way into the printhead and screwing the ferrule. To ensure proper connection,

attempt to pull the tube from the printhead. If the tube wiggles or moves inside the printhead, the tube was not correctly connected.

2. **Connection of the PFA tube to the virtual impactor:** Follow the instructions stated in (1) for the connection between the PFA tube and the virtual impactor.
3. **Printhead (1st), virtual impactor (2nd), and atomizer (3rd):** For each of the components (1- 3), remove it from the Optomec and disassemble it following the inverse procedure described in Section 4. Inspect all O-rings for any imperfections and ensure that the installed O-rings are the right size (see printhead: Figure 3, virtual impactor: Figure 2, atomizer: Figure 1).
4. In addition, all installed O-rings must be properly greased. Visually inspect the part every time a sub-component is re-assembled (see Section 4). The user should take special attention to ensure all subcomponents are aligned and that during the re-assembly process no O-rings were damaged. For the re-assembly of the atomizer, ensure that the cap is completely closed. As mentioned in Section 4, the improper fitting between the cap and the jar makes closing and opening the jar a very arduous task that requires quite a lot of physical effort.
5. **Replacing the PFA tubing:** Cut a new length of tubing and replace the old tubing. Ensure the cuts in both ends of the tube are flat and that the connections of the tube with the printhead and virtual impactor are correct (see 1 and 2).
6. **Replacing the nozzle:** In a few situations we found that the nozzle had been damaged and was the source of leakage. If troubleshooting all the other components of the Optomec does not fix leaking, then replace the nozzle. Please inform the staff about your issues with the nozzle and label the faulty nozzle.

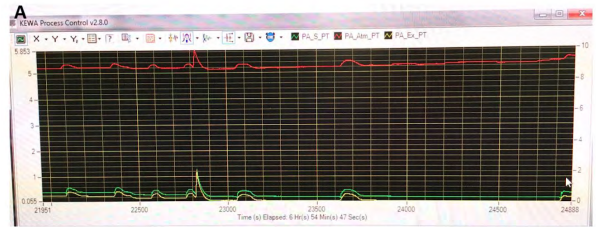
8.3 Clogged Nozzle Tip

An abnormally high pressure on the KEWA Process Control pressure read out window indicates that one or more of the microfluidic components of the Optomec are clogged. Most commonly, clogging will occur at the nozzle tip, but it can also occur at the printhead, virtual impactor, or atomizer. To determine if a component is clogged, remove the part from the Optomec and disassemble following the inverse procedure described in [Section 4](#). Visually inspect the subcomponents of the part in a well-lit area. If the subcomponents present ink material agglomerates, they must be cleaned prior to use. For cleaning clogged components, follow the instructions in [Section 11](#).

8.4 Excessive and Intermittent Jetting of Ink

Excessive and intermittent jetting of ink may occur during printing and may worsen over the course of a printing run. This was a common problem when attempting to print PEDOT:PSS. It was observed formation of excessive ink blobs around the nozzle tip which had to be cleaned using a cotton swab between prints to prevent the blob from falling onto the substrate. Additionally, users observed satellite drops which caused their printed patterns to have poor spatial definition. Also observed beads of ink droplets in the tubing that connects the virtual impactor and the printhead (Figure B), which eventually agglomerated together to form a large ink droplet. This droplet then fell down the tubing, went through the printhead, and finally splashed onto the substrate (Figure C-D). Such events can be correlated with spikes in the exhaust/sheath/atomizer flow (Figure A), although the spikes were not periodic. Users have yet to pinpoint the cause of this issue. Possible solutions include: (1) adjusting ink rheology such as diluting the ink to reduce its viscosity, (2) cleaning the virtual impactor and printhead, (3) replacing tubing, and (4) adjusting the “push” which is defined as the difference between the exhaust flow and atomizer flow. The user should take note that the push does not respond immediately, and that there can be residual pressure in the atomizer that exacerbates this delay.

A. The screenshot of KEWA Process Control window that shows spikes in the gas flows, (D) the large droplet of PEDOT:PSS ink splashing onto the substrate.



B. Beads of PEDOT:PSS ink in the tubing that connects the virtual impactor and printhead.



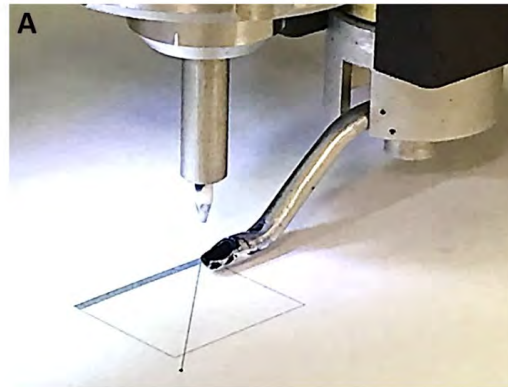
C. The large droplet of PEDOT:PSS ink flowing down the tubing and entering the printhead.



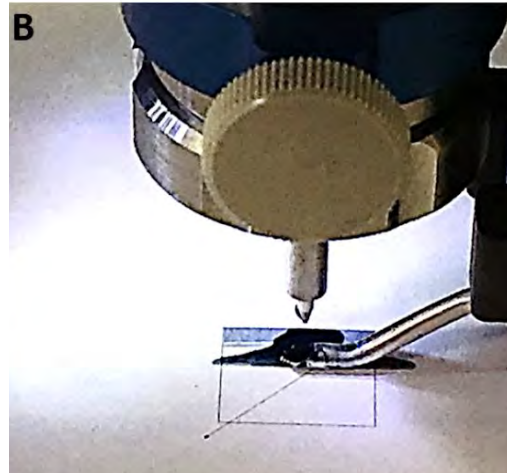
D. The large droplet of PEDOT:PSS ink splashing onto the substrate.



A. PEDOT:PSS printing on paper with good jetting.



B. PEDOT:PSS printing on paper with bad and excessive jetting when pressure spikes on the three gas flows were observed.



Nozzle size (μm)	Sheath flow (sccm)	Atomizer flow (sccm)	Exhaust flow (sccm)
150	55 - 60	\sim 600	\sim 570
200	80 - 90	\sim 600	\sim 570
250	100 - 110	\sim 700	\sim 650-660
300	115 - 130	\sim 800	\sim 740-750

Table 2: Pneumatic fine feature deposition starting parameters. [1]

9. Start Atomizing (2 mins)

Once it is confirmed that there is no leaks or clogging, start atomizing the ink. To avoid clogging, always turn on the gas flows in the following order [1]:

1. Sheath flow
2. Atomizer flow
3. Exhaust flow

The amount of sheath, atomizer, and exhaust flow required for optimal printing depends on the ink. If these values are not available for the ink to be used, follow the recommended starting parameters in the Optomec manual, which we include in Table 2 for the pneumatic fine feature nozzles.

If atomization occurs, the user should see droplets of ink splattering on the wall of the jar, as illustrated in [Figure 1](#) (left). If no atomization is occurring, slowly increase the atomizer and exhaust gas flow in the proper proportion [1]. Once you see good atomization of the ink, take note of the applied atomizer and exhaust flows. Vary the sheath flow to optimize print quality.

You are now ready to print! Enjoy!

10. Disassembly (20 mins)

When printing is finished, Optomec parts must be disassembled properly as described below:

1. Turn off the three gas flows in the following order: atomizer → wait 10 s → exhaust → wait 60 s → sheath
2. Remove assembled parts from the Optomec: atomizer, virtual impactor, and printhead.
 - a. Any of the following assembly you used: ultrasonic, pneumatic, virtual impactor assembly, wide nozzle and fine feature nozzle.
3. Disassemble the printhead shutter subassembly
4. Dispose of tubing
5. Clean up the work stage

11. Cleaning! (4+ hours)

Now that you have printed all your parts it is time to clean the machine.

Generally, each sonication step per cleaning solution must be repeated several times in newly filled cleaning solution for at least 10 minutes before proceeding to the next sonication step. The order of cleaning solutions is: water, Branson, and isopropyl alcohol. Branson is a specially formulated cleaning solution, and it is effective in removing rust and metal oxides.

The Branson solution is prepared by mixing 1 part Branson concentrate to 11 parts water. The minimum cleaning procedure is provided in Table 3, which is suitable for PEDOT:PSS ink, but more thorough cleaning may be required for other ink types. Optomec parts that directly contact the ink are considered to be critical parts and must go through more extensive cleaning

Optomec parts that require thorough cleaning.



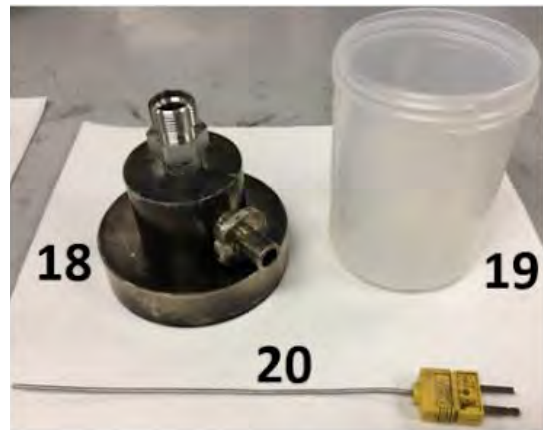
Critical parts: 4, 6, 7, 8, 10, 11, 12.



Plastic parts (ferrules and cones) that can be cleaned together.



Part 18 is a critical part that can not be cleaned with Branson. 19 needs to be cleaned first by clean wipes and then sonicated. 20 does not need to be cleaned but if it looks dirty wipe it down.

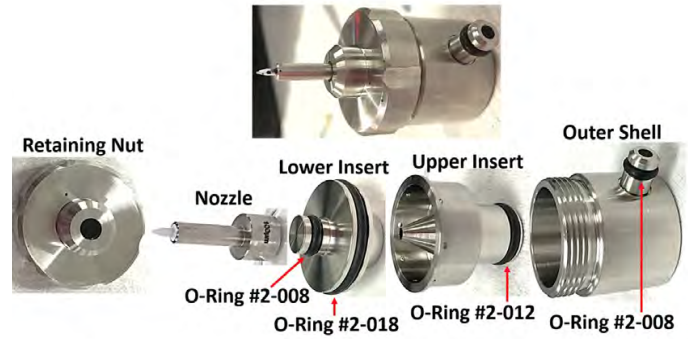


Cleaning Solution	Non-critical parts	Critical Parts	Critical Parts (no Branson)
1) Water	10min x 2 times	10min x 2 times	20min x 3 times (or 10min x 5 times)*
2) Branson	10min x 2 times	10min x 3 times	-
3) Isopropyl alcohol	10min x 2 times	10min x 3 times	10min x 3 times
4) Rinsing with isopropyl alcohol and blow dry with N ₂ gun			

Table 3: Minimum cleaning procedure of Optomec parts.* The choice of suggested cleaning recipe depends on the part condition and ink. [1]

Thorough cleaning of Optomec parts after printing is the most crucial procedure of Optomec operation:

1. Disassemble each part (atomizer, virtual impactor, and printhead) into its multiple subcomponents, following the inverse procedure described in the [Assembly sections](#).



Top assembled, bottom disassembled

2. Transfer disassembled parts to room 155. Place individual subcomponents in a beaker. As a general rule, each subcomponent should be placed in an individual beaker - exceptions are some non-critical parts, such as ferrules and cones, if there is not enough space available in the sonicator to place all subcomponents in separate beakers.



Part in a beaker

3. Fill beakers with cleaning solution and sonicate for 10 to 15 minutes. Ice cubes should be added to the sonication water bath to prevent overheating.



Part in a beaker with cleaning solution

4. Dispose of cleaning solution in the disposal counter in the fume hood and refill beakers with new cleaning solution. Repeat sonication for 10 to 15 minutes. Repeat this step as many times as necessary according to Table 3- the specific cleaning solution as well as the number of times

this step must be repeated will depend on the user's ink.

5. Leave the parts to dry in the fume hood for 15 minutes then put them away in the Optomec drawers.

- A. Optomec parts submerged in water and sonicated (A and B).



- B. Optomec parts submerged in water and inside the sonicator (A and B).



C. Optomec parts submerged in water. Note the amount of liquid that is required to submerge the part.



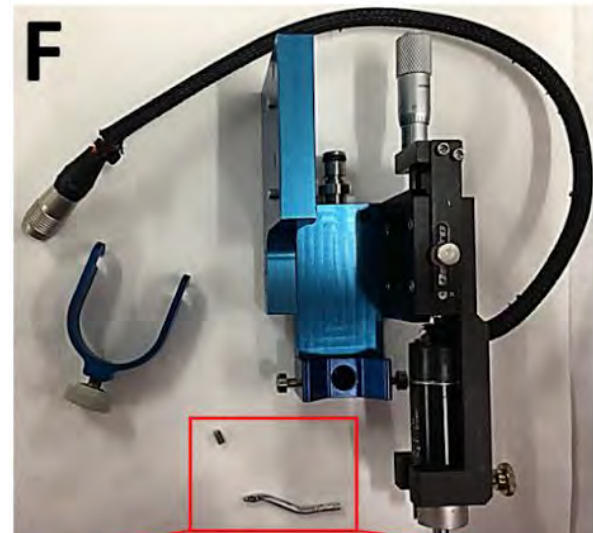
D. A critical Optomec part submerged in water taken out from sonication (C) for thorough cleaning with a brush (D and E).



E. Can be taken out from sonication (C) for thorough cleaning with a brush (D and E).



F. View of Optomec shutter disassembled for cleaning.



G. Zoom-in of shutter components and other small parts (nozzle, cones, and ferrules) to be cleaned in their own separate jars.



References:

1. Neville, Eddie, and Karen D'Arezzo, "Aerosol Jet AJ300 System User Manual (P/N 9000324)"
2. Camila Cendra, Theo Gao, Kye Young Lee, "Standard Operating Procedure of Optomec Aerosol Jet Printer in Pneumatic Atomizer Mode and Characterization of Printed PEDOT:PSS Lines" Wiki SNF E241 Final report on the Optomec <https://drive.google.com/file/d/1UeyCU5vTdEydJThJI9xmWYAO1VJNljtx/view>