# Sicrys™ Silver Inks

# Handbook

Version 12.1

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# Table of Contents

# 1. General Guidelines

## 1.1 Goal

This handbook provides details on Sicrys™ Ag ink products, with guidance on handling, printing and sintering of the inks.

For additional information, see note at the end of the document.

## 1.2 Ag Sicrys™ Products

Sicrys™ Ag inks are solvent-based nanoparticle inks, suitable for inkjet printing and sintering by various possible methods (section 1.7). A comprehensive list of Sicrys™ products can be found at www.pvnanocell.com, including ink specification information, data sheets, and MSDS. The information can also be accessed by sending an email with the specific request to info@pvnanocell.com. The inks mentioned in this handbook include the following:

- Sicrys™ I50T-11
- Sicrys™ I50T-13
- Sicrys™ I30EG-1
- Sicrys™ I20DM-206
- Sicrys™ I40DM-106
- Sicrys™ I50DM-106
- Sicrys™ I50TM-115
- Sicrys™ I50TM-119
- Sicrys™ I50TG4-3
- Sicrys™ I57TG4-025
- Sicrys™ I55DMG4-045

## 1.3 Ink Handling

### Safety and Handling

- Take proper care of inks as chemicals, read the Material Safety Data Sheet (MSDS) and product labels before using the products.
- Use appropriate equipment and safety measures.
- Keep product container closed when not in use to prevent solvent evaporation and spilling hazard.

### Storage

- Keep ink in a cool, ventilated, dry place, at room temperature, without direct light. Keep bottle properly closed. Solvent evaporation will cause ink deterioration (high viscosity and agglomeration). Storage in freezers (or at below room temperature) is not recommended.
- Water or excess humidity in the ink will damage the ink (viscosity increase).

### Shelf Life

- If stored correctly, the ink shelf life is 1 year.

### General Spill Management and Response

**Note: Detailed spill management to be found in specific MSDS**

- Wear personal protective equipment: gloves, lab coat, goggles.
- Ventilate area of spill.
- Contain the spill by pre-installing trays or absorbent materials. Do not allow material to reach electrical connections.
- If material has spilled, clean first with a dry absorbent-type cloth and follow, if desired, with a wet cloth.

### Ink Disposal

- Dispose according to instructions in MSDS. Do not dispose into sewage systems.

## 1.4 Viscosity tuning of ink by dilution

Our inks have been designed to be compatible with most commercial industrial print heads (i.e. KM, Ricoh…). With every batch of our inks we provide a table linking temperature to viscosity, in order to allow users to fine tune the viscosity to their process and print head type. For some consumer print heads (such as Epson, HP, etc.) the viscosity of the inks must be much lower than the viscosity of our inks. In case there is a need to reduce the viscosity of Sicrys™ ink by the customer in order suit the requirements for these consumer print heads, the following steps should be followed (Please note that compatibility of the ink to consumer print heads is not only a factor of the viscosity, but also material compatibility, nozzle size, and other parameters which are the customer's responsibility to check).

### The dilution procedure:

1. Choose the desired viscosity and metal loading after dilution. The following table is an example of the viscosity profile for Sicrys™ I50DM-106 ink.

| Metal Loading (%) | Viscosity @ 25°C (cP) |
|---|---|
| 50 | 21.0 |
| 45 | 14.5 |
| 40 | 11.0 |
| 35 | 8.8 |
| 30 | 7.4 |
| 20 | 5.5 |
| 10 | 3.6 |

2. The dilution should be performed with the solvent of the ink, according to the following table:

| Cat. # | Diluting Solvent |
|---|---|
| **Sicrys™ I50T-11** | Tripropylene glycol monomethyl ether (TPM), CAS: 25498-49-1 * |
| **Sicrys™ I50T-13** | Tripropylene glycol monomethyl ether (TPM), CAS: 25498-49-1 * |
| **Sicrys™ I30EG-1** | Ethylene Glycol, CAS: 107-21-1 |
| **Sicrys™ I20DM-206** | Diethylene glycol monomethyl ether (DGME), CAS: 111-77-3 |
| **Sicrys™ I40DM-106** | Diethylene glycol monomethyl ether (DGME), CAS: 111-77-3 |
| **Sicrys™ I50DM-106** | Diethylene glycol monomethyl ether (DGME), CAS: 111-77-3 |
| **Sicrys™ I50TM-115** | Triethylene glycol monomethyl ether (TGME), CAS: 112-35-6 |
| **Sicrys™ I50TM-119** | Triethylene glycol monomethyl ether (TGME), CAS: 112-35-6 |
| **Sicrys™ I50TG4-3** | Tripropylene glycol monomethyl ether (TPM), CAS: 25498-49-1 * |
| **Sicrys™ I57TG4-025** | Tripropylene glycol monomethyl ether (TPM), CAS: 25498-49-1 * |
| **Sicrys™ I55DMG4-045** | Diethylene glycol monomethyl ether (DGME), CAS: 111-77-3 |

* When using TPM solvent for dilution, use dry TPM.

3. Use the $ML_1W_1 = ML_2W_2$ relation to calculate the amount of solvent needed, where $ML_1$ and $W_1$ are the metal loading and weight of the original ink, respectively; $ML_2$ and $W_2$ are the metal loading and weight of the diluted ink, respectively. The amount of diluting solvent is: $W_2$-$W_1$.
4. Weigh the solvent quantity needed and add to the original ink.
5. Mix the diluted ink (magnetic stirring for 5-10 min).

## 1.5 Substrate handling and cleaning

This section describes our experience with handling substrates, and is only intended to be used as a generic guideline. Customers should also get advice form the producers/suppliers of the substrates, and adjust handling and cleaning procedures to their process requirements.

### In-organic substrates: Glass and ITO

1. Handle the substrate with care, and use gloves at all times.
2. Carefully remove all dust or loose particles from the glass surface by using clean air pressure (make sure there are no oil residues in the air) or an anti-static dust removing roller. Make sure not to scratch or damage the surface.
3. Make sure to remove all stains from the glass / ITO surface by wiping it with a moistened clean room cloth with ethanol or IPA.
4. Cloth used should be fibreless and soft (used in clean rooms). Never use industrial paper towels, toilet paper or sponges.
5. Stains on the glass that cannot be removed with ethanol should be removed by washing the glass surface with soap and water followed by repeating the cleaning procedure with ethanol according to steps 3 and 4 above.
6. Let the glass fully dry prior to printing.
7. Print on the clean and dried glass.

### Polymeric/organic substrates

1. Handle the substrate with care, and use gloves at all times.
2. Carefully remove all dust or loose particles from the surface by using clean air pressure (no oil residues in air) or an anti-static dust removing roller. Make sure not to scratch or damage the surface.
3. In the case of stains on the surface, wipe the surface with dry fibreless and soft cloth (used in clean rooms).

Note: Solvents may change surface properties of the polymeric/organic substrates. Thereby, we do not recommend to clean these substrates with solvents. Nevertheless, we suggest to consult with producers/suppliers of the substrates.

## 1.6 Printing

Sicrys™ inks have been designed by PVN to be compatible with a variety of commercially available inkjet print heads. However, the information shared in this handbook pertains to Konica Minolta KM1024, Ricoh Gen3 E3 and Dimatix cartridge print heads. The information hereby shared is provided "As Is", based on PVN experience, and PVN does not warrant its accuracy, completeness or suitability.

## General Printing Guidelines:

Use suitable inkjet printer and print head, compatible with conductive inks. Follow print head supplier guidance.

Note: Sicrys™ inks have high metal content; therefore high densities. Take this into consideration when adjusting printing parameters such as vacuum meniscus.

### Before Printing

- Make sure all electrical connections in the printer are protected so that none of them is exposed to the conductive ink during the printing process. PVN inks are metallic and should not come into contact with electrical connections.
- Clean the ink supply line of the print head with appropriate recommended flushing fluid (or ink specific solvent) to remove contaminants and previous residual inks/solvents. Other solvents/inks may be incompatible with our inks.
- Mix bottle containing the ink (hand shake bottle) before filling the print head.
- Optional (usually not needed) – filter ink before use (with 300 series stainless steel filter media).

### During Printing

- Work at a head temperature that correlates with print head supplier and PVN recommendations for ink viscosity.
- We recommend wiping the nozzle outlets during the print session with a moistened clean room cloth with the recommended flushing fluid. This will ensure no clogging of the nozzles occurs. A good practice is to define a wipe cycle for your system and application. Follow print head manufacturing guidance.
- Cloth used for wiping the print head must be fibreless and soft (used in clean rooms) so as not to damage the print head. Never use industrial paper towels, toilet paper or sponges.
- Capping, spitting or tickle modes are recommended if ink remains idle between print sessions.

## After Printing

- The ink may be left in the print head between printing sessions if the system has capping capabilities to avoid drying on the orifice plate of the print head.
- If you would like to empty the print head, discharge the remaining ink from the print head. Clean the print head with appropriate flushing fluid, performing purges and wipes. Perform this step until the cloth wiping the print head comes out clean, with no remnants of the ink.
- Cloth used for wiping the print head must be fibreless and soft (used in clean rooms) so as not to damage the print head. Never use industrial paper towels, toilet paper or sponges.

## Flushing Fluid

- Use appropriate flushing fluid, as follows:

| Cat. # | Recommended Flushing Fluid |
|---|---|
| **Sicrys™ I50T-11** | Tripropylene glycol monomethyl ether (TPM) ** |
| **Sicrys™ I50T-13** | Tripropylene glycol monomethyl ether (TPM) ** |
| **Sicrys™ I30EG-1** | Ethylene Glycol |
| **Sicrys™ I50DM-106** | Diethylene glycol monomethyl ether (DGME) |
| **Sicrys™ I50TM-115** | FL119-01 * |
| **Sicrys™ I50TM-119** | FL119-01 * |
| **Sicrys™ I50TG4-3** | Tripropylene glycol monomethyl ether (TPM) ** |
| **Sicrys™ I57TG4-025** | Tripropylene glycol monomethyl ether (TPM) ** |
| **Sicrys™ I55DMG4-045** | Diethylene glycol monomethyl ether (DGME) |

* Contact sales@pvnanocell.com to order product.
** When using TPM solvent for flushing, use dry TPM.

# 1.7 Sintering

Sicrys™ Ag inks may be sintered by various methods:

## 1.7.1 Thermal Sintering

Recommended thermal sintering conditions are in a box oven in air, at the highest temperature which is compatible with the substrate material. Sintering may be performed at as low as 120$^{o}$C, see specific ink datasheet. Resistivity values depend on the sintering temperature.

- When using a convection oven with a thin substrate, affix the substrate so that it will not move in the air flow.

## 1.7.2 Laser Sintering

Laser sintering conditions should be fine-tuned to the type of laser used and specific application. Laser sintering may be carried out in ambient conditions (air). Sample resistivity values are 3-6xbulk (ink and process dependent). See table below, for examples of laser sintering process results (not optimized).

Laser wavelength: 532nm

Laser operation mode: Continuous

Laser spot size: 350µm

| | | Laser Data | | | | Line Dimensions | | Resistivity | |
|---|---|---|---|---|---|---|---|---|---|
| INK | Substrate | Scanning profile | Fluence [J/cm$^2$] | Power [mW] | Scan speed [mm/sec] | Width [µm] | Avg. Thickness [µm] | µΩcm | x Bulk (Ag) |
| I50DM-106 | Glass | Raster , 0.1mm step | 200 | 1000 | 5 | 510 | 1.5 | 5.2 | 3.3 |
| | | Raster , 0.1mm step | 150 | 1000 | 6.7 | 927 | 1.8 | 6.4 | 4 |
| | | Along line | 50 | 15000 | 100 | 300 | 1.2 | 6.4 | 4 |
| | Kapton | Along line | 8 | 5000 | 200 | 150 | 2 | 4.8 | 3 |
| | PET | Along line | 7 | 2000 | 100 | 150 | 2 | 6.4 | 4 |
| I50TM-119 | Glass | Raster , 0.1mm step | 198 | 990 | 5 | 1633 | 5.4 | 8.6 | 5 |
| | | Raster , 0.1mm step | 150 | 997 | 6.7 | 1594 | 5.9 | 10.1 | 6 |
| | | Raster , 0.1mm step | 200 | 1000 | 5 | 2cm square | 2.2 | 6.6 | 4.1 |
| | Kapton | Along line | 38 | 1300 | 10 | 75 | 5 | 7.7 | 4.8 |
| | | Along line | 159 | 560 | 1 | 75 | 10 | 9.4 | 5.9 |

### 1.7.3 NIR Sintering

NIR lamp can be used for sintering. Achievable resistivity values: <4xbulk (ink and process dependent).

Following are examples of NIR sintering process results (not optimized):

| | | NIR Data * | | | Line Dimensions | | Resistivity | |
|---|---|---|---|---|---|---|---|---|
| INK | Substrate | Fluence [J/cm$^2$] | Power [KW] | Exposure time [sec] | Width [µm] | Avg. Thickness [µm] | µΩcm | x Bulk (Ag) |
| I50DM-106 | PET | 41.5 | 21.6 | 0.4 | 507 | 3.4 | 3.7 | 2.3 |
| | PEN | 10.8 | 27 | 0.1 | 561 | 3.1 | 6.1 | 3.8 |
| | Glass | 1080 | 32.4 | 10 | 527 | 0.8 | 3.6 | 2.3 |
| | ITO | 648 | 32.4 | 6 | 500 | 6 | 4 | 2.5 |

* Adphos NIR lamp.

### 1.7.4 UV Flash Sintering

UV flash conditions should be fine-tuned to the type and power of lamp. Sintering may be carried out in air. Achievable resistivity values: ~6xbulk (ink and process dependent).

### 1.7.5 Photonic Sintering

Photonic sintering should be fine-tuned to the type and power of lamp. Sintering may be carried out in air. With Xe lamp, achievable resistivity values: <10xbulk (ink and process dependent).

### 1.7.6 Pressure Sintering

Combining heat and pressure can improve resistivity of printed silver ink. Achievable resistivity values: <3xbulk (ink and process dependent).

Following are examples of pressure sintering process results (not optimized):

| | | Sintering Data | | | Line Dimensions | | Resistivity | |
|---|---|---|---|---|---|---|---|---|
| INK | Substrate | Temperature [°C] | Time [min] | Pressure [psi] | Width [µm] | Avg. Thickness [µm] | µΩcm | x Bulk (Ag) |
| I50DM-106 | FR4 | 186 | 73 | 340 | 300 | 6 | 4.2 | 2.6 |
| | Kapton | 186 | 73 | 340 | 300 | 6 | 4.2 | 2.6 |

## 1.8 Adhesion

Sicrys™ products are compatible with a variety of substrates. For a comprehensive list of products and substrates to which they are compatible with, visit PV Nano Cell website at:

- Sicrys™ General Purpose Silver Inks
- Sicrys™ Silver Inks for Solar, Ceramic and Glass

Note: when applying ASTM or ISO adhesion standards, make sure the test is relevant to your application (the cut done in the standards is usually not needed for conductive patterns).

## 1.9 Soldering

Printed and sintered Sicrys™ products may be soldered with the products outlined in this section. Please note that the soldering process must be fine-tuned to the application, including temperature suitable for the substrate, thickness, etc.

### Solder Paste

Manufacturer: Koki Company Limited
Product #: SS4-M951DK
Composition: $Sn_{62}Pb_{36}Ag_2$ Flux RMA 13%

Additional information, including data sheet, may be found in the following link:
https://www.datasheets.com/en/details/SS4M951DK-KOKI+Company-42677933

### Silver Conductive Epoxy Adhesive

Manufacturer: MG Chemical
Product #: M331-14G

Additional information, including data sheet, may be found in the following link:
https://www.mouser.com/ProductDetail/MG-Chemicals/8331-14G?qs=sGAEpiMZZMvJqaFk9BIiv6jhjM0Pk6JzHea7mFx9BnQ%3D

The silver conductive epoxy has been used by us to connect LEDs.

# 2. Printing Guidelines

## 2.1 Printing conditions for Ag Sicrys™ inks

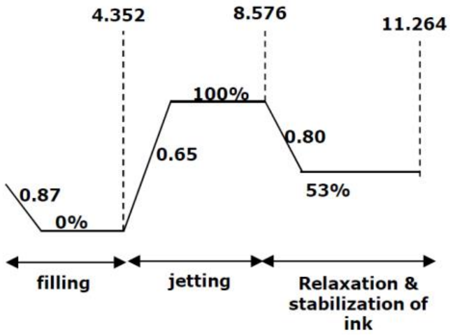
Sicrys™ inks have been designed by PVN to be compatible with a variety of commercially available print heads such as XAAR, Dimatix, Ricoh, and Konica Minolta (some print head models may not be compatible with conductive solvent inks, print head data sheet should be checked). However, the information shared in this handbook pertains specifically to Konica Minolta KM1024, Ricoh Gen3 E3 and Dimatix cartridge print heads. In sections 2.1.1, 0 and 2.1.3, we recommend starting printing conditions for the different inks in these print heads. The waveform printing conditions hereby shared are provided "As Is", based on PVN experience, and PVN does not warrant its accuracy, completeness or suitability. The information is meant to be used as a starting point for the user. It is recommended that the user perform optimization of the printing process in order to accommodate its needs to the specific system and application of interest.

Further information and specifications of each print head are available in the print head manufacturer's website. Please follow the guidelines and instructions of the printer system and print head provider.

### 2.1.1 Sicrys™ Printing Conditions with DMC-11610 Print Head

| Cat. # | Head temp [°C] | frequency [kHz] | Waveform (V) |
|---|---|---|---|
| **Sicrys™ I50T-11** | 35 | 10 | 19 |
| **Sicrys™ I50T-13** | 35 | 10 | 19 |
| **Sicrys™ I30EG-1** | 45 | 10 | 17 |
| **Sicrys™ I40DM-106** | 30 | 5 | 25 |
| **Sicrys™ I50DM-106** | 35 | 5 | 25 |
| **Sicrys™ I50TG4-3** | 35 | 10 | 17 |

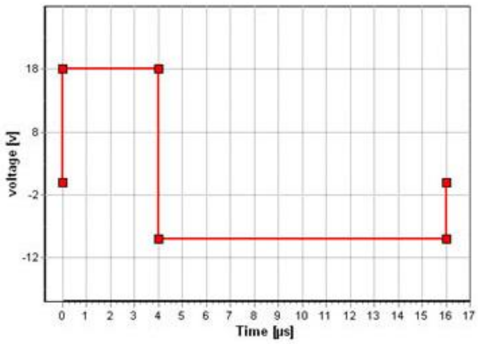
**DMC-11610 Pulse Shape:**




### 2.1.2 Sicrys™ Printing Conditions with KM1024 SHB Print Head

| Cat. # | Head temp [°C] | frequency [kHz] | Waveform (V,µs) |
|---|---|---|---|
| **Sicrys™ I50T-11** | 35 | 6 | (14,4)(-8,11) |
| **Sicrys™ I50T-13** | 35 | 6 | (14,4)(-8,11) |
| **Sicrys™ I30EG-1** | 40 | 6 | (20,8)(-10,15) |
| **Sicrys™ I50DM-106** | 35 | 6 | (16,4)(-8,12) |
| **Sicrys™ I50TM-115** | 35 | 6 | (18,4)(-9,12) |
| **Sicrys™ I50TM-119** | 40 | 6 | (18,4)(-9,12) |
| **Sicrys™ I50TG4-3** | 35 | 6 | (16,4)(-8,10) |
| **Sicrys™ I57TG4-025** | 35 | 6 | (16,4)(-8,48) |
| **Sicrys™ I55DMG4-045** | 35 | 6 | (15,4)(-7.5,12) |

**KM 1024 Pulse Shape:**



### 2.1.3 Sicrys™ Printing Conditions with Ricoh E3 Gen3 Print Head

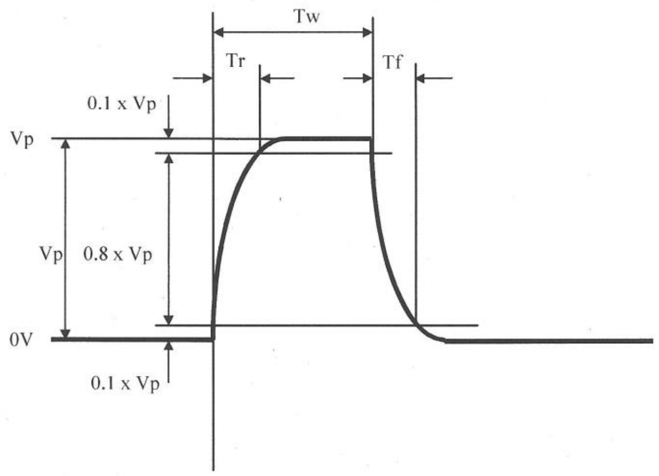
Fire sequence: 3 phase channel

Phase delay time: 35µs

| Cat. # | Head temp [°C] | frequency [kHz] | Waveform * Vp (V), Tw (µs) |
|---|---|---|---|
| **Sicrys™ I50T-11** | 35 | 6 | (23,7.3) |
| **Sicrys™ I50T-13** | 35 | 6 | (20,7.2) |
| **Sicrys™ I30EG-1** | 35 | 12 | (17.9,7.5) |
| **Sicrys™ I40DM-106** | 26 | 12 | (16.2,9.8) |
| **Sicrys™ I50DM-106** | 35 | 12 | (16.2,8.5) |
| **Sicrys™ I50TM-115** | 38 | 6 | (22,7) |
| **Sicrys™ I50TM-119** | 40 | 12 | (17.2, 8.3) |
| **Sicrys™ I50TG4-3** | 35 | 6 | (18, 9) |
| **Sicrys™ I57TG4-025** | 38 | 6 | (16,10) |
| **Sicrys™ I55DMG4-045** | 35 | 6 | (16.3,6.7) |

* The system sets the rise time (Tr) and fall time (Tf) at 2.8µs (measured between 10 and 90% amplitude) and the slew rate.

**Ricoh Gen3 E3 Pulse Shape:**



### 2.1.4 Sicrys™ Printing with Consumer Grade Print Heads

Ink **Sicrys™ I20DM-206** is suitable for consumer grade printers, which require lower viscosity inks than industrial printers.

Disclaimer: Not all printers and print heads have been tested, however the viscosity and surface tension of ink Sicrys™ I20DM-206 is suitable for many print head types. Please take note that compatibility of the ink with consumer print heads is not only a factor of the viscosity, but also material compatibility, nozzle size, and other parameters which are the customer's responsibility to check.

## 2.2 Printing recommendations for Sicrys™ ink

The following printing recommendations hereby shared are provided "As Is", based on PVN experience, and PVN does not warrant its accuracy, completeness or suitability. Note that the performance is also influenced by substrates and other parameters as thickness and width of the printed pattern. Customer should optimize its process for his specific requirements.

### 2.2.1 Printing high quality samples

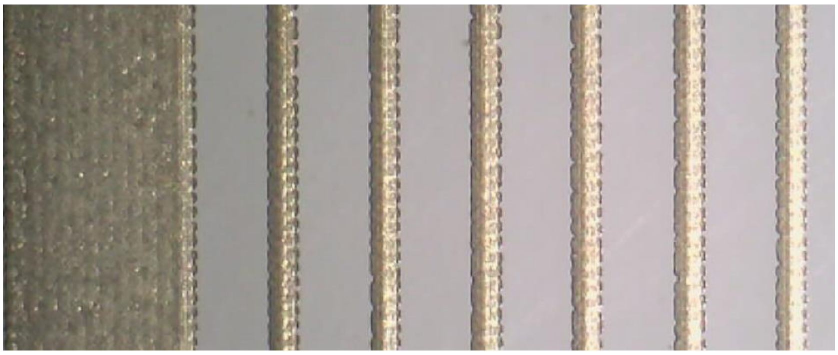
Follow the steps below for printing good quality samples:

1. Before printing make sure:
    a. All print head nozzles are open
    b. Use a 'DOT CHECK' file to make sure all dots are printed in their position, with no spraying or shape distortion. Note the printing speed.
2. Make sure the substrate is clean of dust or any other contamination before placing it on the stage. Clean the substrate according to appropriate cleaning instructions if needed.
3. Set the appropriate printing resolution for the required printed pattern thickness. If the desired thickness is slightly lower than the resulting printed thickness, it is possible to dilute the file.
4. Adjust the gap distance between the print head and the substrate. The print head-to-substrate distance should be in general as close as possible for good print quality, but not too close in order to avoid damage to the nozzles from heating of the stage, or from collision between them.
5. In general, the system divides the image into layers (according to resolution), where each layer contains part of the information in such a way that when all

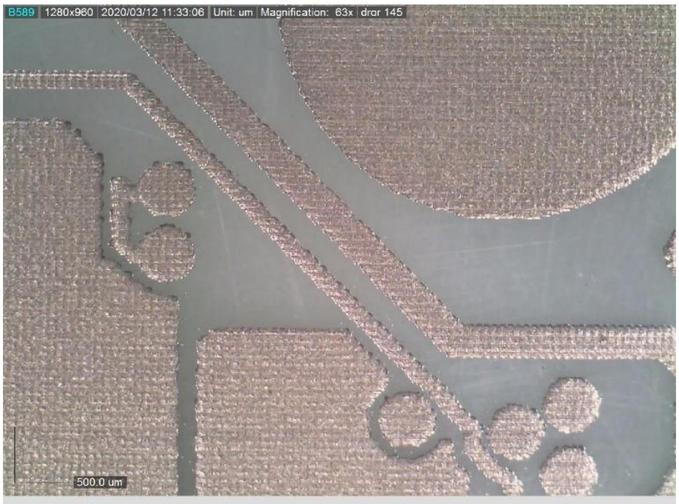
layers are printed one on top of the other, the image obtained contains 100% of the information.

6. Adjust the stage temperature so that each layer completely dries before printing the next layer. If the layer does not dry, puddles will appear as stains after the final drying.
7. When the table temperature cannot be raised to a high enough temperature, increase the waiting time between layers to ensure complete drying of each layer before printing any additional layers.
8. Set the printing speed to match the one used for the dot check file printing (step 1B).

Examples of good quality printed lines with ink on glass and PET substrates:



Ag Sicrys™ ink I50TM-119 printed on glass, ~2 µm thickness
Narrow lines of ~150 µm width




Ag Sicrys™ ink I50TM-119 printed on PET

### 2.2.2 Printing narrow lines

It is recommended to follow the steps outlined below in order to obtain narrow lines with Sicrys™ ink:

#### With printed dot shifting:

1. Print dots at low dpi, where dots do not touch.
2. Print additional shifted dots until reaching a continuous line. For best results, wait sufficient time between layers in order to ensure the previous layer has dried.
3. Repeat (1) and (2) until desired thickness is achieved.

Note: Printed pattern thickness determines the final dpi and number of times will repeat (1) and (2).

#### Without printed dot shifting:

1. Print a single layer at a wide range of resolutions and choose the resolution that provides the narrowest continuous line without bulging characteristics.
2. Print at the chosen dpi from (1) until reaching desired thickness. For best results, wait sufficient time between layers in order to ensure the previous layer has dried.

#### Additional recommendations:

**1.** It is recommended to print at a higher resolution in the cross-print direction than in the print direction.
**2.** Higher substrate temperatures may be used in order to produce narrower lines and decrease drying time.

An example for printing with I55DMG4.045 on silicon nitride coated wafer, showing the effect of stage temperature on the printed line width:

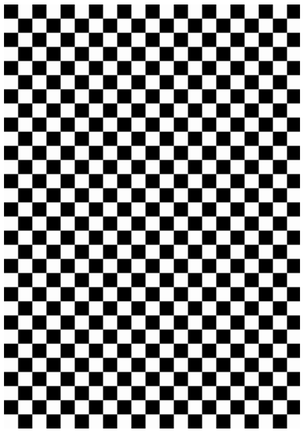
| Stage Temperature (°C) | Line Width |
|---|---|
| **60** | ~50µm |
| **100** | ~40µm |

### 2.2.3 Avoiding coffee stains

If coffee stain effect is observed in the printed pattern it is recommended to lower the stage temperature in order to reduce the effect.

### 2.2.4 Wide area printing

It is recommended to print wide area patterns in layers in order to control the thickness homogeneity of the resulting printout, whereby, the first few layers are pixel diluted, providing partial area coverage. Each successive diluted layer should provide the complementary pattern to the layer below it, in order to provide homogeneous layer coverage. In this manner, dots of each successive diluted layer are printed between the dots of the layer below it. The following pattern shows an example of a 50% area coverage. The percent coverage and number of diluted layers should be modified according to the application (pattern thickness, substrate, stage temperature, etc.).



An additional recommendation is to wait before each successive layer in order to dry the layer as much as possible.

### 2.2.5 Cold Printing Procedure

"Cold Printing" is defined by PV Nano Cell as printing without a heated stage. In order to form nice defined conductive lines by Cold Printing, a specific procedure is required. In sections 2.2.5.1 through 2.2.5.3, PV Nano Cell shares the Cold Printing technique developed for the company's "DemonJet" printers. The procedure was developed with PV Nano Cell's Sicrys™ I20DM-206 ink and printing resolution of 2880x1440 dpi. Another ink, printing resolution, or printer may require fine tuning of the process.

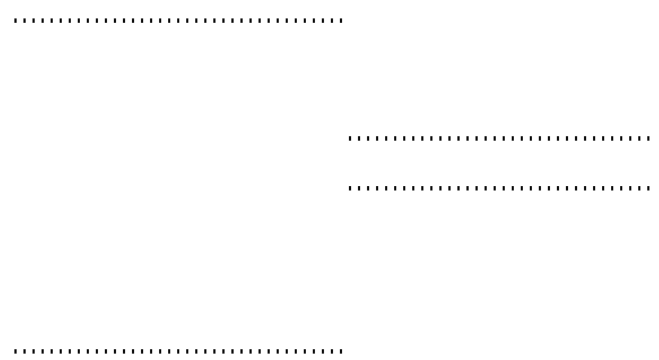
The idea behind Cold Printing is to print first an “outline” of the pattern, by printing several layers of separated dots, until a continuous line is achieved, then follow by filling the pattern area with separated dots, forming the “skeleton” of the pattern. The outline and skeleton create “pinned boundaries” that stop the wet ink from spreading during the final stage of printing additional layers to fill the printed pattern. The drying time of each layer depends on the image to be printed and the printer’s drying methods.

The detailed Cold Printing procedure is described below for printing a line and pad pattern in the DemonJet printer.

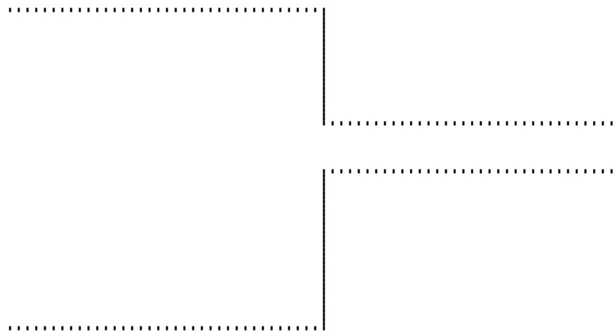
#### 2.2.5.1 Outline

The first step of pattern formation is creating the print pattern outline. The outline is formed from several printed layers of dots, where each printed dot dries individually.

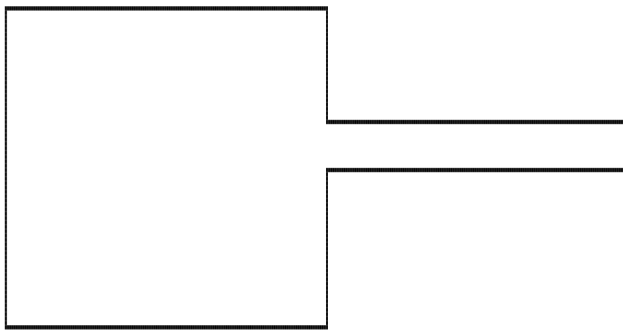
In the following example of printing a line and a pad, the first image of the outline is created by dots with 3 pixels spacing.



The second layer includes dots that fall in between the first set of dots, i.e. in pixel #2 (in the case of 3 pixels space between the dots).



- In the DemonJet printer, the vertical resolution is lower and less sensitive than the horizontal one, since there is a double spacing between the dots. For symmetrical, high resolution printing, the method for horizontal line printing should fit the vertical lines as well.
- With two additional steps, the entire outline is printed. PV Nano Cell's recommendation is for customers to examine whether the missing dots can be printed in one layer.

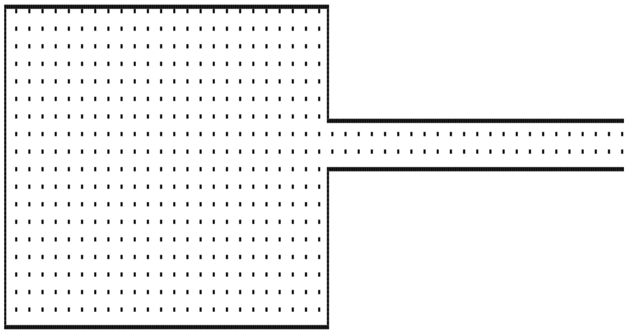


#### 2.2.5.2 Base layers ("skeleton")

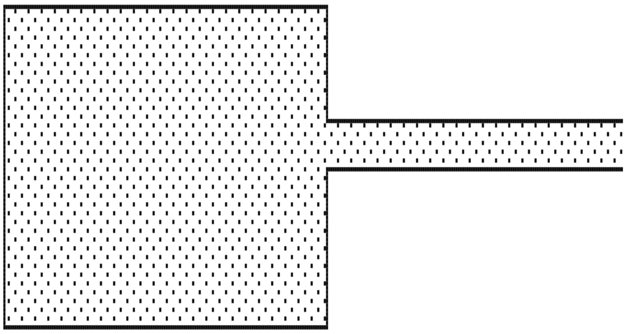
The base layers fill the area inside the outline with separate printed dots. The layers are printed and dried before a large amount of ink is printed inside the outline to fill the printed pattern area.

PV Nano Cell prints with the DemonJet printer two base layers:

A. A first layer includes dots with spaces of 3 pixels vertically and 5 pixels horizontally.



B. A shifted second layer (dots with spaces of 3 pixels vertically and 5 pixels horizontally), where dots are printed between the first layer dots, paying attention not to print outside the outline.

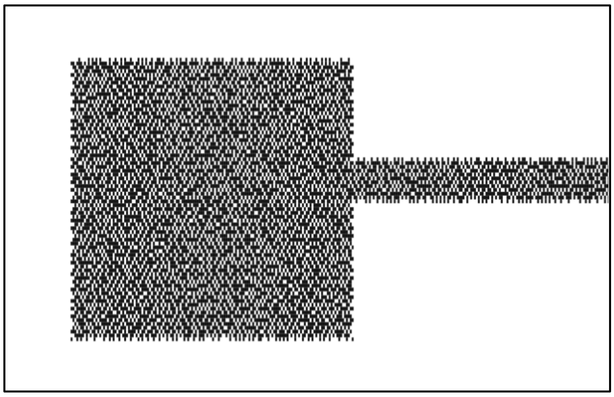


At this stage, the skeleton of the pad and line printed pattern is complete. The structure of the printed skeleton is designed to prevent ink from spreading outside of the pattern's boundaries.

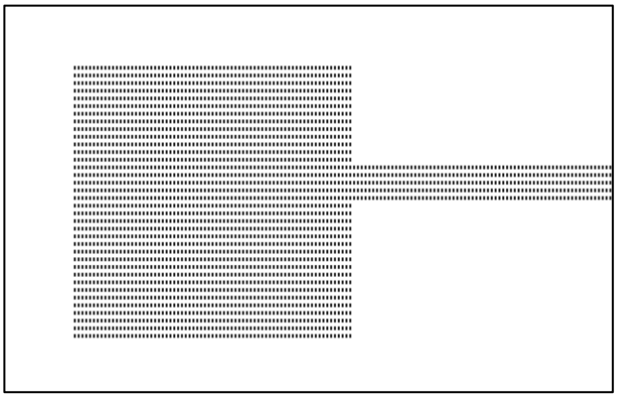
#### 2.2.5.3 Fill Layers

The next step includes finishing filling the pattern by printing diluted layers on top of the skeleton pattern. Different dilutions of varying % coverage and dilution techniques can work here.

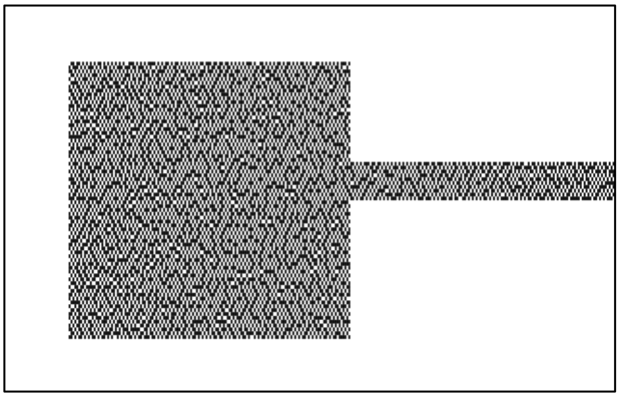
A few examples:



**75% stochastic**



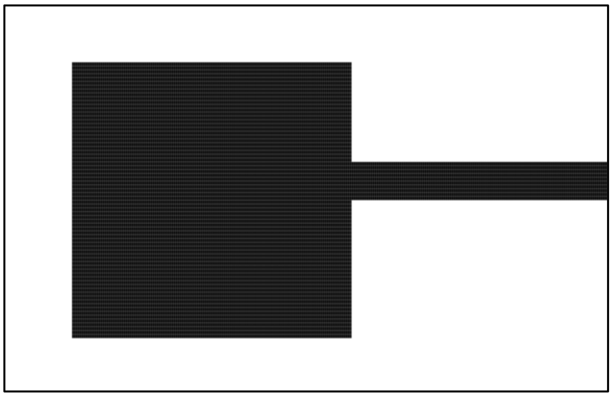
**25% pattern**

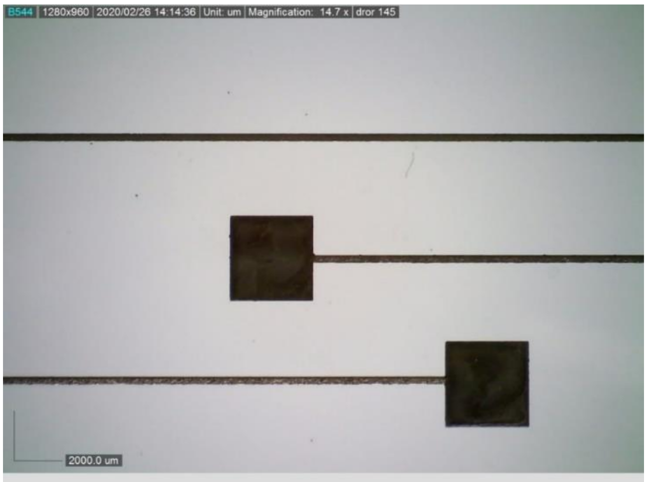


**60% stochastic**

The number of layers depends on the thickness and electrical properties required of the conductive lines.

Eventually, a solid pattern is formed.




B544
1280x960
2020/02/26 14:14:36
Unit: um
Magnification: 14.7 x
dror 145
2000.0 um

## 2.3 Printer Work Procedures

### 2.3.1 Printer Startup and Shutdown Procedure with Sicrys™ inks for printers without capping (ink cannot be kept in system overnight)

#### 2.3.1.1 Goals

- Cleaning the print head at the end of each day and before the weekend.
- Maintaining the print head in good condition.
- Allowing easy start up at the beginning of each printing shift.
- Priming the print head.
- Changing between inks.

#### 2.3.1.2 Printer Startup

1. At the beginning of a printing shift, purge all flushing fluid out of the system before introducing ink into the system.
2. Priming the print head:
   - Perform a long purge.
   - Wait 10 sec.
   - Perform a short purge.
   - Adjust the meniscus pressure (Sicrys™ inks are high density inks. Adjust the meniscus pressure accordingly).

#### 2.3.1.3 Printer Shutdown

1. Empty the ink out of the system (according to ink system procedures).
2. Introduce flushing fluid into the system.
3. Purge the print head with alternating pulses of flushing fluid and air. Run each pulse for the duration of 5 sec.
4. Repeat step 3 three to four times or until clear fluid comes out the nozzles.
5. Cap the print head in a solvent-rich environment.

#### 2.3.1.4 Additional Recommendations

- Clean the ink tank from ink before adding the flushing fluid.
- Wait 10 sec between washing cycles.
- Between ink changes in the printer, use shutdown procedure (without step 5) followed by the startup procedure.

### 2.3.2 For printers with capping (ink can be left in system overnight)

- At the beginning of the day perform long maintenance cycle.
- At the end of the day, perform regular maintenance cycle and perform capping to the print head.

### 2.3.3 Printer Maintenance Procedure with Sicrys™ inks

#### 2.3.3.1 Goals

- Maintenance procedure to be implemented throughout the printing session.
- Maintaining the print head in good condition.
- Keeping all nozzles running between print runs.
- Opening clogged nozzles.
- Straightening crooked jetting.

#### 2.3.3.2 Maintenance Procedure

1. If required due to missing nozzles or crooked jetting:
2. Perform a wet wipe:
   2.1. Use a lint free wipe, wet with the advised flushing fluid.
3. Perform a nozzle check: Print a test pattern using all nozzles in order to check the nozzle condition.
4. If not all nozzles are firing, repeat step 2.
5. If after two wipes nozzles are still missing, perform short purge and wipe.

## For additional questions or comments please contact:

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