



Sicrys™ Silver Inks Handbook

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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 1.5). 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™ I40DM-106
- Sicrys™ I50DM-106
- Sicrys™ I50TM-115
- Sicrys™ I50TM-119
- Sicrys™ I50TNG4.3-2
- 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 usually over 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.
- 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 Printing

Sicrys™ inks have been designed by PVN to be compatible with many 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 printing). 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 perform a wipe every 10 minutes. 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

- When printing session has been completed, 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 where it is recommended in the handbook.

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™ I50TNG4.3-2	Tripropylene glycol monomethyl ether (TPM)
Sicrys™ I57TG4-025	Tripropylene glycol monomethyl ether (TPM)
Sicrys™ I55DMG4-045	Diethylene glycol monomethyl ether (DGME)

* Contact sales@pvnano.com to order product.

1.5 Sintering

Sicrys™ Ag inks may be sintered by various methods:

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 from 120°C. Resistivity values depend on the sintering temperature. Achievable resistivity values at 150°C, 30min are ~6xbulk silver (ink and process dependent).
 - When using a convection oven with a thin substrate, hold the substrate in a way it will not move due to air flow.
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). Achievable resistivity values are: ~3-5xbulk (ink and process dependent).

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

Laser wave length: 532nm.

Laser operation mode: Continues.

Laser spot size: 350µm.

INK	Substrate	Laser Data				Line Dimensions		Resistivity	
		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

3. NIR Sintering: NIR lamp can be used for sintering. Achievable resistivity values: <3xbulk (ink and process dependent).

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

INK	Substrate	NIR Data			Line Dimensions		Resistivity	
		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

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).
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).
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):

INK	Substrate	Sintering Data			Line Dimensions		Resistivity	
		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

1.6 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 NanoCell website at: <http://www.pvnanocell.com/product-shortlist.html>.

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).

2. Printing Guidelines

2.1 Printing conditions for Ag Sicrys™ inks

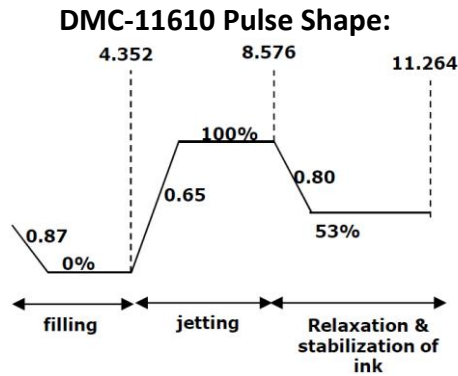
Sicrys™ inks have been designed by PVN to be compatible with many commercially available print heads such as XAAR, Dimatix, Ricoh, and Konica Minolta (some print head models may not be compatible with conductive solvent inks, print head data sheet should be checked). However, the information shared in this handbook pertains specifically to Konica Minolta KM1024, Ricoh Gen3 E3 and Dimatix cartridge print heads. In sections 2.1.1, 2.1.2 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

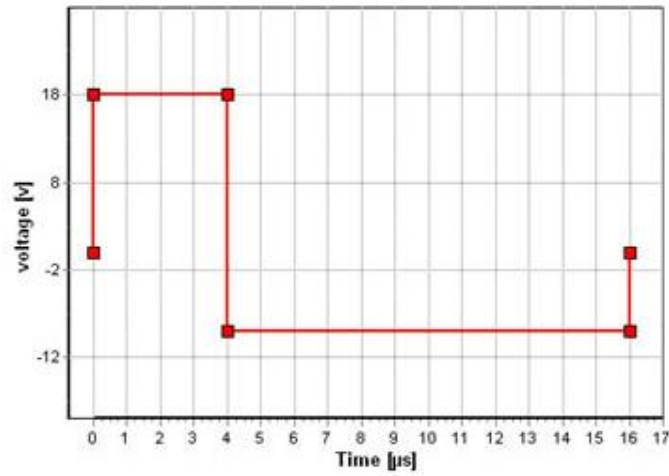
Sicrys™ I50TNG4.3-2	35	10	17
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2.1.2 Sicrys™ Printing Conditions with KM1024 SHB Print Head

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™ I50TNG4.3-2	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:



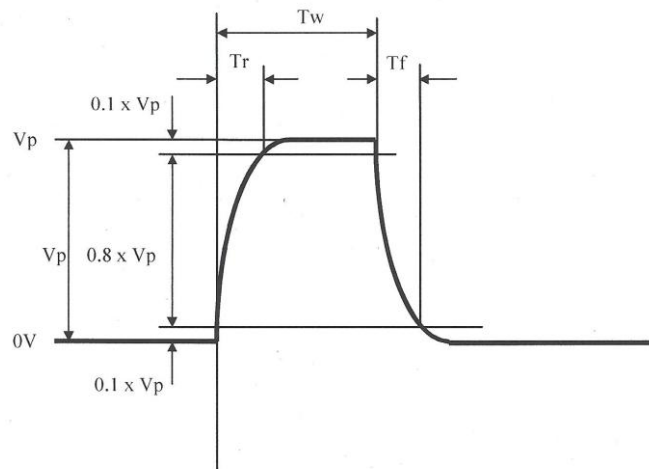
2.1.3 Sicrys™ Printing Conditions with Ricoh E3 Gen3 Print Head

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	38	6	(22,8.8)
Sicrys™ I50DM-106	30	6	(22,7.6)
Sicrys™ I50TM-115	38	6	(22,7)
Sicrys™ I50TM-119	40	8.5	(20, 8.5)
Sicrys™ I50TNG4.3-2	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:

2.2 Printing recommendations for Sicrys™ ink

2.2.1 Printing recommendations for narrow line printing

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

1. Resolution screening: Print a single layer at a wide range of resolutions and choose the resolution that provides the narrowest continuous line without bulging characteristics.
2. Printing:
 - a. Print at the chosen resolution from (1) the first few line layers. A higher resolution may be used to print additional layers, in order to build the desired line thickness.
 - b. 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

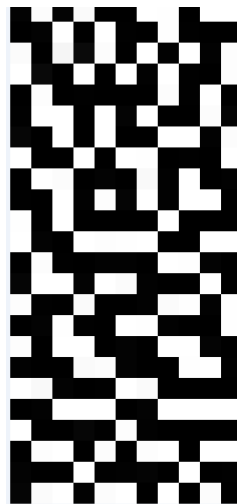
2.2.2 Printing recommendations to avoid coffee stains

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

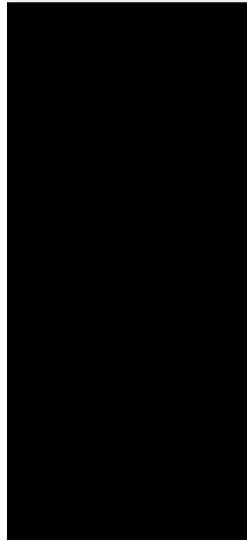
2.2.3 Printing recommendations for wide area printing

It is recommended to follow the steps outlined below in order to obtain wide area printing with Sicrys™ ink:

1. Print the first few layers (1-2) at 60% area coverage (60% of desired pattern):



2. Print the remaining layers at 100% area coverage (100% of desired pattern):



2.3 Printer Work Procedures

2.3.1 Printer Startup and Shutdown Procedure with Sicrys™ inks

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 Printer Maintenance Procedure with Sicrys™ inks

2.3.2.1 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.

2.3.2.2 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 2 wipes nozzles are still missing, perform: short purge and wipe.

For additional questions or comments please contact:

info@pvnanocell.com or sales@pvnanocell.com

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