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Complete Additive Manufacturing Solution for Mass-Production Printed Electronics

Hanan Markovich
PV Nano Cell

December 7th, 2021

Current Massive Wave: Electronics Everywhere

Enabled By Our Digital Additive Printing Technology!


Smart Automotive

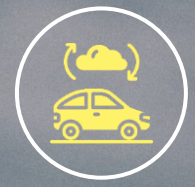

Solar Cells


IoT Applications

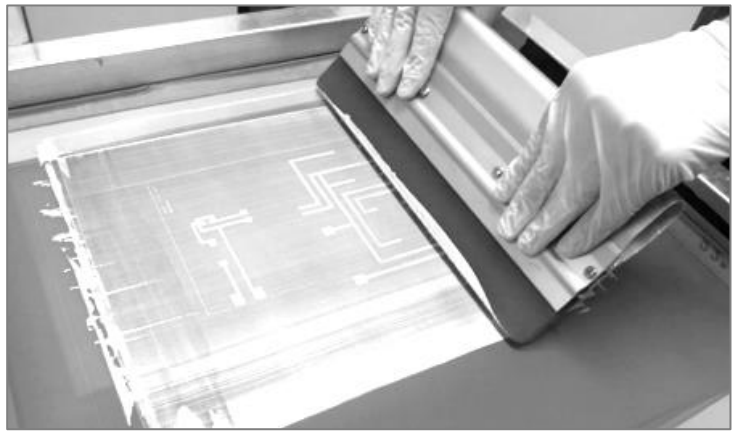

Wearables


Flexible Electronics


Medical Devices

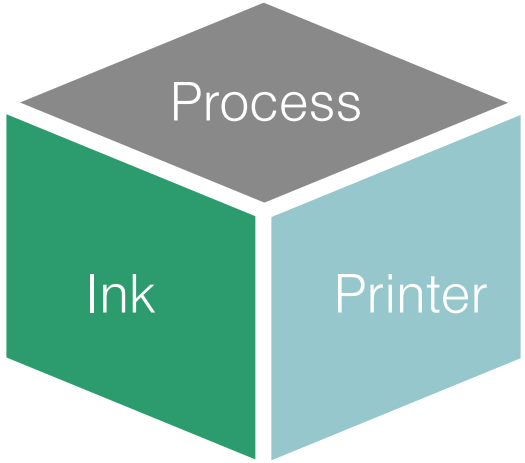

Self-Driving Cars

Digital Conductive Printing for Mass Production

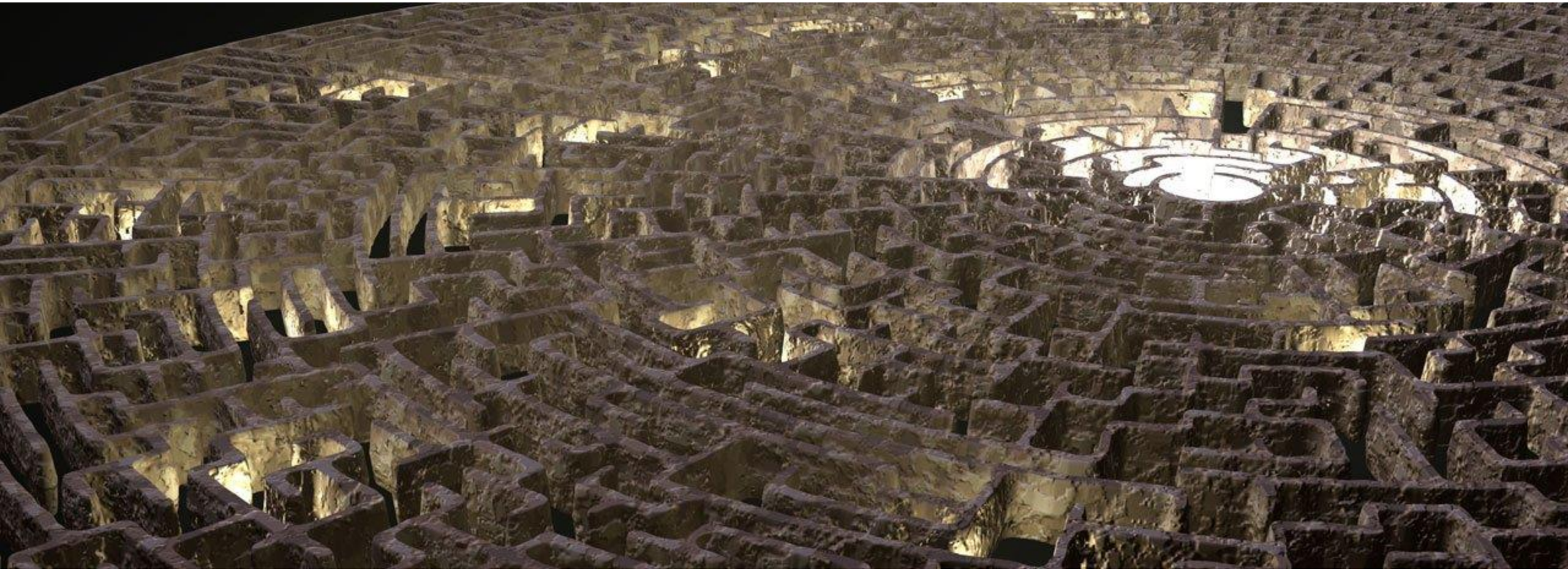


Replacing ~110 year old Analog Printing

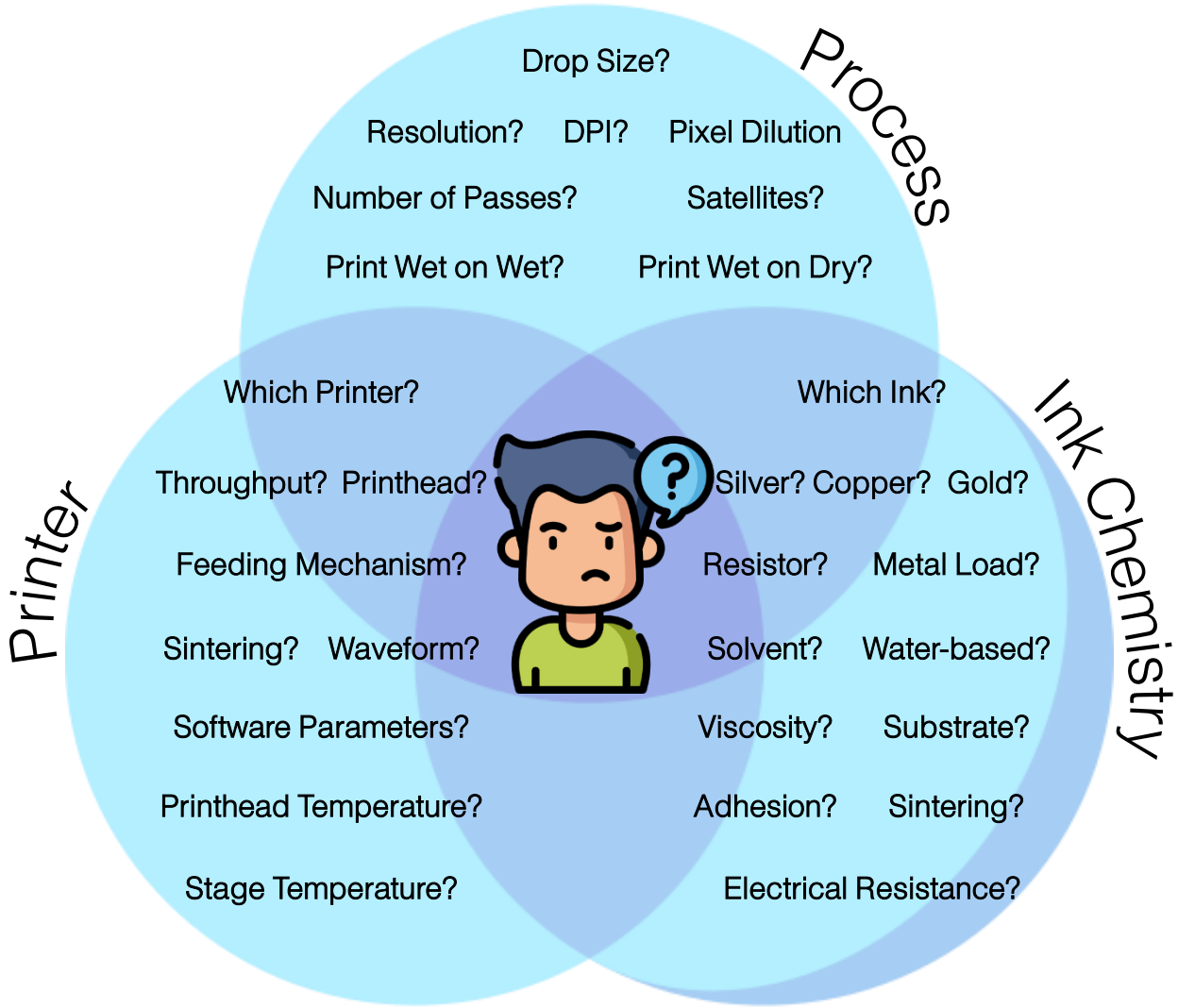
With Modern, Digital Printing



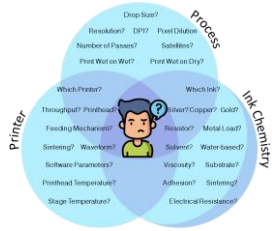
Current Digital Printed Electronics is Complicated!



Customer needs a PhD in Printed Electronics



PVN's Complete Solution Makes it as Easy as Driving



Driving Essentials:

Car

Gas

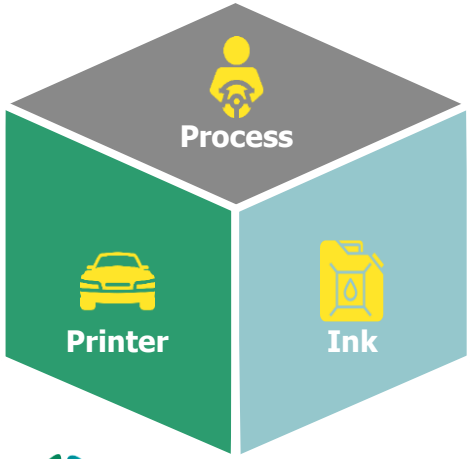
Know how to Drive

PVN's Solution:

Printer

Ink

3D Printing Process



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Complete Solution

PV Nano Cell's Offering: 3D Technology

Printers

Conductive Inks
for Mass Production

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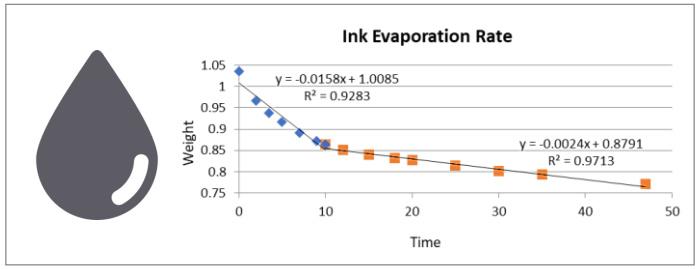
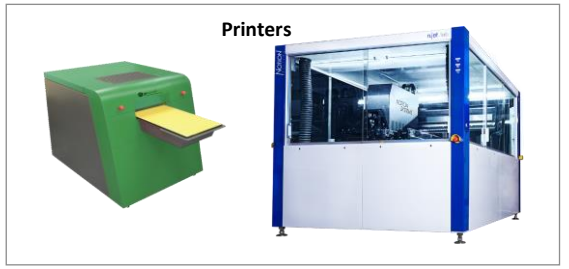
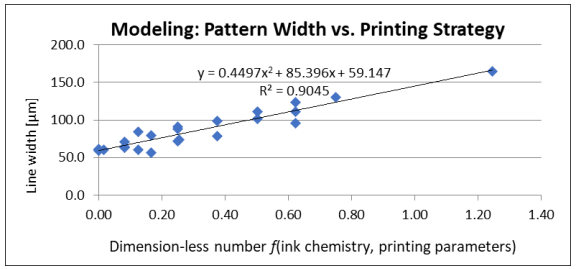
Sicrys™ Digital Inks
Single Crystal Nano Inks

3D Printing Process







Families of Sicrys™ – Single Crystal Nano Inks

- High metal load, over 60%
- Stability: Shelf life – over 12 months
- Low sintering temperature (< 130 °C).
- Low resistivity: ρ < 2.5 x bulk.

- Narrow pattern printing as narrow as 50 µm.
- Lower viscosity at high metal loading (50%+).
- Green & clean process, no hazardous material.
- SMT/soldering-capable.

Sicrys™ Digital Silver Inks: Technical Characteristics

Ink properties	I20DM-206	I40DM-106	I50DM-106	I50TM-115	I50TM-119	I50T-13	I30EG-1	I60PM-116
Metal Loading (% w/w)	20%	40%	50%	50%	50%	50%	30%	60%
Main Solvent[1]	DGME	DGME	DGME	TGME	TGME	TPM	EG	PM/DGME
Typical Viscosity @ 25°C (cP)	5	11	20	37	34	26	28	26
Surface Tension (dyn/cm) (Pendant Drop method)	34	34	34	36	29	26	47	23
Open Time[2] (jetting temperature,°C)	15 min (25°C)	10 min (30°C)	10 min (30°C)	30 min (40°C)	10 min (35°C)	60 min (35°C)	5 min (35°C)	
Resistivity (μΩcm) (thermal sintering,°C, min)	≤ 10 (150,30) ≤ 12 (130,30)	≤ 10 (150,30) ≤ 12 (130,30)	≤ 10 (150,30) ≤ 12 (130,30)	≤ 10 (150,30) ≤ 12 (130,30)	≤ 10 (150,30) ≤ 12 (130,30)	≤ 10 (200,30) ≤ 24 (150,30)	≤ 10 (180,30) ≤ 14 (150,30)	≤ 10 (130,60)
Sheet Resistance (mΩ/□) (thickness, μm)	10 (10 μm)	10 (10 μm)	10 (10 μm)	100 (1 μm) 20 (4 μm)	30 (3.5 μm) 15 (8 μm)	100 (1 μm) 25 (4 μm)	100 (1 μm) 25 (4 μm)	
Substrate Adhesion[3] (tested)[4]	ITO, Glass	ITO, Glass	ITO, Glass	ITO, Glass, PET, PC	Kapton®, FR4, PET, PC, ITO, Glass, CTO	PC, PEN, PET	Kapton®, PC, PEN, LCP, Glass	Kapton®, PC, PA, PC/ABS, Glass
Compatible Printing Technologies	Inkjet	Inkjet	Inkjet	Inkjet	Inkjet	Inkjet	Inkjet, Aerosol	Aerosol
Compatible Printheads (tested)[4]	Epson DemonJet Desktop printers	KM1024 KM1024i Ricoh E3 DMC-11610 Samba	KM1024 KM1024i Ricoh E3 DMC-11610 SapphireQS-10pl	KM1024 KM1024i KM512 Ricoh E3 SapphireQS-10pl	KM1024 KM1024i Ricoh E3	KM1024 KM1024i Ricoh E3 DMC-11610 SapphireQS-10pl	KM1024 KM1024i Ricoh E3 DMC-11610 Aerosol	Aerosol (pneumatic) atomizer)
Shelf life: 12 months. Storage at room temperature. No need to stir the inks.								

[1] - Solvents: DGME - diethylene glycol methyl ether, TGME - triethylene glycol methyl ether, PM - propylene glycol methyl ether, EG - ethylene glycol, TPM - tripropylene glycol methyl ether
[2] - Ricoh E3 printhead
[3] - Adhesion depends on substrate, sintering conditions, substrate pretreatment and pattern thickness (tested according to ASTM-3359-09 or ISO-2409)
[4] - Substrates and printheads listed here were tested and perform well. Other substrates and compatible printheads may also be applicable.

Sicrys™ Digital Silver Inks: Technical Characteristics

Ink properties	I50TM-119
Metal Loading (% w/w)	50%
Main Solvent[1]	TGME
Typical Viscosity @ 25°C (cP)	34

Sicrys™ Digital Silver Inks: Technical Characteristics

Ink properties	I50TM-119
Resistivity (μΩcm) (thermal sintering,°C, min)	≤ 10 (150,30) ≤ 12 (130,30)
Substrate Adhesion[3] (tested)[4]	Kapton®, FR4, PET, PC, ITO, Glass, CTO
Compatible Printing Technologies	Inkjet
Compatible Printheads (tested)[4]	KM1024 KM1024i Ricoh E3

Sicrys™ Digital Copper Inks: Technical Characteristics

Ink properties	IC25EG-1	IC40DM-7	IC50DM-7	IC50TM-8
Metal Loading (% w/w)	20%	40%	50%	50%
Main Solvent[1]	EG	DGME	DGME	TGME
Cu oxide in Cu nano-particles	< 10%	< 5%	< 5%	< 5%
Typical Viscosity @ 25°C (cP)	32	16	20	32
Surface Tension (dyn/cm) (Pendant Drop method)	47	28	28	30
Open Time[2] (jetting temperature,°C)	5 min (35°C)	1.5 min (35°C)	1.5 min (35°C)	20 min (40°C)
Resistivity (μΩcm) - Laser sintering (Photonic sintering)	≤ 5 (≤ 32)	≤ 5	≤ 5	≤ 5
Resistivity (μΩcm) - Thermal sintering (°C, min, Argon)	≤ 90 (300, 30,Ar)	≤ 120 (300, 30, Ar)	≤ 120 (300, 30, Ar)	≤ 120 (300, 30, Ar)
Substrate Adhesion[3] (tested)[4]	Kapton®, PA, LCP, Glass	Kapton®, FR4, ITO, Glass	Kapton®, FR4, ITO, Glass	Kapton®, FR4, ITO, Glass
Compatible Printing Technologies	Inkjet Aerosol	Inkjet	Inkjet Aerosol	Inkjet
Compatible Printheads[4]	KM1024 KM1024i Ricoh E3 Aerosol	KM1024 KM1024i Ricoh E3 DMC-11610	KM1024 KM1024i Ricoh E3 Aerosol	KM1024 KM1024i Ricoh E3

Shelf life: 12 months. Storage at room temperature under Argon. No need to stir the ink. Copper ink can be exposed to air for short periods of time (minutes), refill the bottle with Argon every time the bottle is opened.

[1] - Solvents: EG - ethylene glycol, DGME - diethylene glycol methyl ether, TGME - triethylene glycol methyl ether
[2] - Ricoh E3 printhead
[3] - Adhesion depends on substrate, sintering conditions, substrate pretreatment and pattern thickness (tested according to ASTM-3359-09 or ISO-2409)
[4] - Substrates and printheads listed here were tested and perform well. Other substrates and compatible printheads may also be applicable

Sicrys™ Digital Copper Inks: Technical Characteristics

Ink properties	IC25EG-1
Resistivity (μΩcm) - Laser sintering (Photonic sintering)	≤ 5 (≤ 32)
Resistivity (μΩcm) - Thermal sintering (°C, min, Argon)	≤ 90 (300, 30,Ar)
Substrate Adhesion[3] (tested)[4]	Kapton®, PA, LCP, Glass
Compatible Printing Technologies	Inkjet Aerosol
Compatible Printheads[4]	KM1024 KM1024i Ricoh E3 Aerosol

Sicrys™ Gold, Dielectric and Resistor Inks: Technical Characteristics

Sicrys™ **Product Data Sheet**
Product Catalog Number: **Sicrys™ IAu20W-1**

General Information
Sicrys™ IAu20W-1 is a gold nanoparticle water-based conductive ink for digital inkjet and aerosol printing. The ink offers low viscosity, reliable jetting and good printability. Storage at ambient conditions.

Ink Properties

Properties	Typical Values
Metal Loading, Au (w/w)	20 %
Particle Size (Lumisizer®)	d50 = 75 nm, d90 = 130 nm
Viscosity (Brookfield, Cone Spindle 40, 25°C)	9 cP
Surface Tension (Pendant Drop Method)	38 dyn/cm

Electrical and Adhesion Properties

Sintering Conditions (Substrate)	**Resistivity** (4PP)	**Sheet Resistance** (Layer Thickness)
Thermal Sintering: 200°C/60min (Glass)	≤40 μΩ·cm (≤16 bulk)	0.5 Ω/□ (1μm)
Photonic Sintering: Xenon Lamp (PET)	≤35 μΩ·cm (≤14 bulk)	1 Ω/□ (0.5 μm)
Adhesion to (tested):	Glass, PET	
(ASTM 3359-09 or ISO-2409)		

Compatible Printheads
Ink works well, among others, with printheads: **DMC-11610, Epson**

Product Applications
Digital Printing (Inkjet, Aerosol), Printed Electronics

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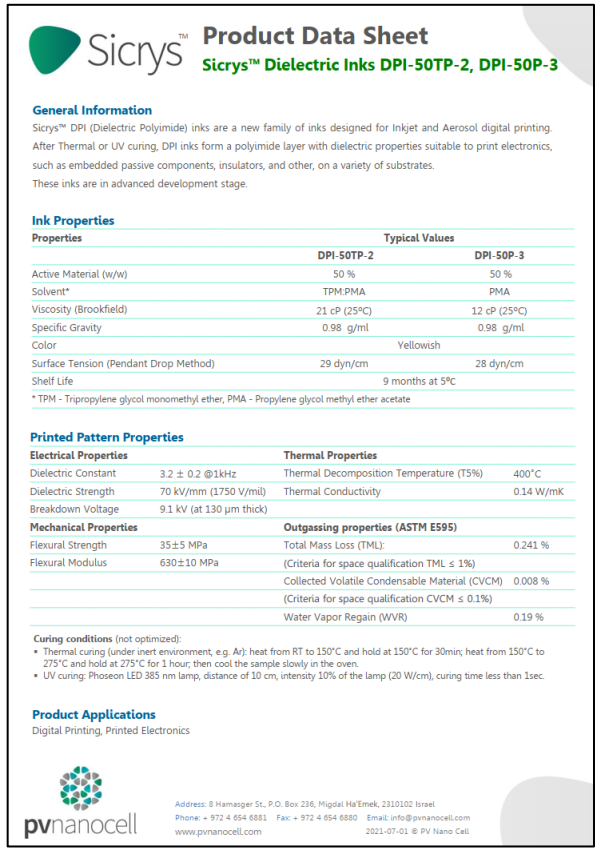
Gold Ink



Sicrys™ **Product Data Sheet**
Sicrys™ Dielectric Inks DPI-50TP-2, DPI-50P-3

General Information
Sicrys™ DPI (Dielectric Polyimide) inks are a new family of inks designed for Inkjet and Aerosol digital printing. After Thermal or UV curing, DPI inks form a polyimide layer with dielectric properties suitable to print electronics, such as embedded passive components, insulators, and other, on a variety of substrates.
These inks are in advanced development stage.

Ink Properties

Properties	Typical Values	
	DPI-50TP-2	DPI-50P-3
Active Material (w/w)	50 %	50 %
Solvent*	TPM:PMA	PMA
Viscosity (Brookfield)	21 cP (25°C)	12 cP (25°C)
Specific Gravity	0.98 g/ml	0.98 g/ml
Color	Yellowish	
Surface Tension (Pendant Drop Method)	29 dyn/cm	28 dyn/cm
Shelf Life	9 months at 5°C	

* TPM - Tripropylene glycol monomethyl ether, PMA - Propylene glycol methyl ether acetate

Printed Pattern Properties

Electrical Properties		**Thermal Properties**	
Dielectric Constant	3.2 ± 0.2 @1kHz	Thermal Decomposition Temperature (T5%)	400°C
Dielectric Strength	70 kV/mm (1750 V/mil)	Thermal Conductivity	0.14 W/mK
Breakdown Voltage	9.1 kV (at 130 μm thick)		
Mechanical Properties		**Outgassing properties (ASTM E595)**	
Flexural Strength	35±5 MPa	Total Mass Loss (TML):	0.241 %
Flexural Modulus	630±10 MPa	(Criteria for space qualification TML ≤ 1%)	
		Collected Volatile Condensable Material (CVCM)	0.008 %
		(Criteria for space qualification CVCM ≤ 0.1%)	
		Water Vapor Regain (WVR)	0.19 %

Curing conditions (not optimized):
- Thermal curing (under inert environment, e.g. Ar): heat from RT to 150°C and hold at 150°C for 30min; heat from 150°C to 275°C and hold at 275°C for 1 hour; then cool the sample slowly in the oven.
- UV curing: Phoseon LED 385 nm lamp, distance of 10 cm, intensity 10% of the lamp (20 W/cm), curing time less than 1sec.

Product Applications
Digital Printing, Printed Electronics

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Dielectric Ink

Sicrys™ **Product Data Sheet**
Product Catalog Number: **Sicrys™ RI-6DM-3**

General Information
Sicrys™ RI-6DM-3, a resistive ink based on **carbon black nanoparticles** in diethylene glycol monomethyl ether (DGME), designed for digital Inkjet printing, for use with printheads that require low viscosity inks, such as Epson printheads. The ink offers low viscosity, robust jetting, good printability and storage at ambient conditions. This ink can be used to print embedded resistors.

Ink Properties

Properties	Typical Values
Solid (w/w)	6 %
Carbon Black (w/w)	3 %
Particle Size (Lumisizer®)	d50 = 66 nm, d90 = 110 nm
Specific Gravity	1.05 g/ml
Viscosity (Brookfield, Cone Spindle 40, 25°C)	6 cP
Surface Tension (Pendant Drop Method)	34 dyn/cm
Shelf Life	9 months at 25°C

Electrical Properties

Substrate	Sintering Profile	**Resistivity** (4PP)
Glass	150°C / 60 min	~ 0.6 Ω·cm
Glass	240°C / 60 min	~ 0.3 Ω·cm

Compatible printheads#
Ink works well, among others, with printheads: **Epson**

Product Applications
Digital Printing (Inkjet), Printed Electronics, Embedded Resistors

#- Printheads listed here were tested and perform well. Other compatible printheads may also be applicable.

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Resistor Ink

Sicrys™ **Product Data Sheet**
Product Catalog Number: **Sicrys™ RI-20DM-1**

General Information
Sicrys™ RI-20DM-1, a resistive ink based on **carbon black nanoparticles** in diethylene glycol monomethyl ether (DGME), designed for digital Inkjet printing. The ink offers low viscosity, robust jetting, good printability and storage at ambient conditions. This ink can be used to print embedded resistors.

Ink Properties

Properties	Typical Values
Solid (w/w)	20 %
Carbon Black (w/w)	10 %
Particle Size (Lumisizer®)	d50 = 66 nm, d90 = 110 nm
Specific Gravity	1.06 g/ml
Viscosity (Brookfield, Cone Spindle 40)	25 cP (25°C) 22 cP (30°C) 20 cP (35°C) 18 cP (40°C)
Surface Tension (Pendant Drop Method)	34 dyn/cm
Shelf Life	9 months at 25°C

Electrical Properties

Substrate	Sintering Profile	**Resistivity** (4PP)
Glass	150°C / 60 min	~ 0.6 Ω·cm
Glass	240°C / 60 min	~ 0.3 Ω·cm

Compatible printheads#
Ink works well, among others, with printheads: **Ricoh E3**

Product Applications
Digital Printing (Inkjet), Printed Electronics, Embedded Resistors

#- Printheads listed here were tested and perform well. Other compatible printheads may also be applicable.

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Resistor Ink

DemonJet: R&D and Low Volume Manufacturing Printer

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Contact us for more info:
sales@pvnanocell.com

Specifications

Printing method	Epson Micro Piezo™ TFP print head
Resolution	360 x 360 dpi and up to 2880 x 1440 dpi
Minimum droplet size	3.5 pL
# of inks per printing session	Up to 10
# of nozzles	360 x 10 channels
Maximum substrate size	440 x 640 mm (17.3'' x25.2'')
Printed size	up to 427 x 635 mm (16.8'' x 25'')
Speed	14 minutes - full plate (1.1 sqm/h 1,705 sq. in./H)
Position accuracy	Maximum: ±5 µm
	Average: ±2.1 µm
Repeatability	Standard deviation, 1σ: ±2.1 µm
Size accuracy	Maximum: ±6 µm
	Average: ±2.1 µm
Supported substrate thickness*	Maximum 3.7 mm / 0.145''
Substrate materials**	PET, ITO, Glass, PI, Other
Dryer	IR lamp
Sintering	IR lamp
Power	• 220-240 VAC 50Hz + Ground. Line circuit breaker 16 Amp. (for 220 Volt countries) • 110-120 VAV 60/Hz + ground. Line circuit breaker 20 Amp. (for 110 Volt countries)
Size	180 cm x 118 cm x 108 cm (L x H x W) / 70.8'' x 46.4'' x 42.5''
Weight	450 Kg / 992 lb

* For thicker substrates please contact us
** For other substrates please contact us

Contact: sales@pvnanocell.com www.pvnanocell.com

High Throughput
Up to 1000's of Parts per Hour

Camera-based
Registration

Software
Automation

IR Lamp for
Drying & Sintering

Up to 10 Inks
per Printing Session

Accuracy:
±2.1 µm (average)

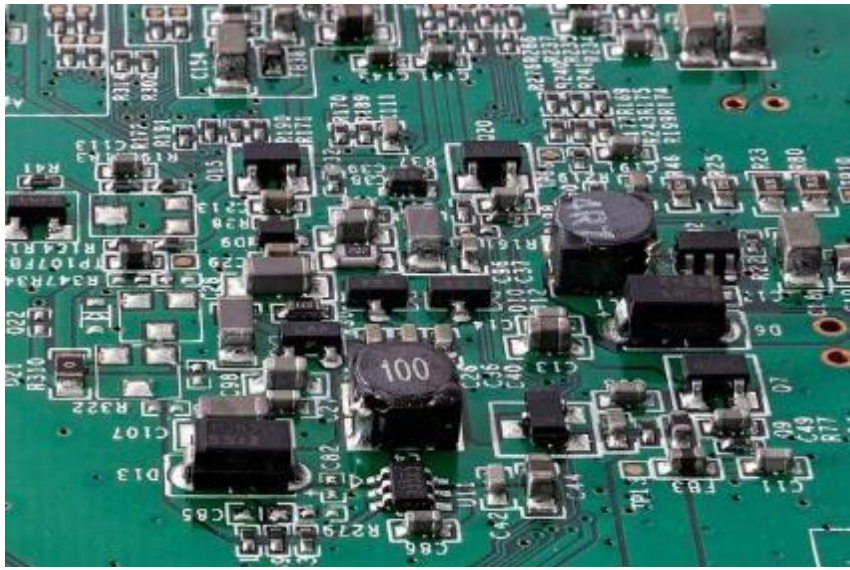
Printed Size:
427 mm x 365 mm

Printing Speed:
14 Minutes (full plate)

Focus: Mass-Production Markets

Automotive

Solar

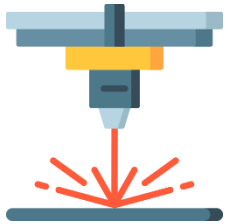


Embedded Passive Components

Automotive Market: Project Tinker

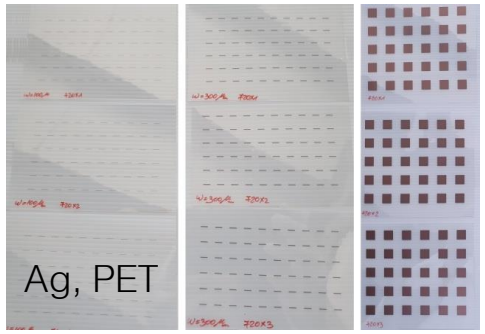
UV-Curable Copper Ink

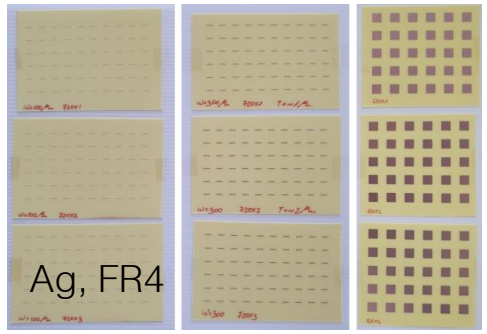
UV-Curable Silver Ink

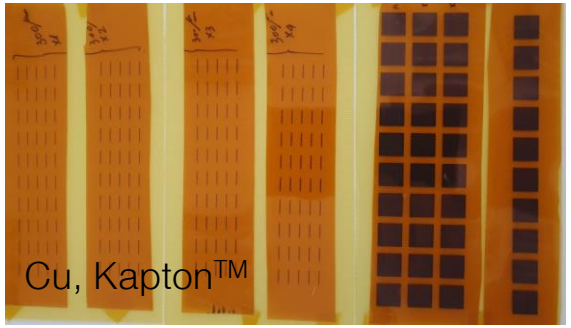


Laser Sintering

Samples prepared for Forth, Laser Sintering: (~100µm & ~300µm width, 1-7.5µm thickness)

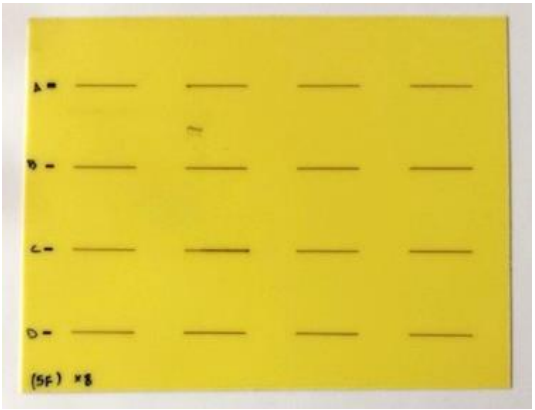






@PVN: Cu on FR4 feasibility with Green laser: Gaussian beam, 5mm/s, 0.7W (~150µm width, 4-7µm thickness)

Line	Resistance (Ω)	Width (µm)	Avg. H (µm)	Resistivity (µΩcm)	Resistivity (xBulk)
5F-A1	0.237	123	6.5	7.5	4.4
5F-B1	0.240	161	4.6	7.1	4.2
5F-C1	0.220	154	4.3	5.8	3.4
5F-D1	0.230	157	4.2	6.1	3.6



Automotive Glass

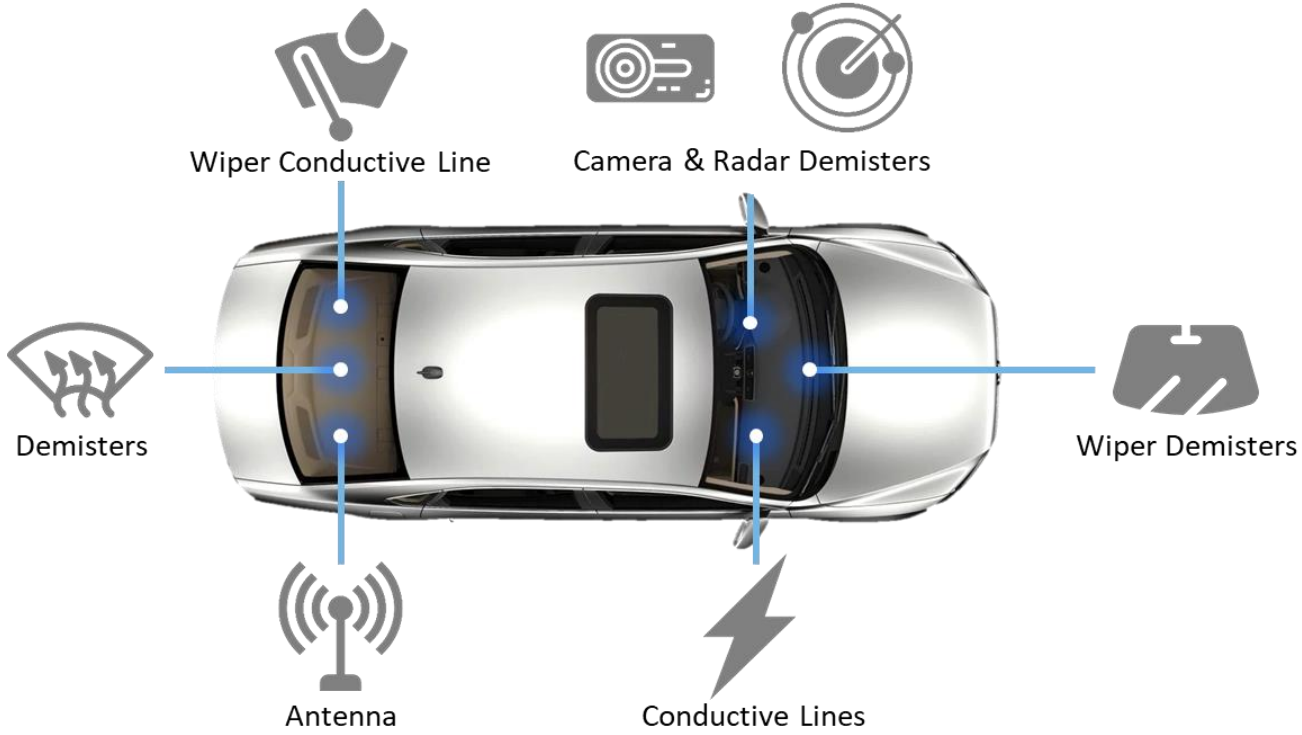
Silver per Window [gr]#	New Cars Annually	Silver [Ton]	Ink [Ton]
5	76,000,000	380	760

3 grams (rear defroster) + 2 grams (front defroster & other electronics).
* High volumes of inks.

Commercial Applications: Automotive Market

- Windshields are filled with Electronics
  - Multi inks printed using one printer.
  - Narrow & dense electronics.
  - Large format
  - Each windshield is different.

- Bus Bars Resistivity: 1.5 mΩ/□
- Fine Lines Width < 0.6 mm
- Fine Lines Resistivity: 2.0 mΩ/□



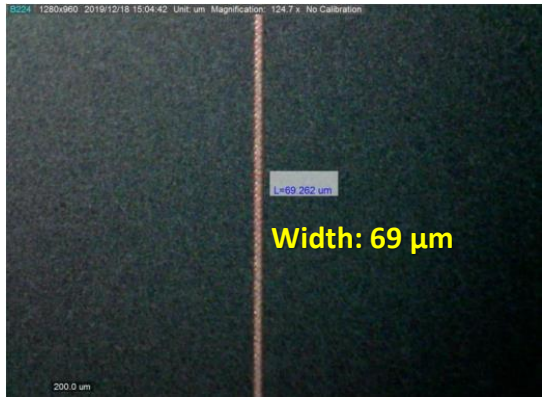
Solar Market

Type of Cell	Silver per Gwp [Ton]	Gwp in 2020	Annual Silver [Ton]	Annual Ink [Ton]
Thin Film, OPV & HJT*	12.9	20.3	261	521
Silicon	11.3	114.7	1,291	2,582

* Temperature-sensitive cells.
# Future high-volume quantities

Revolutionizing Solar Cells Performance

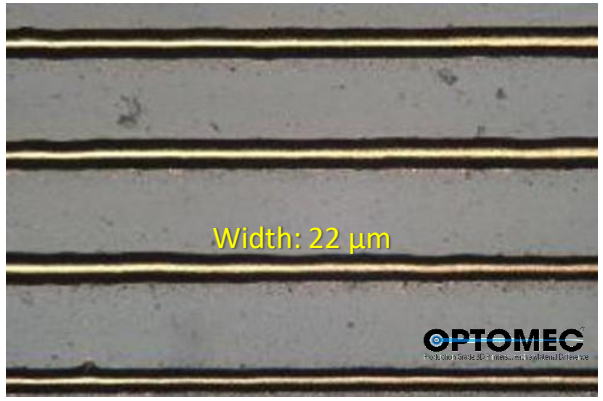
5 to 6 times better conductivity at low sintering temp. enables narrower fingers.



Sicrys™ Silver inks inkjet-printed on IZO, ITO, etc.
Width = ~70 µm, Thickness = ~4 µm. Resistivity =~6 µΩcm. Sintered at 200 ºC. Industrial Thin Film cells.

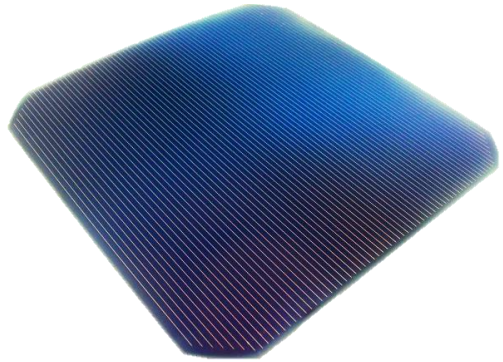
Reduce amount of silver by a factor of 3 to 5 when sintering low temperatures

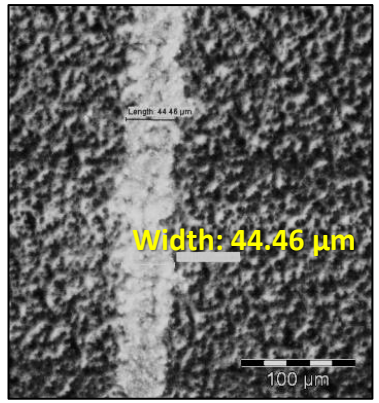
Inkjet-print finger width of 35 to 45 µm and Aerosol print as narrow as 20 µm



Sicrys™ Silver ink Aerosol-printed on glass.
Width =22 µm, Thickness = 2 µm, Resistivity = 1.16x10-7 Ωm at @ 200 ºC for 1 hr

Inkjet: a contactless printing technology. enables use of thinner wafers.

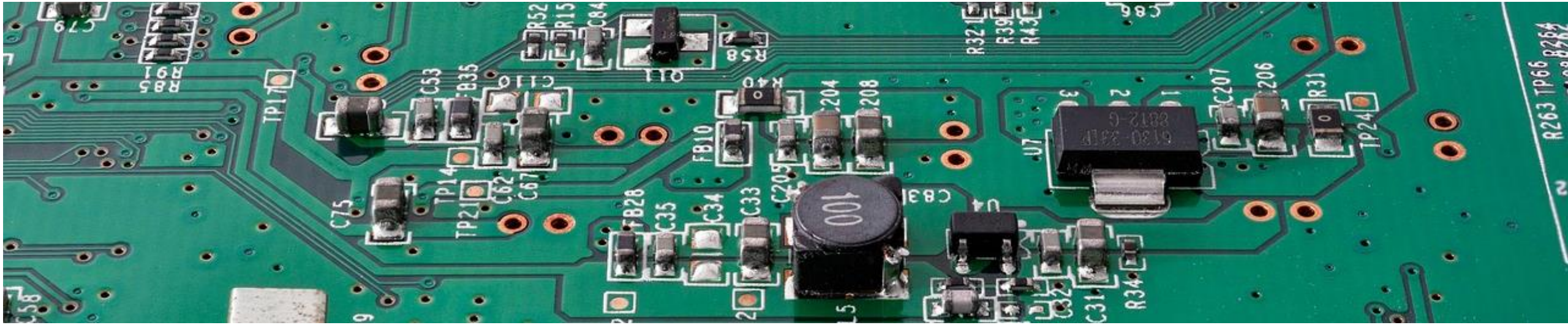




Sicrys™ Silver ink with Glass Frits Inkjet-printed
Width = 45 ÷ 50 µm. Thickness = ~4 µm. Resistivity < 2 µΩcm. Firing at up to 750ºC. Crystalline Silicon Cell.

Inkjet is contactless printing technology enabling usage of thinner wafers. 3 to 4 pL print heads will enable printing narrower patterns.

Target Market #3: Embedded Passive Components >>$B



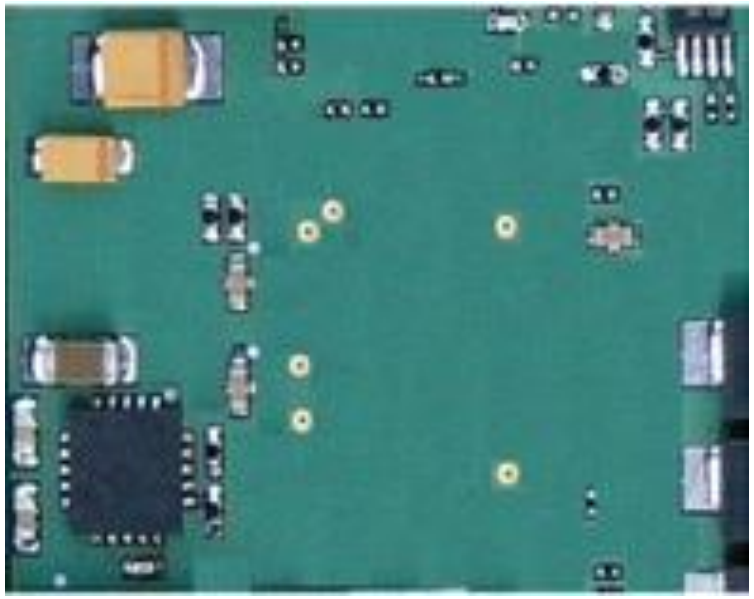
Value Proposition

- Improved Performance
- Flexible Electronics
- Thinner Electronics
- Improved Reliability
- Clean technology.

Source 1
Source 2

Upcoming Revolution: **Embedded Passive Components (EPC)**

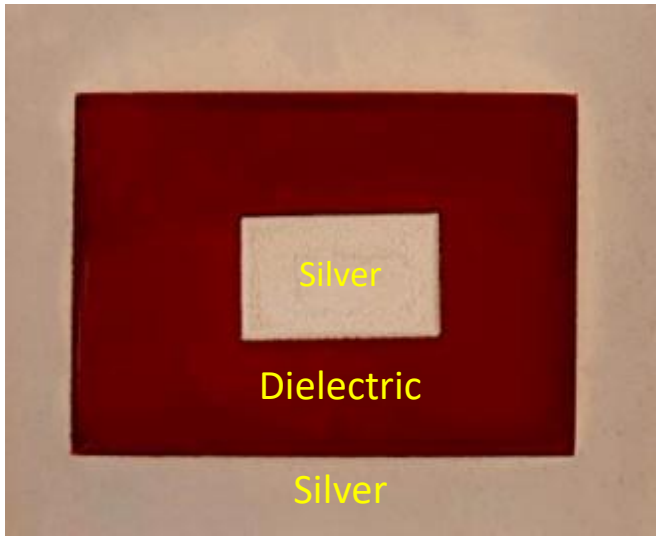
Surface Mount



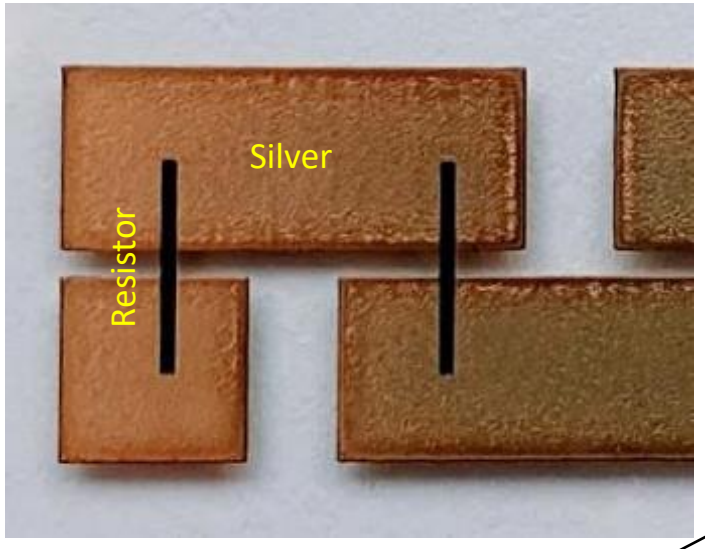
Embedded

Source: PRINTED CIRCUIT DESIGN & FAB

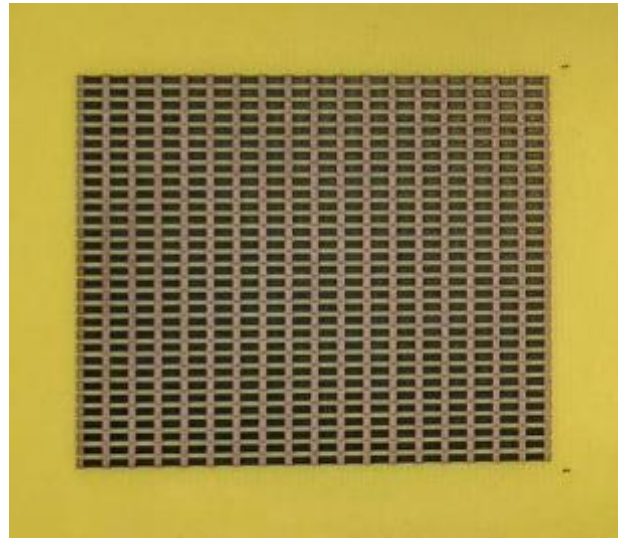
PVN Is Ready With Its Embedded Passive Technology



Printed Capacitor

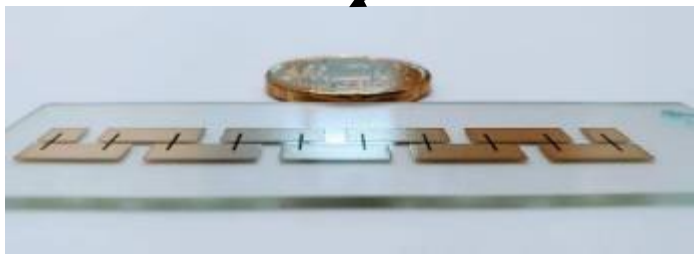


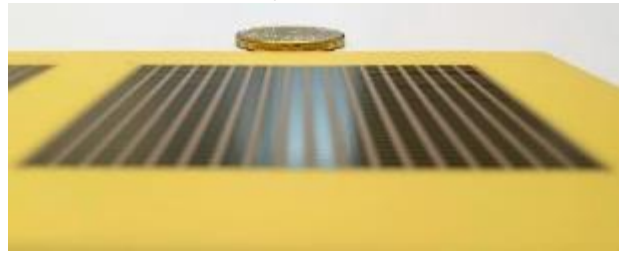
Printed Resistor



18 x 31 = 558 Printed Resistors

DemonJet Printer

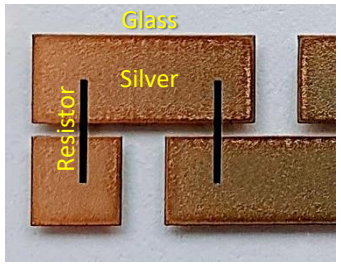




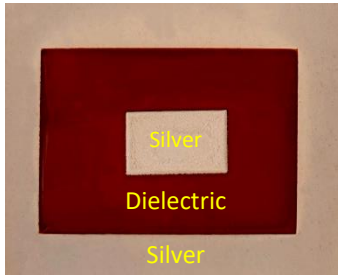
Commercial Applications & Markets Served

Automotive Windshields

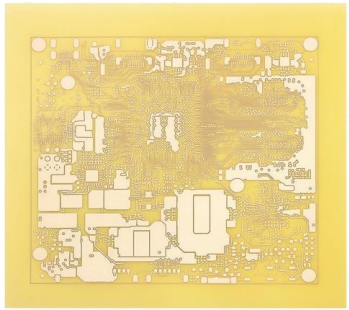
Solar Cell Fingers & Busbars



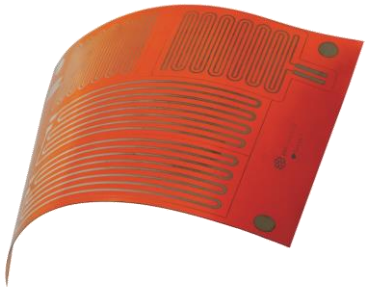
Embedded Printed Resistor



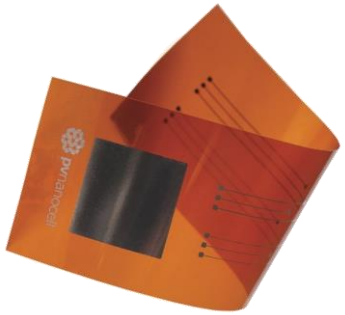
Embedded Printed Capacitor



Printed Circuit Board on FR4

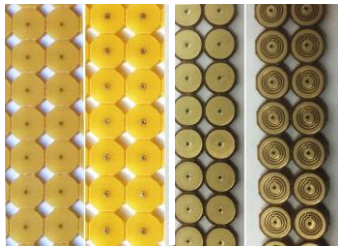


Flexible Antenna

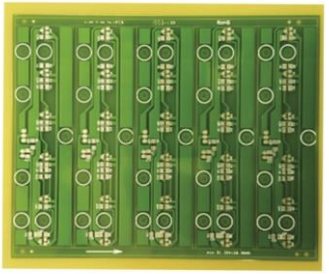


Flexible Heater

Phone Antenna



Special Heater

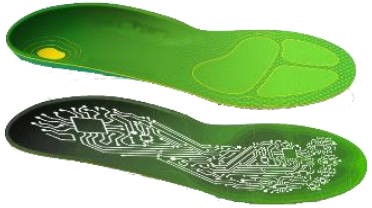


1-Layer PCB

4-Layer PCB

Medical Sensor on Paper

Coil with 18 Turns



Electronic Insole

pvnanocell

Horizon 2020
European Union Funding
for Research & Innovation

רשות החדשנות
Israel Innovation
Authority

eurostars™

Ministry of Energy
www.energy.gov.il

SOLAR-ERA.NET

Prestigious Development Projects (Funded Consortiums)

Our engineers are involved in an array of projects around the world with leading research centers, companies, universities and more to bring the technologies of the next century

TINKER
Digital manufacturing of LIDAR & RADAR sensors

ROLA-FLEX
Flexible electronics, LIFT technology

inkjetPCB
Embedded Passive Components

BUSSARD
Solar cells, very narrow metallization

Intellectual Property

Sicrys™ Patents Granted:

USA	US	9,556,350 & 10,166,602
Russia	RU	2593311 & 2730285
China	CN	103282969
Japan	JP	6067573 & JP 6363138
Europe	EP	2649621 (Germany, Netherlands, UK, France)
Europe	EP	3113897 (Germany, Netherlands, UK, France, Finland, Ireland)
Israel	IL	226665
India	IN	324986
Korea	KR	10-1932781
Brazil	BR	11 2013 013885-8 A2

Copper WO PCT/1B2015/051536 (WO2015132719) National phase.

Silver WO PCT/US2011/063459 (WO2012078590) National phase.

Additional Patents:

PVnanocell joint patent with TAU:

IP Nano wires for thin solar cells metallization:
WO 2013/128458
US 9,373,515 B2 Conductive Nanowires Films.

PV Nano Cell IP General
(Sono chemistry – nano materials – owned by subsidiary NZE):
USA 7,157,058; USA 7,504,075; IL 144638; IL 149932.

Main Claims: Single Crystal Nano Particles Dispersions & Inks

Strong Article Patents, Single Crystals can be Policed

DigiFlex Patents:
Process for Producing a Photomask on a Photopolymeric Surface: USA 9,513,551 and 12 countries.

Process for Dry-coating of Flexographic Surfaces: USA 9,352,544

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Safe Harbor

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