

FUNCTIONAL INKS WORKSHOP

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INKS - Product composition

Composition		Functionality
Pigments	Ag, AgCl, AGCu, Cu, Ni, Graphite, Carbon Black, Insulating Pigments, Phospors	Conductivity, Isolation, Resistors, Capacitors, Electrodes, Antennas, RF Absorption/Reflection, light emitting
Resins	Thermoplastic Thermosetting UV Curable	Adhesion, Cohesion, Flexibility, abrasion resistance, chemical resistance, environmental stability
Carrier	Organic Solvents Water	Medium for dissolving resins/dispersing pigments Viscosity Evaporation Compatibility with substrates
Additives	Many	Enhancing functionalities above

Substrates

Our materials can be supplied for use on different substrates. Depending on the application, the following substrates are used in combination with our products:

- Plastic films - Polyester (PET), PVC, PC, polyimide, ABS, among others.
- Different grades of paper and cardboard substrates
- PCB materials - FR2 (phenolic), FR4 (epoxy), CEM1, among others.
- Glass
- Ceramics
- Plastic housings - PC, ABS, PA, PU, polyester, among others.

Substrate selection may limit product use due to solvent sensitivity, temperature limitations and compatibility. Therefore, product performance on the substrate and product/process compatibility with the substrate must be verified.

Product properties

- Shelf life
- stability, sedimentation
- Wet product specification
- solids, viscosity
- Storage conditions
- room temperature, refrigerator, freezer
- Application method
- screen printing, spraying or other methods
- Required drying/curing conditions
- temperature, UV
- Selling price
 - For the customer, cost in use is important (not only the price per kg).

Properties of the Applied Ink

Coating properties after application may include:

- Substrate compatibility
- Electrical properties
- Surface resistance
- Dielectric properties
- Mechanical properties
- Adhesion/Cohesion
- Flexibility
- Hardness
- Environmental stability
 - Heat
 - Humidity
 - Silver migration
 - Resistance to solvents and chemicals

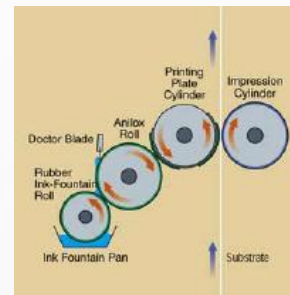
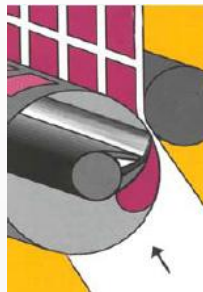
Printing methods

- Flexographic printing
- Gravure printing
- Screen printing

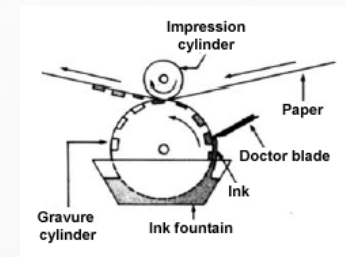
The advantage of screen printing is that it allows thick layers (5-25 μm) to be applied, but it is a slow printing process compared with flexography or gravure printing.



Printing speed



Flexografía



Huecograbado

Velocidad de
impresión

Serigrafía

2 squeegee angle

3 contact angle

4 printing direction

5 squeegee

6 printing ink

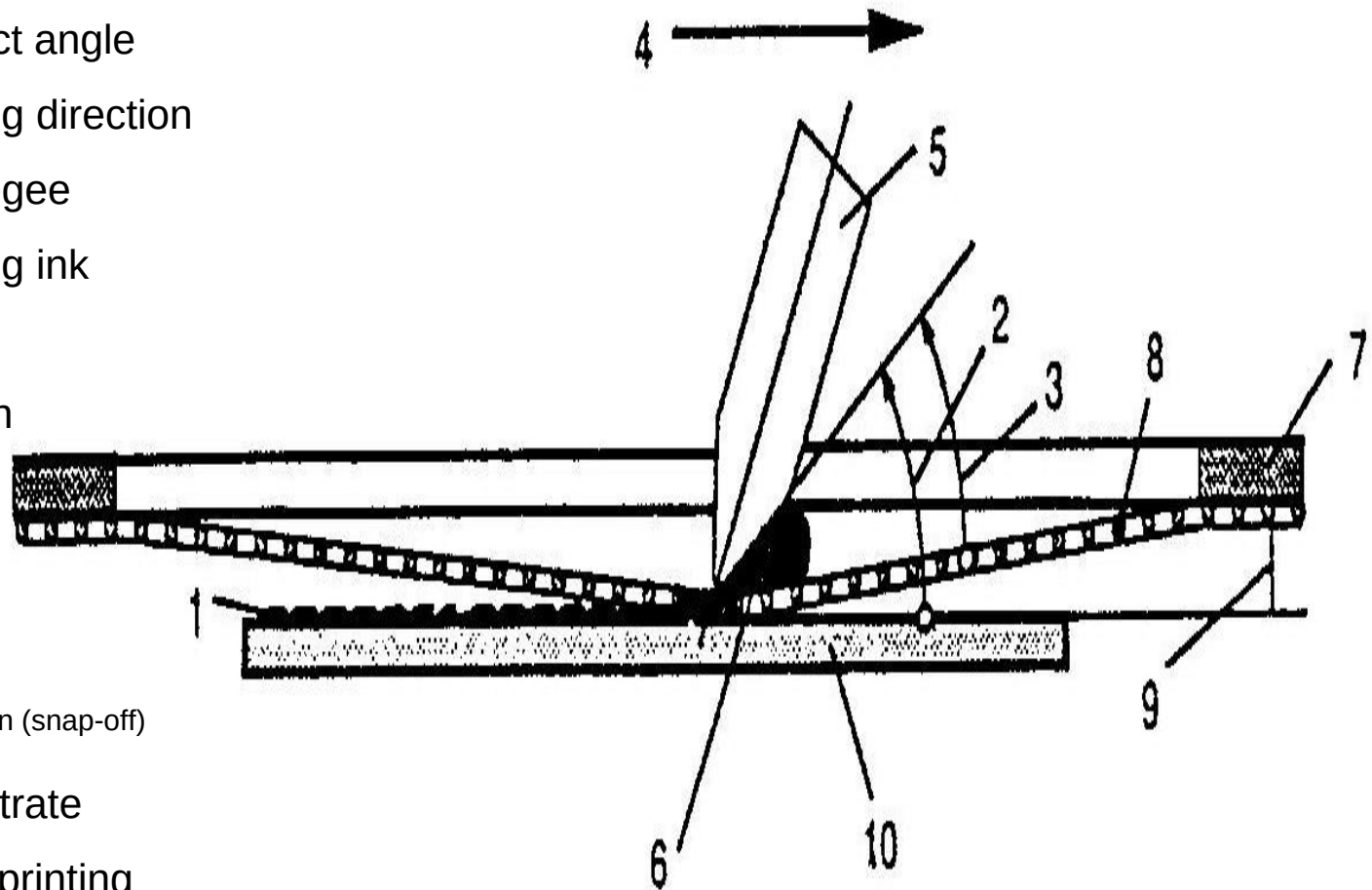
7 frame

8 screen

9 separation (snap-off)

10 substrate

Screen printing



Secado y curado

- Solvent-based inks

- Static ovens
 - Conveyor ovens

- Hot air + infrared
 - Contact dryers

- UV ovens

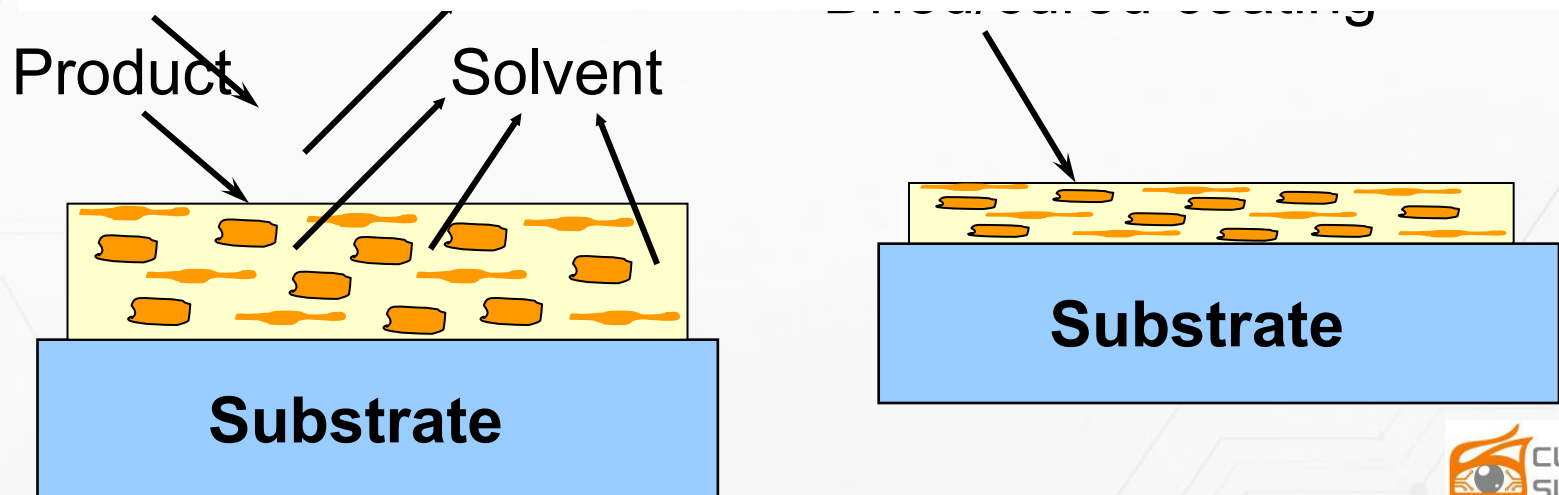
- Different UV lamps can be used

Drying and curing

□ Pueden usarse distintas lámparas UV

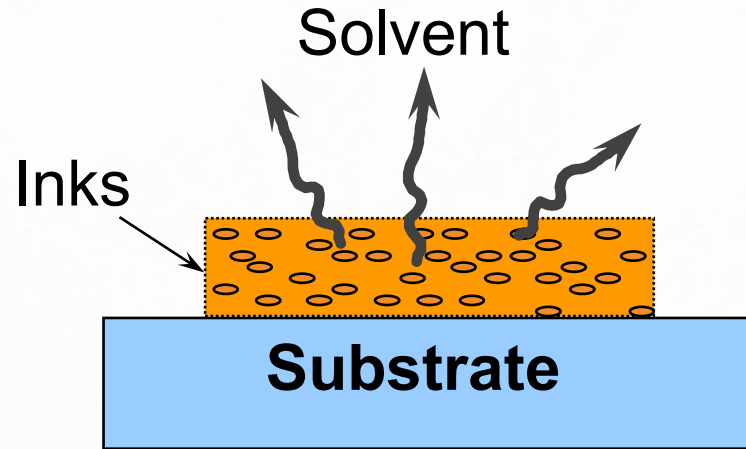
AEM - Drying and curing

Proper drying/curing is very important to achieve the required coating performance. Products are applied wet to the substrate. The drying/curing process removes solvent from the coating and promotes crosslinking of the resin matrix (thermosetting systems). The coating shrinks and contact between particles creates the functionality (conductivity).

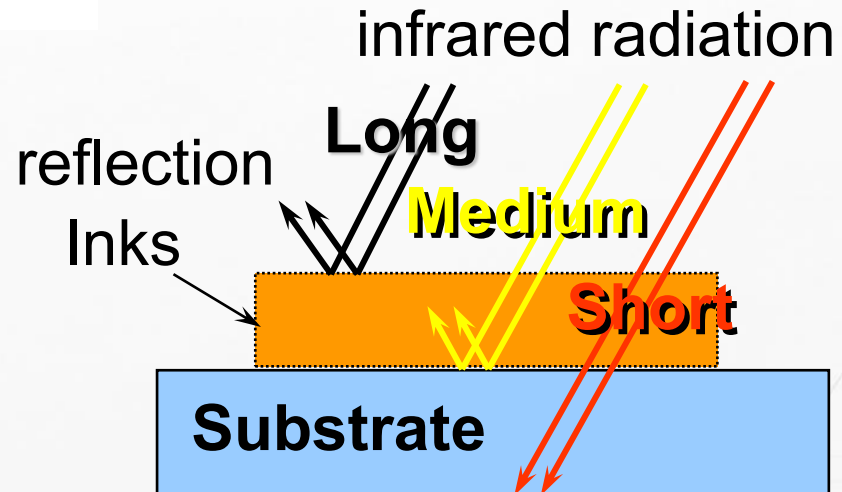


AEM - Drying and curing

By convection



By infrared radiation



AEM - Drying and curing

Infrared drying (IR)

- Only medium-wave IR radiation (1.7-2.8 μm) is suitable for increasing coating drying/curing speed.
- IR radiation contains a great deal of energy, making it

a risky drying/curing method. Preferably, convection drying (first) is combined with IR drying (second).

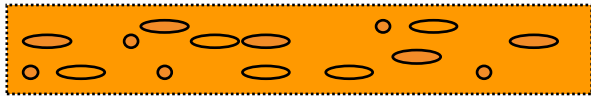
- A black (carbon) coating will absorb much more

energy than a reflective (silver) coating. Therefore, it is difficult to specify temperatures for IR ovens.

- The performance of an IR-dried/cured coating should always be compared with a convection-dried/cured sample.

Drying and curing

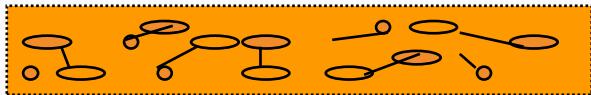
UV ink curing mechanism



A-Fluid film



B-Exposure to light



C-Propagation of polymerisation

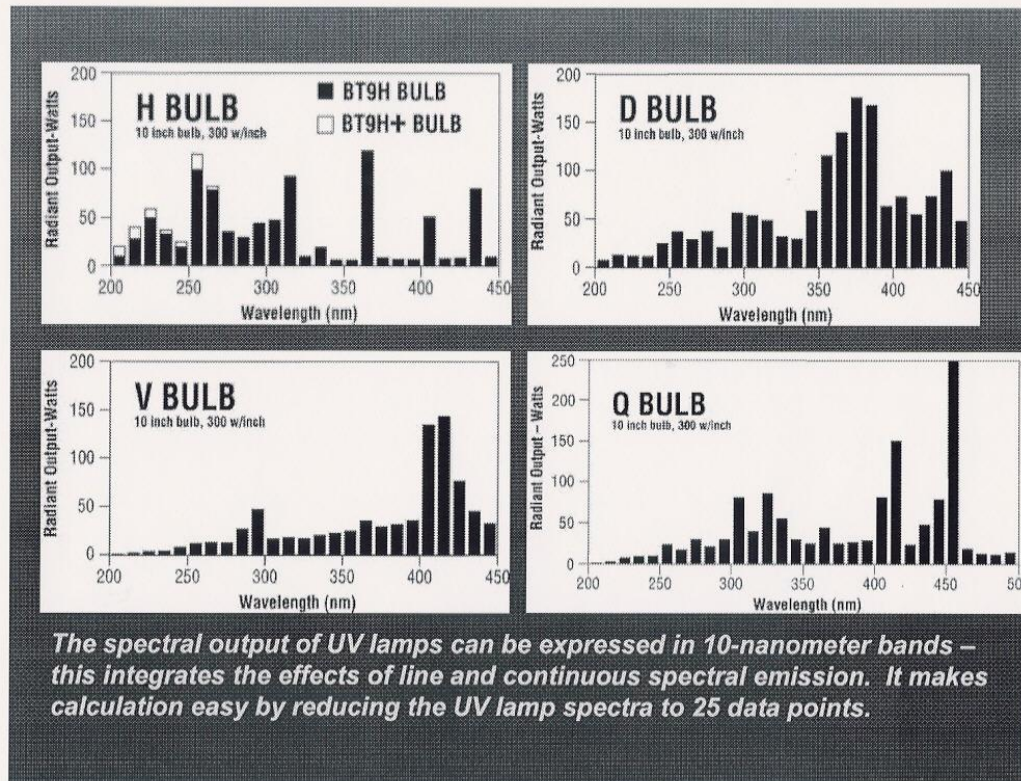


D-Cured film

- **Photoinitiator**
- **Monomer**
- **Oligomer**

AEM - Drying and curing

Espectros de diferentes lámparas UV



Spectra of different UV lamps

Doping mercury UV lamps with iron or gallium provides a longer wavelength (nm), increasing penetration in pigmented systems.

Typical product data

Electrodag PF-410 is a silver ink for flexible circuits with the following typical product data:

- Liquid product properties

- Solids content: $\pm 74.5\%$
- Brookfield viscosity: ± 15000 mPas
- Density: ± 2500 kg/m³
- Flash point: 110°C
- Storage conditions: 5
 - 30°C
- Shelf life: at least 12 months
- Theoretical coverage: ± 15 m²/kg @ 10µm

- Coating properties

- Surface resistance: ± 0.016 ohm/sq/25µm
- Adhesion (ASTM 3359B): 5B on PET
- Cohesion: no failures
- Flexibility: resistance increase <100%
- Pencil hardness (ASTM 3363): >2H
- Environmental stability: no increase in resistance or change in adhesion

Surface resistance

Resistance calculation

$$R_p(\Omega/\text{sq.}/\mu\text{m}) = \frac{R_t \times t \times W}{25 \times L} \quad \text{or} \quad R_t = \frac{R_p \times L \times c}{25 \times W}$$

R_p = product resistance (ohm/sq./25 μm)

R_t = track resistance (ohm)

t = dry coating thickness (μm)

W = track width (mm)

L = track length (mm)

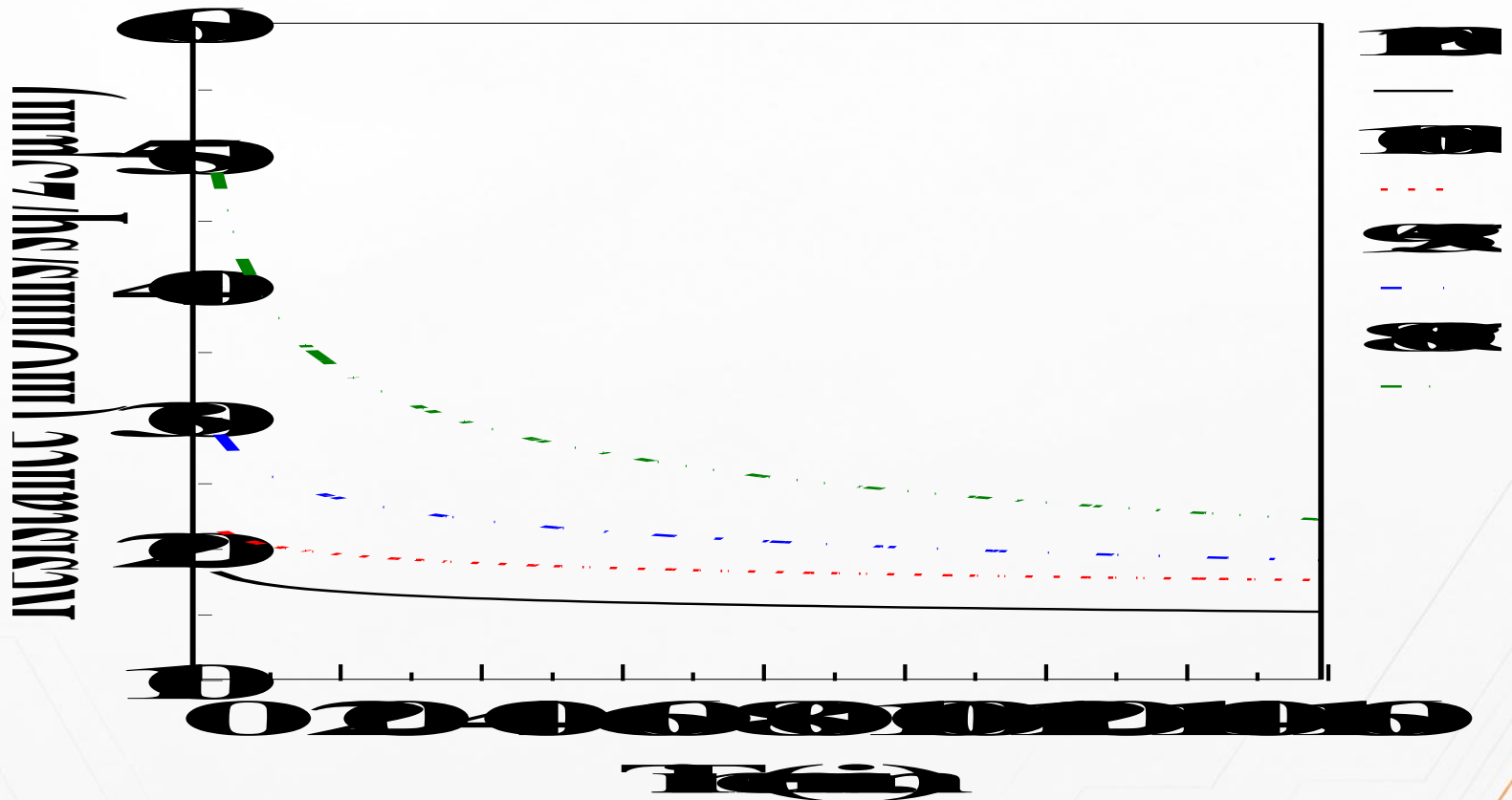


Calculation Example:

1. A track with a length of 100 mm and a width of 2 mm is $100/2 = 50$ sq.
2. The track has a resistance of 3.0 ohm, which means $3.0/50 = 0.060$ ohm/sq.
3. The dry film thickness is 10 μm , so product resistance is $0.060 \times 10/25 = 0.024$ ohm/sq./25 μm

Drying and curing (PF-410)

Influence of drying time/temperature on resistance



Ensayo de adhesión

Adhesión según ASTM-3359B

Rating	Appearance of the crosscut after adhesion test
5B	no removal
4B	
3B	
2B	
- 5B: no removal	
- 3B: 5-15% removed	

- 2B: 15-35% removed

- 1B: 35-65% removed

- 0B: >65% removed

Adhesion test

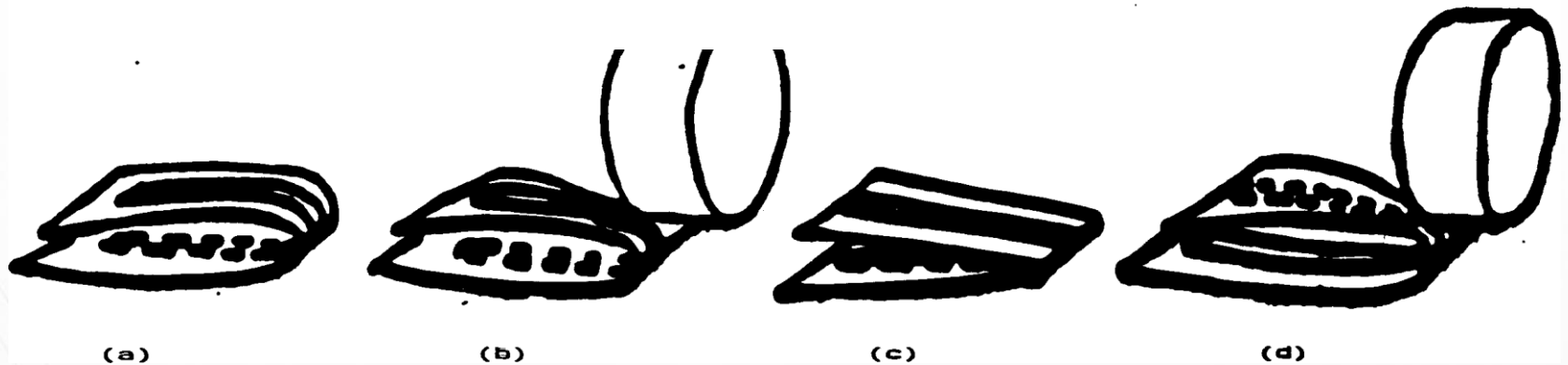
Adhesion according to
ASTM-3359B

➤ 1B: 35-65 % removido

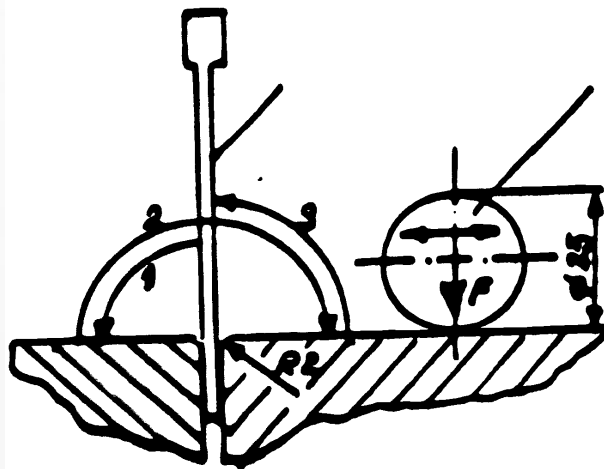
➤ 0B: >65 % removido

Flexibility test with 1800 g roller

DIN 42115 flexibility test



Ensayo de flexibilidad DIN 42115



Fenómeno de migración de plata

- Migration of silver ions from the positively charged track toward the negatively charged track
- Migration can occur both horizontally and vertically



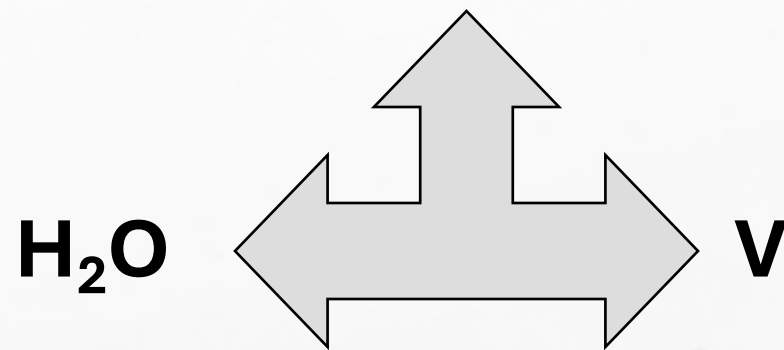
Silver migration phenomenon



Conditions for silver migration

- Silver must be printed on an insulating substrate
- Tracks must be under DC voltage
- Presence of moisture

Ag



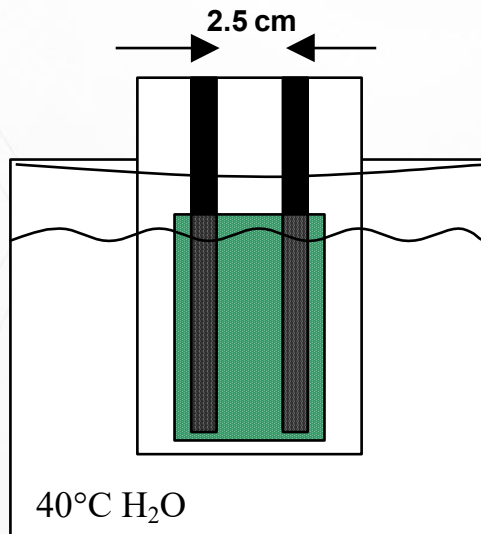
Silver migration

How to avoid/reduce the risk of silver migration:

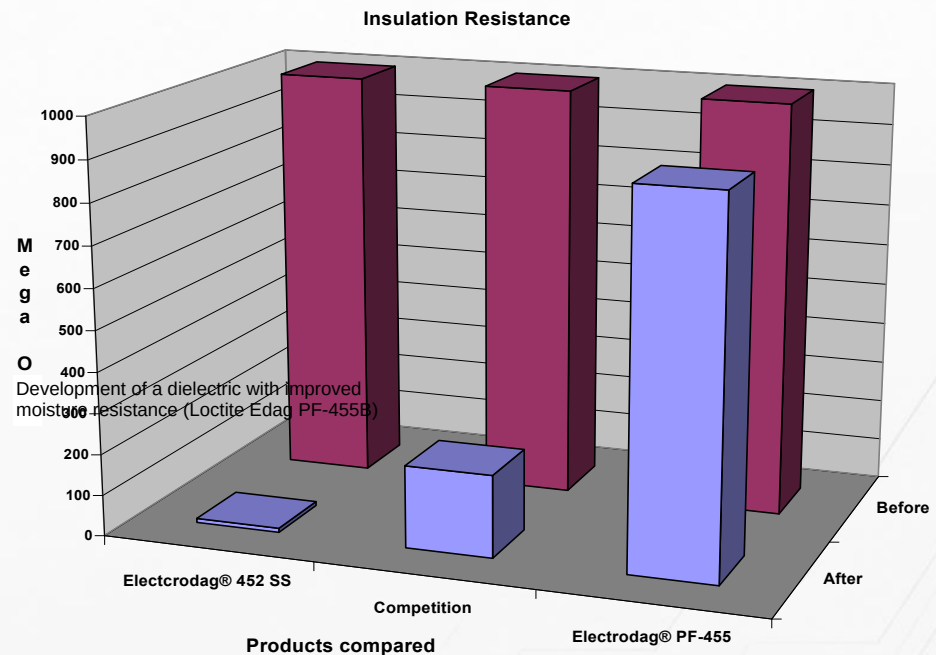
- No constant load on the tracks
 - Prevent moisture absorption
 - Protect the silver tracks
 - Improve track design
 - Use silver-free PTF inks
 - Use dielectric coatings with better moisture resistance
-
- Do not print crossovers
-
- THP
-
- Old concept (separate circuits)

Silver migration

Desarrollo de un dieléctrico con mejor resistencia a la humedad (Loctite Edag PF-455B)



25µm thick dielectric,
15 minutes immersed, 500 volt
load



- Silver inks

Interruptores de membrana, teclados de recorrido completo y otros circuitos flexibles

❖ Tintas de plata

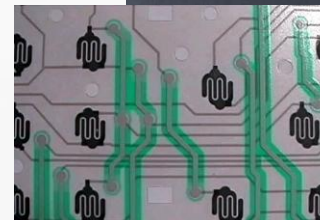
CI-1036, among others
- Carbon inks

Loctite Edag PF-407A, PF-407C,
965 SS, CI-2001, among others
- Dielectric inks

Loctite Edag PF-407A, PF-407C,
965 SS, CI-2001, entre otras

❖ Tintas dieléctricas

Membrane switches, full-travel keyboards and other flexible circuits



Applications - Flexible circuits

Adhesive

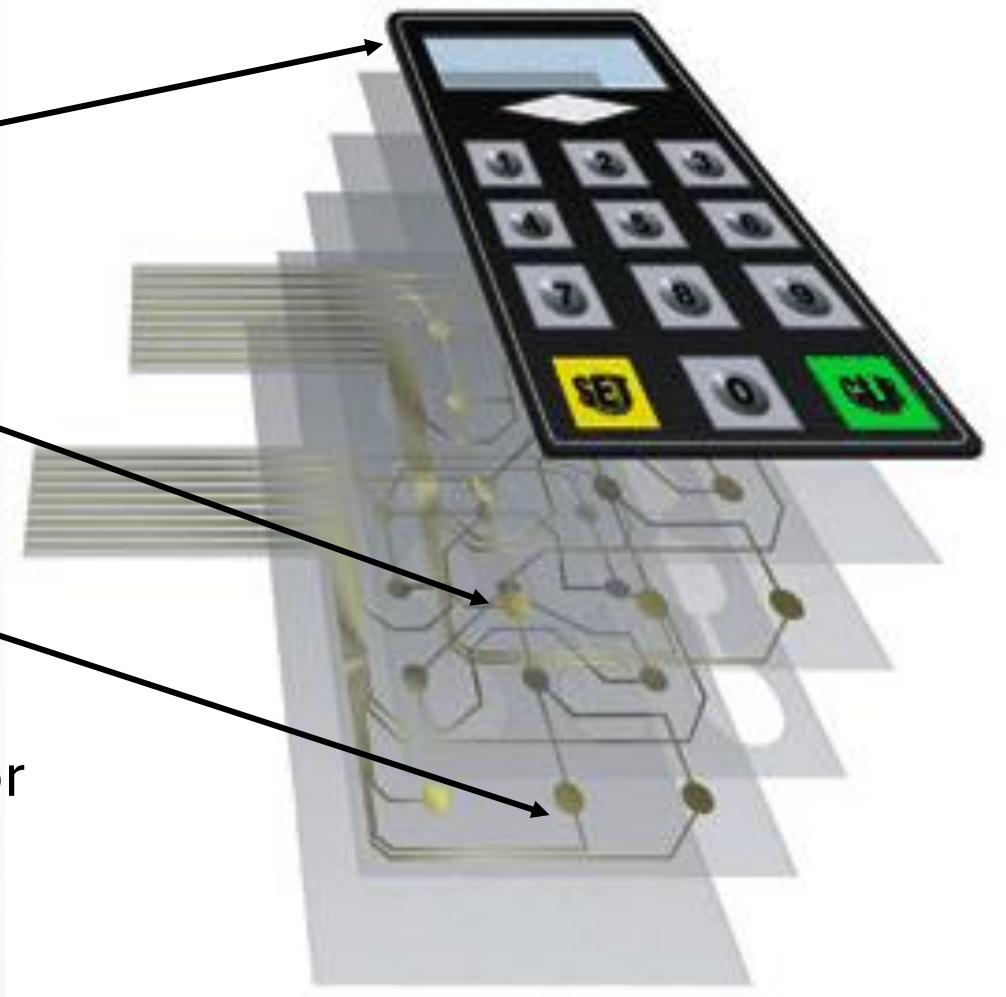
Circuit layer

Switch spacer

Circuit layer

Back adhesive

Adhesivo posterior



Applications - Flexible circuits

- Conductive circuits are printed with silver ink
- Optimum conductivity
- Dry coating thickness 6-10 μ m
- Contact areas can be printed with carbon ink
- Inert pigment
- Dry coating thickness 5-8 μ m
- The dielectric layer and conformal coating are printed with dielectric
 - Dielectric applied in 2 layers (total 25-35 μ m)
 - Conformal coating applied in 1 layer (10-15 μ m)

Note: Carbon coating resistance is approximately
1000x higher than silver

- Silver inks

Cruces/puentes, through holes, protección de contactos de cobre y resistores en placas rígidas de circuito impreso

- Emanik 310, Minico M 4100
- Carbon inks

- Loctite Edag PR-406B
- Resistive inks

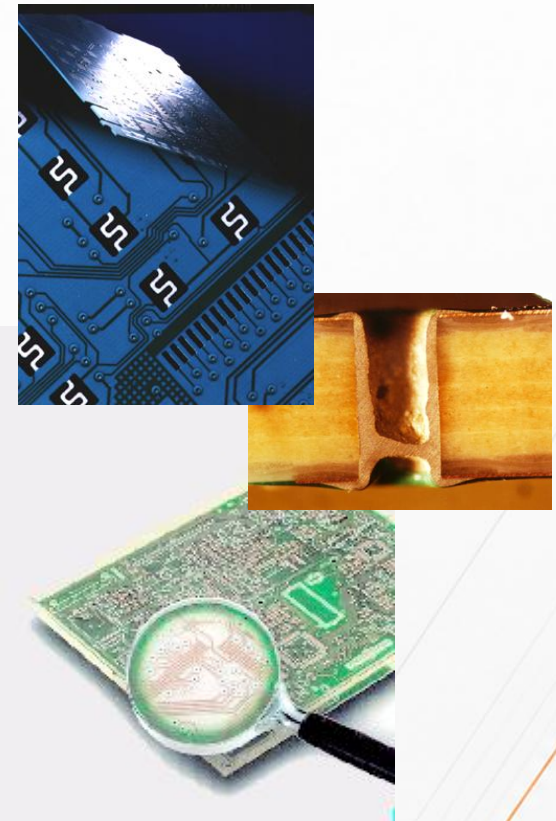
- Edag PR-400 series,

- Minico M 2000 series (mod2)
- Through-hole inks

➤ Serie Minico M 2000 (mod2)

❖ Tintas para through hole

Crossovers/bridges, through holes, copper contact protection and resistors on rigid printed circuit boards



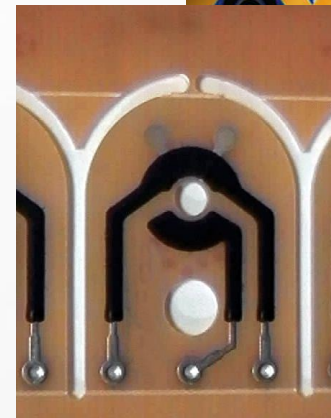
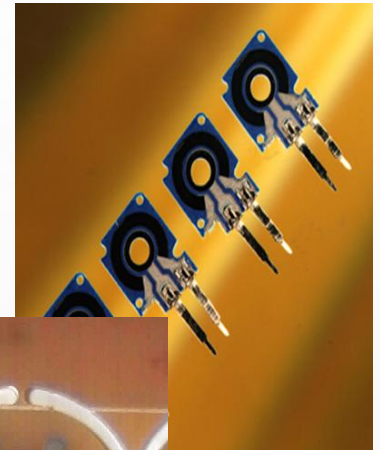
- Silver ink

Recubrimientos para pistas resistivas, áreas de contacto y capas protectoras para potenciómetros sobre sustratos rígidos (PCB o cerámica)

- Minico M-4100
- Resistive inks
- Minico M-2000 MOD2 series
- Dielectric inks
 - Serie Minico M-2000 MOD2

❖ Tintas dieléctricas

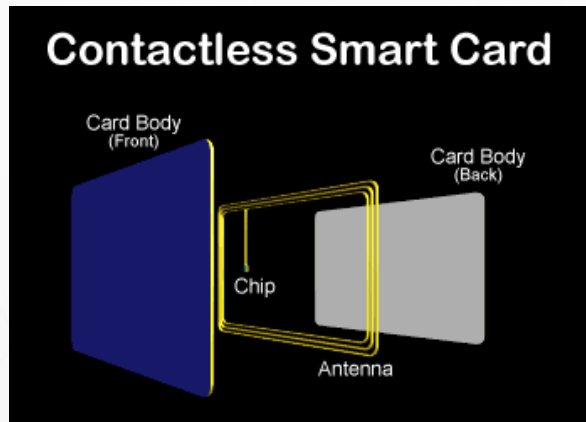
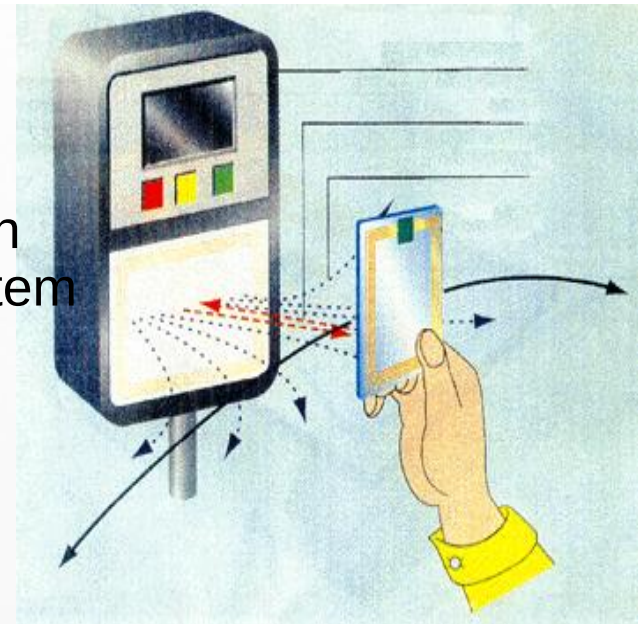
Coatings for resistive tracks, contact areas and protective layers for potentiometers on rigid substrates (PCB or ceramic)



Aplicaciones - Tarjetas/etiquetas inteligentes sin contacto

Applications - Contactless smart cards/tags

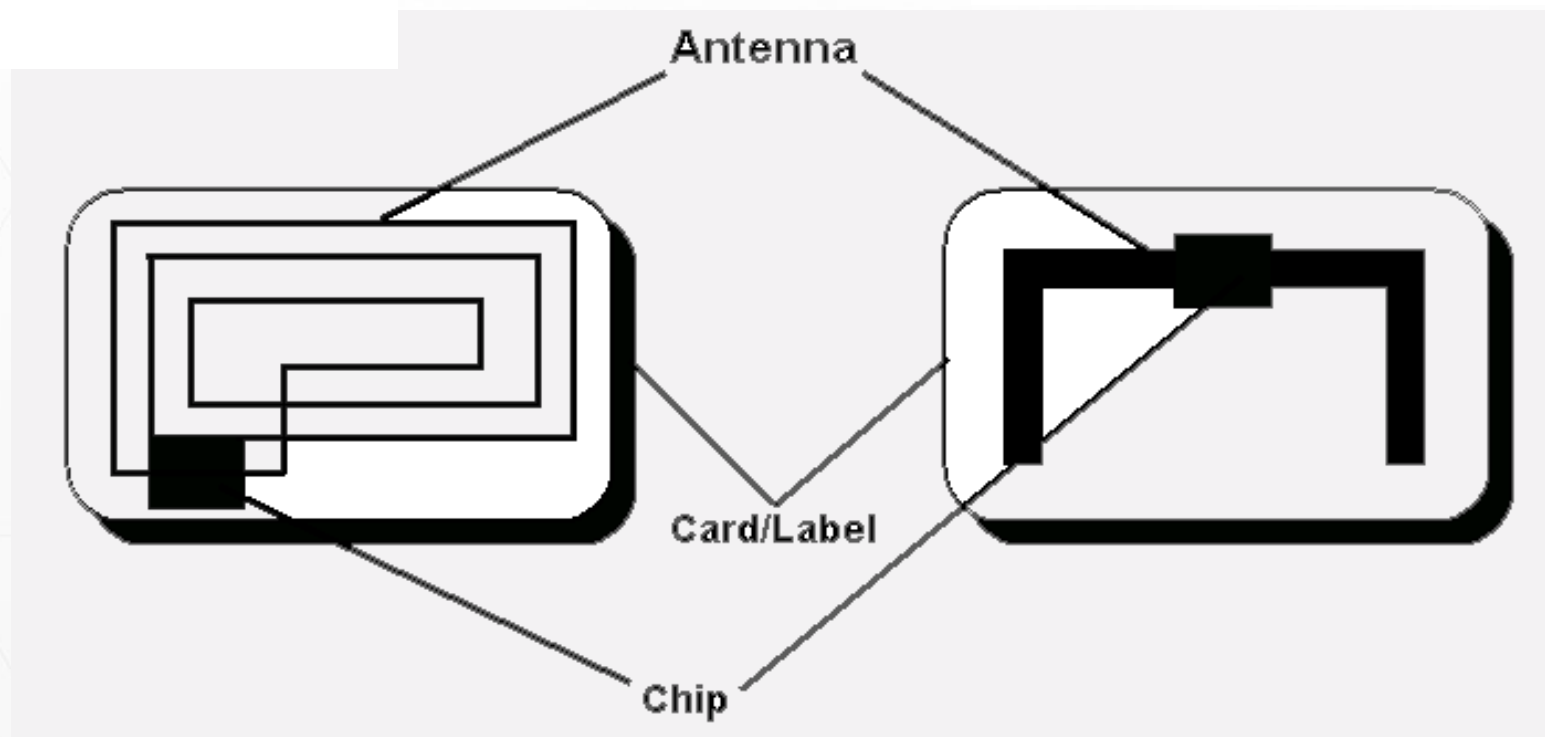
- Smart information carrier (with chip module) capable of exchanging data through radio-frequency (RF) interaction with an electronic card reader/writer system



Applications - Contactless smart cards/tags

Short range
Inductive coupling
?125 KHz (LF)
?13.56 MHz (HF)

Long range
Electric antenna (dipole)
?UHF (850-950 MHz)
?2.45 GHz



Applications - Contactless smart cards/tags

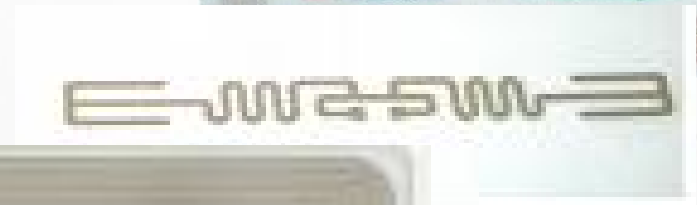
Las antenas HF y UHF para intercambio de información con tarjetas inteligentes y etiquetas inteligentes sin contacto (RFID) pueden imprimirse con tintas conductoras

- Silver inks

Edag PM-406, PM-470, 725A, PM-460A, among others

- Dielectric inks

Edag 452 SS, PF-455B, 1015, among others



- Silver inks

Roof

- Electrodag PF-410, 725A (6S-54)
- Carbon inks / non-conductive inks
- Electrodag 6017 SS, PM-404, which are mixed

to adjust the resistance level

- PTC inks

- Dielectric inks

para ajustar el nivel de resistencia

➤ Tintas PTC

❖ Tintas dieléctricas

Resistors and heating elements can be printed with silver and PTC carbon inks (Positive Temperature Coefficient). Product selection depends on voltage, power, design, temperature and substrate.

Calefacción de
retrovisor



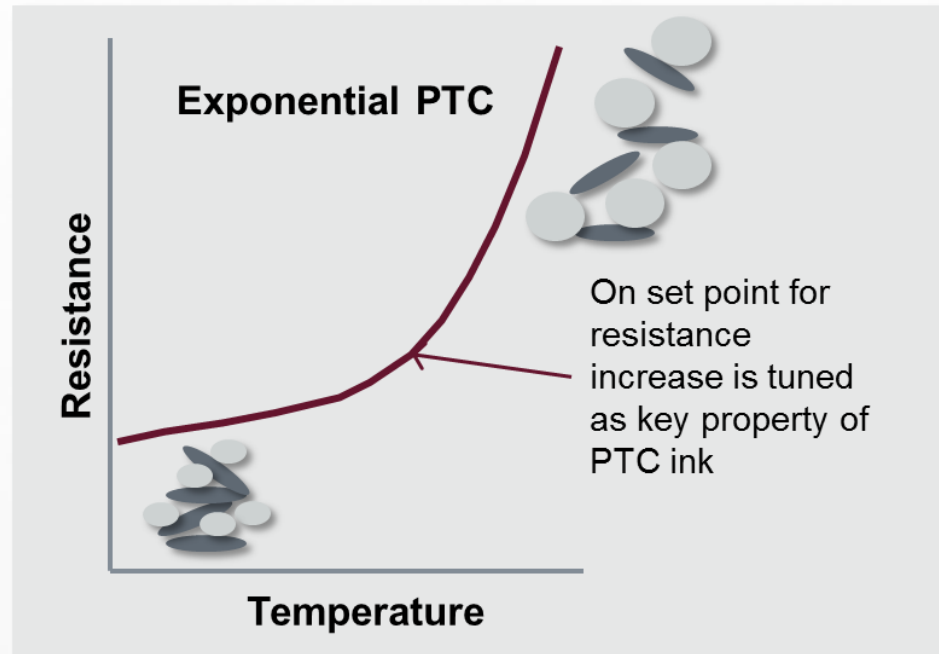
Calefacción de
techo



PTC heaters – How does it work

PTC-inks – what does it mean?

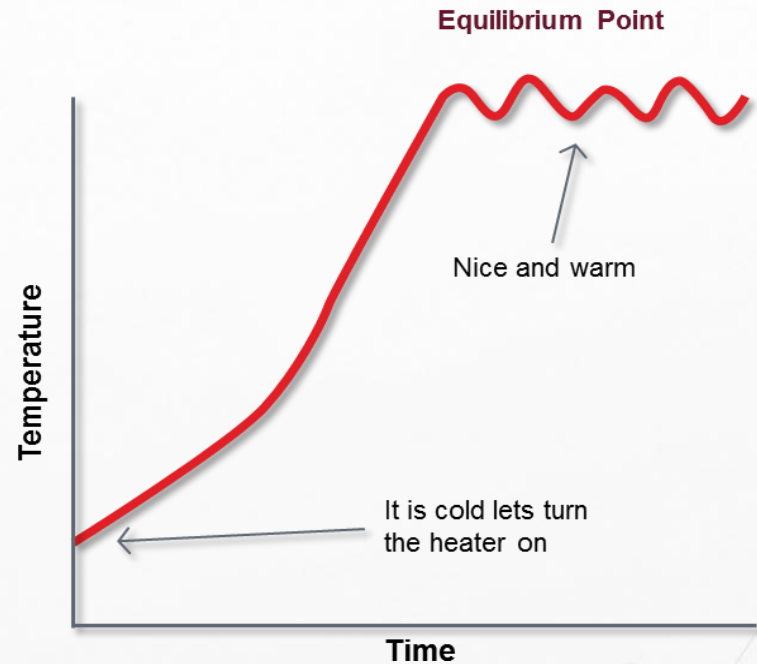
- PTC ink = Positive Temperature Coefficient ink
- Resistance increases as temperature increases



PTC heaters – how can it be used?

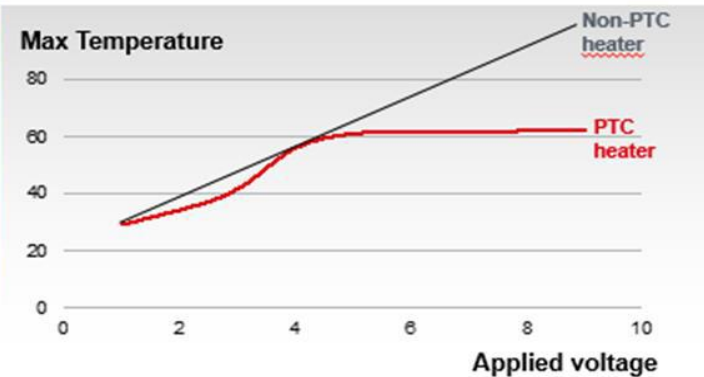
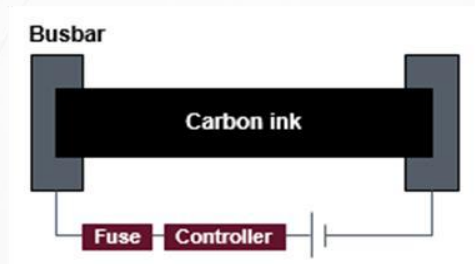
PTC-inks – how can they be used?

- A PTC heating element has a certain resistance and when a voltage is applied a current will flow and power is generated.
- The heater heats up, the resistance of the PTC-coating will increase
- At a certain T, an equilibrium is reached, a **self regulating heater**



PTC heaters – non-PTC

versus PTC heaters



- Non-linear relation between voltage and temperature for PTC heater
- Temperature is self regulating
- No fuse needed
- Control unit can be eliminated in some applications

PTC heaters - Advantages

Value	Details
Rapid heating	Resistance remains low till just before self regulating kicks in, high power and thus heat generation
Uniform/flexible Heating	Wire/cables have hot/cold spots, by design optimization these can be eliminated for PTC heaters. Design can be easily adjusted to the shape of the surface which needs to be heated
Self regulation	Because of self regulation chances of overheating are significantly reduced. Safety is increased. No external temperature control necessary
Light weight	Substrate is light, thin layers are printed. Limited space/weight needed to implement material
Sustainability	Environmentally very stable and long life time. Printing process is additive process, less waste compared to etch processes

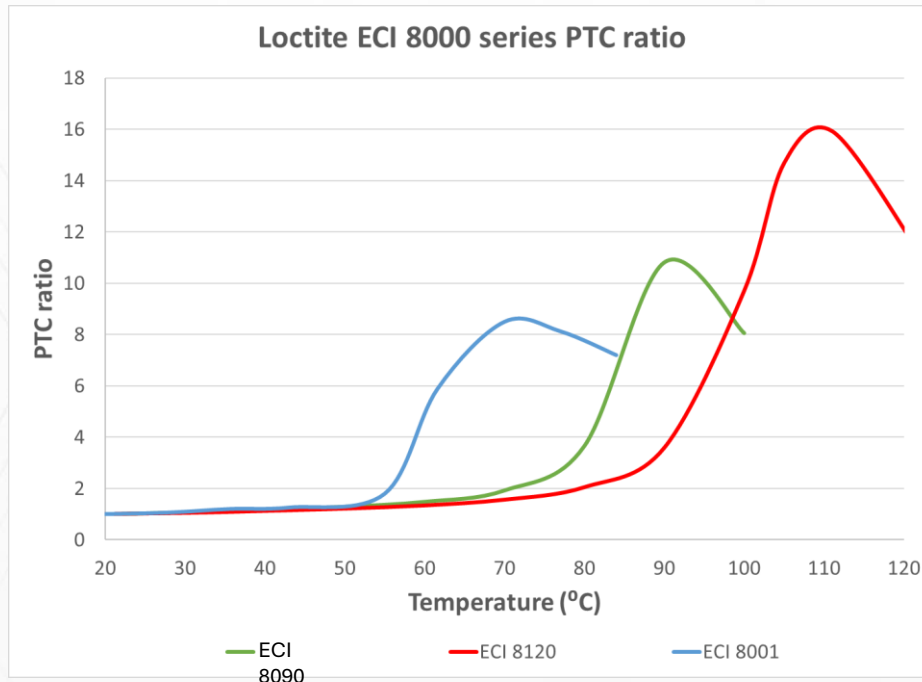
PTC technology provides rapid, safe and flexible heating. It gives a sustainable light weight solution to keep things warm

PTC inks – Loctite ECI 8000 series

- Carbon based PTC inks with different “switch off” temperatures for low voltage (<50 Volt) applications
- Products can be applied by screen printing and are compatible with polyester foil, several silver inks, dielectric inks and

Product	Drying (min/°C)	Resistance (kΩ/sq@25μm)	PTC ratio	Comments
ECI 8001	10/120	1.4 – 2.0	>7	For overheat protection at 60°C
ECI 8090	10/140	0.7 – 1.2	>7	For overheat protection at 90°C
ECI 8120	10/140	1.4 – 2.0	>10	For overheat protection at 105°C

PTC inks – Loctite ECI 8000 series



PTC ratios is peak resistance divided by resistance at room temperature

Sharp increase of resistance at “switch off” temperature and little resistance increase before

PTC inks – High voltage material

- High voltage PTC heaters requires inks with higher resistance level
- The ECI8060 HV is a high(er) resistive material and can be used for PTC heaters up to 250 Volt
- The ECI8060 HV has a resistance level of $\pm 30 \text{ kohm/sq/25um}$ and a PTC ratio of >15

Silver inks – printed silver busbars

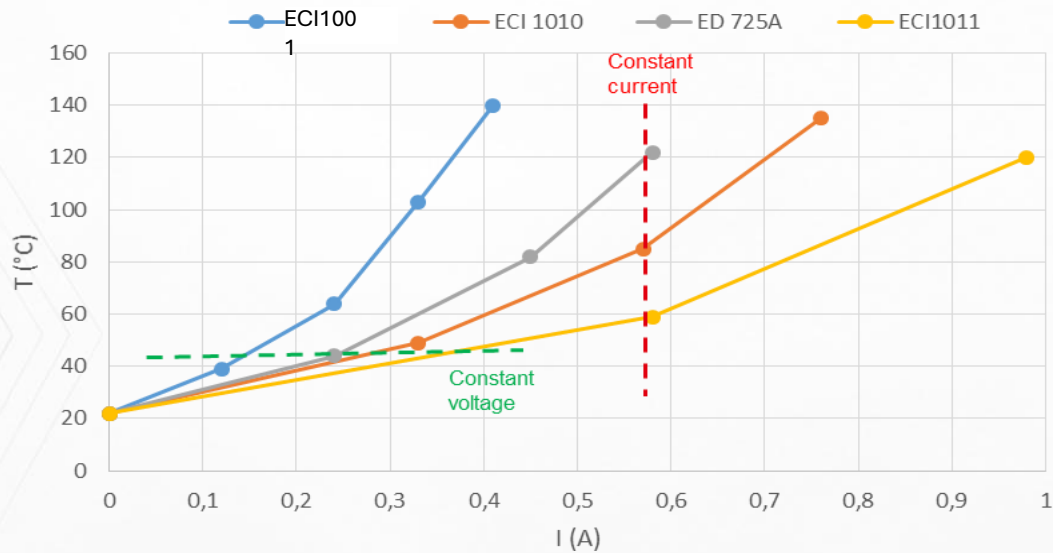
PTC heaters require busbars, fingers and contact areas for which the following silver inks can be considered:

Product	Drying (min/°C)	Resistance (Ω /sq@25 μ m)	Comments
PF-410	15/120	± 0.016	General purpose product
725A	15/120	± 0.012	General purpose product
ECI1010	15/120	± 0.006	High conductive, good flexibility
ECI1011	10/150	± 0.003	Super highly conductive

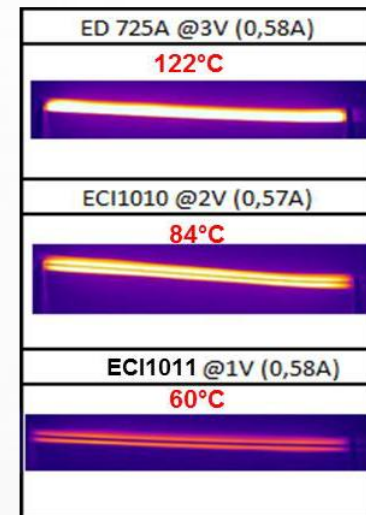
- Reduced resistance of silver ink will improve current capacity of the busbar
- ECI1010 is the most recommended silver ink for PTC heater. It combine excellent conductivity with optimum mechanical strength

Silver inks – printed silver busbars

Lower resistance means higher current capacity
and
less temperature increase of the silver busbar



Constant current tests



Preferable the power density for the silver busbar need to stay below 0.2 W/cm²

Design calculation – Required information

For designing a (PTC) heater the following information will be required:

- Heater dimensions → Available area
- Used substrate → Compatibility
- Max temperature → Selection PTC ink
- **Used voltage (V)**
- **Required power (Watt) at roomtemperature**

Design Calculation – Busbar material / width

If max. current for the heating element have been calculated the attached excel file can help to calculate the required line width.

Fill out product, sheet resistance, dry coating thickness and Watt density (yellow area) and the max current for certain line width will be calculated (green area)

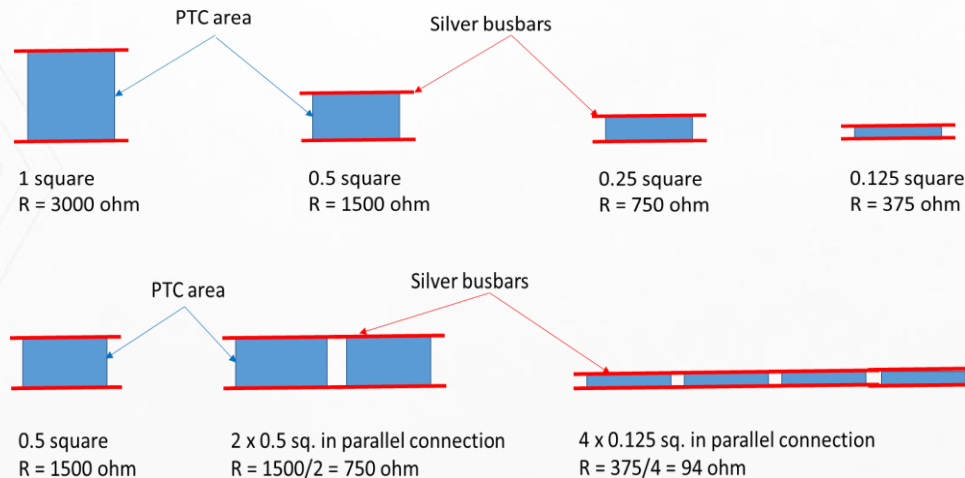
Theoretical max current (A) for silver busbars to generate a power of 0.2 W/cm²

Product	resistance (ohm/sq/25μm)	DFT (um)	Watt density (W/cm ²)	resistance (ohm/sq)	Resistance (ohm/cm ²) for busbar of				Max current (A) for busbar of			
					1 mm	2 mm	5 mm	10 mm	1 mm	2 mm	5 mm	10 mm
PF-410	0.016	8	0.2	0.050	5.00	1.25	0.200	0.050	0.20	0.40	1.0	2.0
479 SS	0.014	8	0.2	0.044	4.38	1.09	0.175	0.044	0.21	0.43	1.1	2.1
725A	0.012	8	0.2	0.038	3.75	0.938	0.150	0.038	0.23	0.46	1.2	2.3
ECI 1010	0.005	8	0.2	0.016	1.56	0.391	0.063	0.016	0.36	0.72	1.8	3.6
ECI 1011	0.003	8	0.2	0.009	0.938	0.234	0.038	0.009	0.46	0.9	2.3	4.6

- In worst case scenario 0.2 W/cm² can give max temperature increase of 80°C
- Maximum allowable current can be increased by using better conductive material, apply thicker coating, print wider busbars or allow higher watt density with improved heat-sink

Design Calculation – PTC resistors

- PTC resistors areas can only be printed as shorts track (max. 10 mm) between high conductive busbars in parallel connection
- Low voltage PTC ink resistance $\pm 1.75 \text{ kohm/sq/25um}$ will result in $\pm 3000 \text{ ohm/square}$ if a dry coating thickness of 15 um will be applied

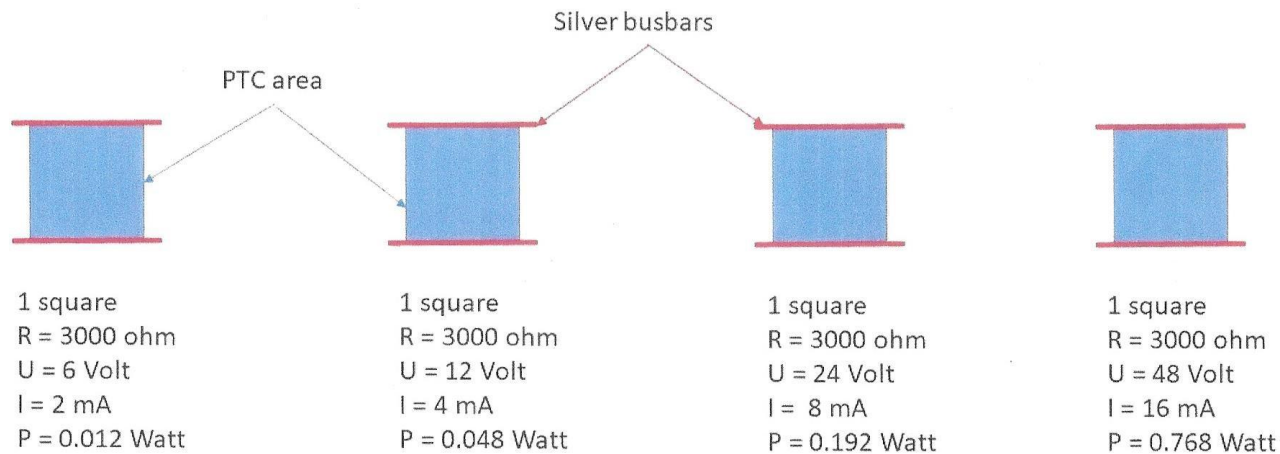


- Play around with parallel connected PTC resistor areas to obtain the required resistance
- Final heater resistance is PTC area resistance divided by number of areas (R/n) plus 0.33 times busbar resistance

Design Calculation – Influence of Voltage

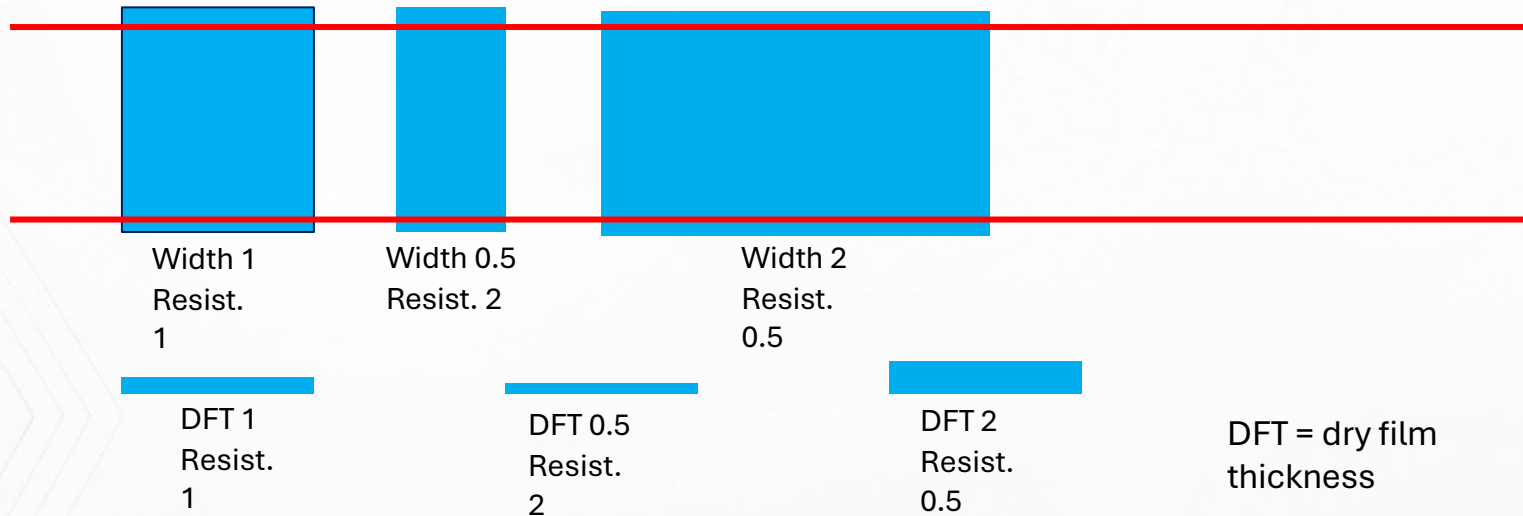
Design rules

Influence of voltage



Increasing the voltage over a PTC resistor will result in a proportional increase if the initial current and a exponential increase of initial power.

Design calculations – Influence PTC ink volume



More volume, which means wider track or higher thickness of the PTC area will reduce resistance and increase power of the PTC heater

Design calculation - Example

Heating element for 9 Volt and power of 15 Watt with a max temp of 60°C:

- Resistance is $U^2/P = (9 \times 9)/15 = 5.4 \text{ ohm}$
- Current is $U/R = 9/5.4 = 1.75 \text{ Amp}$

Design solution

- ECI1010 busbar of >5mm wide will have sufficient current capacity
- Loctite ECI8001 will limit temperature to 60°C
- 1 square PTC areas need $3000/5 = \pm 600$ parallel connected PTC areas
or
0.5 square PTC areas need $1500/5 = \pm 300$ parallel connected PTC areas or
0.25 square PTC areas need $750/5 = \pm 150$ parallel connected PTC areas.

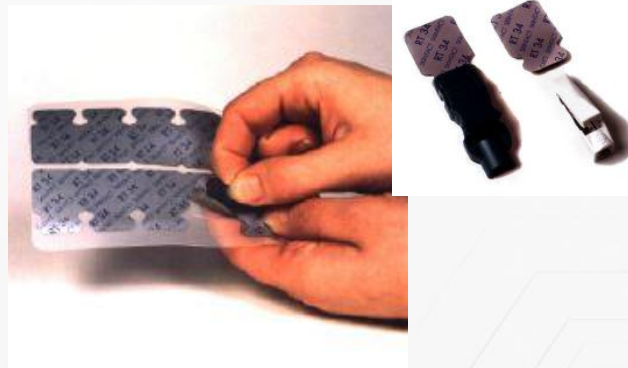
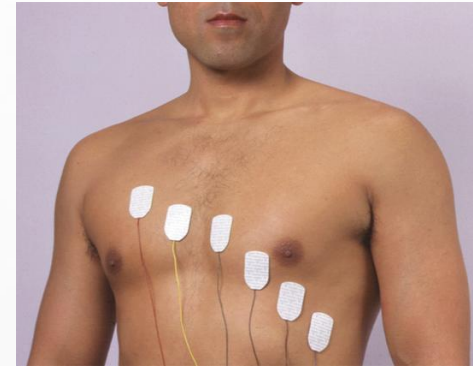
Selection will depend on available area!!!

Applications - ECG electrodes

ECG electrodes require conductivity and silver/silver chloride contacts.

- Carbon inks
- Edag PF-407A, PF-407C
- Silver/silver chloride inks

➤ Edag 6038 SS, PE-409, CI-4040

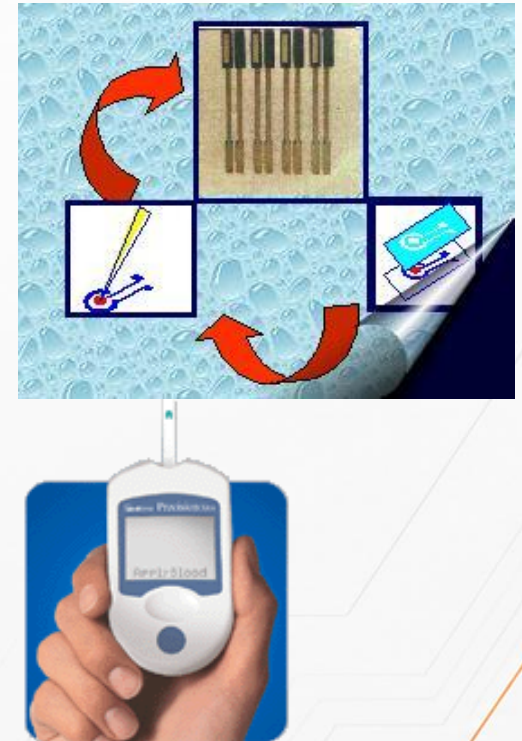


Applications - Biosensors

Biosensors are devices used to measure designated targets using biological detection agents such as enzymes, antibodies, bacteria, etc. Electrochemical biosensors may require conductive tracks, reference electrodes and conformal coatings.

- Carbon ink
- Edag PF-407C, PF-407A
- Silver ink
- Edag PF-410, 418 SS
- Silver/silver chloride inks
- Edag PE 409, CI-4040
- Protective inks

➤ Edag 452 SS, PF-455B



Applications - Touch screens

A touch screen allows commands to be sent to a computer by pressing a specific area of a CRT or LCD monitor. As with a keyboard, conductive and insulating layers are required.

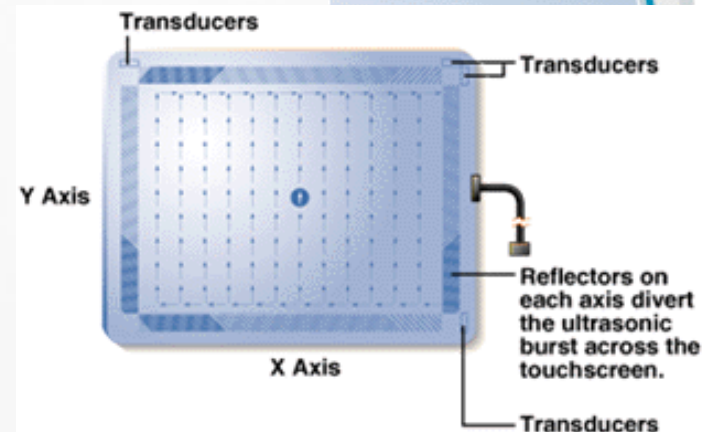
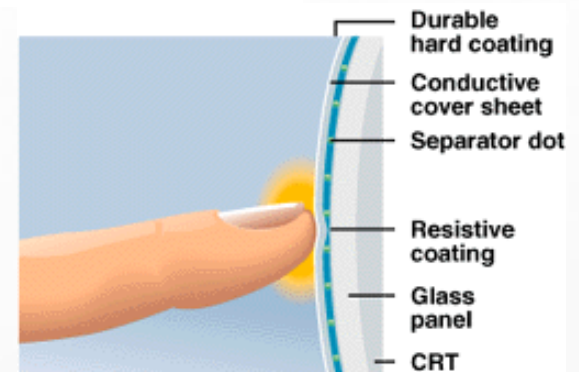
- Busbar ink

➤ Loctite ECI 1010, IQ INQ 1002,

CI-1036

- Dielectric ink

➤ PD-038



Applications - Photovoltaic cells

Los recubrimientos conductores y aislantes AEM podrían ser adecuados para la producción de células solares rígidas y flexibles. Se requieren materiales conductores para los colectores de electricidad

- Silver inks

- Loctite ECI 1011 (Flexible), Emanink 310

(Rigid)

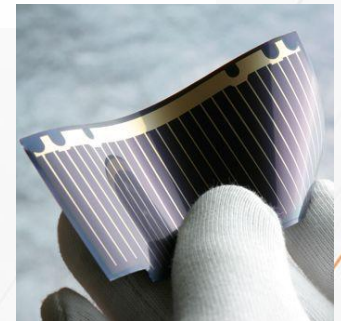
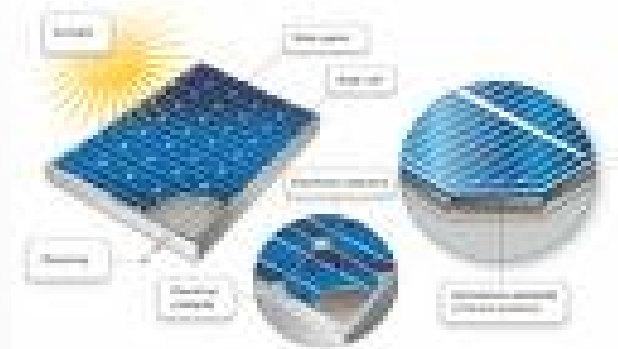
- Carbon inks

- Electrodag 965 SS (Flexible), PR-406B

(Rigid)

- Dielectric ink

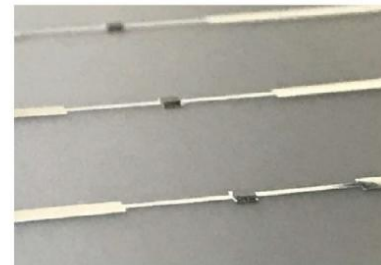
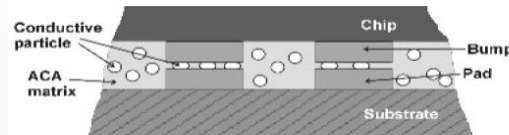
- PD-038 (dot spacer)



Anisotropic Conductive Adhesive

Adhesivos conductores que conducen solo en Z (vertical). Se aplican con presión (2-3 N) y temperatura (150-180°C).

Ideal para los chips mas pequeños para evitar corto circuitos entre los pads



Anisotropic Conductive Pastes
ACP's



Thank you for coming!

Questions?